QUICK USE OF SATELLITE AND GI TECHNOLOGIES AFTER EARTHQUAKE - PETRINJA 29.12.2020.

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Summary: *On December 29th, 2020, the wider area of Banija was hit by a strong earthquake with a strength of 6.2 on the Richter scale with an epicenter near town of Petrinja. The quake, which was also felt outside Croatia's borders, caused the deaths of seven people and major devastation. Thousands of buildings were destroyed and become unusable, as well as significant parts of the utility infrastructure. Also, visible traces of soil movement were observed. Before and after the main quake, the epicentral area was hit by many aftershocks, several of them with magnitude higher than 4.5 on the Richter scale.*

Before that, on March 22nd, 2020, town of Zagreb was also hit by a strong earthquake with the strength of 5.5 on the Richter scale. Already after Zagreb earthquake a great need for spatial interpretation of the event and its aftermath has been recognized. Therefore, after the earthquake in Petrinja, a quick reaction of geodetic experts followed, using modern satellite and geoinformation (GI) technologies to provide information on the aftermath of the earthquake. In a few days GIS applications have been developed for delivery of help to endangered citizens and to record damages, as well as information on the earthquake scattering and ground movements in the epicenter area. Synergy of different methods and fast reaction, i.e. quality information and applications in great helped the organization of crisis management, information to services and citizens, registration of damages and reconstruction planning.

This paper presents an overview of the systems, sensors and data used, their processing and the results obtained, i.e., the applications developed for crisis management purposes are presented. The results of soil displacement obtained using the data of permanent GNSS stations processed by the authors of this paper are particularly emphasized, showing that in Sisak there was a horizontal displacement of about 5.5 cm and a shrug of about 2 cm.

Keywords: *Earthquakes, satellite and GI technologies, GIS applications, ground movement*

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1. INTRODUCTION – ZAGREB EARTHQUAKE ON MARCH 22nd 2020

Croatia was marked by two devastating earthquakes in 2020, in addition to the Covid-19 pandemic. The first one hit in the morning of 22nd March 2020, at 06:24 CET, Zagreb and its sourrounding. Its epicenter was 7 km north of the center of Zagreb, in the vicinity of setlements Markuševac and Čučerje, and the hypocenter was at a depth of 10 km. The earthquake had a magnitude M_L=5.5 on Richter scale and was felt all over Croatia, even at a distance of more than 1000 km from the epicenter [1]. The main shock followed a series of stronger and weaker aftershocks over the next few months that caused additional damage and caused fear and nervousness among the population. The quake killed one person and caused major damage in the Podsljeme zone and the city centre, especially on older houses. Damage to many older buildings, especially the collapse of chimneys and roofs, are characteristic of the Zagreb Earthquake, and rescue services and civil engineers worked weeks after the earthquake to determine damage and remove parts of buildings that endangered the safety of citizens and the functioning of the city. For this purpose, satellite images and aerial imaging using drones were intensively used to record all damage and create prerequisites for the systematic restoration of damaged objects. In doing so, the speed of reaction in the event of devastating earthquakes is of particular importance, which is a known fact, which gained new meaning after the catastrophic earthquake in Haiti in 2010. Haiti earthquake was a breaking point in the approach to how new technologies and geographical information are used as well as the role of experts and virtual communities in providing various information about the situation and establishing services in case of earthquake [2]. For example, the day after the earthquake, on 23rd March 2020 the GDi company from Zagreb, for the needs of the City of Zagreb, created and put in use an application through which citizens could report the damage caused by the earthquake to their homes, which was recorded in the GIS application and connected to geodetic spatial maps and recordings [3].

Two weeks later, experts of the Chair of Satellite Geodesy at the Faculty of Geodesy processed observation data of the Croatian permanent GNSS network (CROPOS) station Zagreb (CORS ZAGR) which is located on the roof of the Faculty building. Considering the location of ZAGR station being distant approx. 9 km from the earthquake epicenter and bearing in mind the damages suffered by the buildings in the Zagreb downtown, it was supposed that the effect of the earthquake could be registered, assessed, and subsequently analyzed by a kinematic solution. After the Post-Processed Kinematic (PPK) computations, the statistics of Easting (E), Northing (N), and Height (H) values were analyzed. The first analysis of the 1-hour time window, paying special attention to the range values (Range = Max – Min), has shown large values, being far beyond the expected noise level, especially in Easting and Northing components: ΔE = 0.059 m, ΔN = 0.132 m and ΔH = 0.047 m [4]. To gain insight into the dynamics of the movement of the CORS ZAGR antenna during the earthquake, which includes soil displacements caused by the earthquake itself and the elastic motion of the building on which the antenna is located, the motion of the antenna itself was calculated at intervals of 1 second for 29 seconds interval of the earthquake, Figure 1.

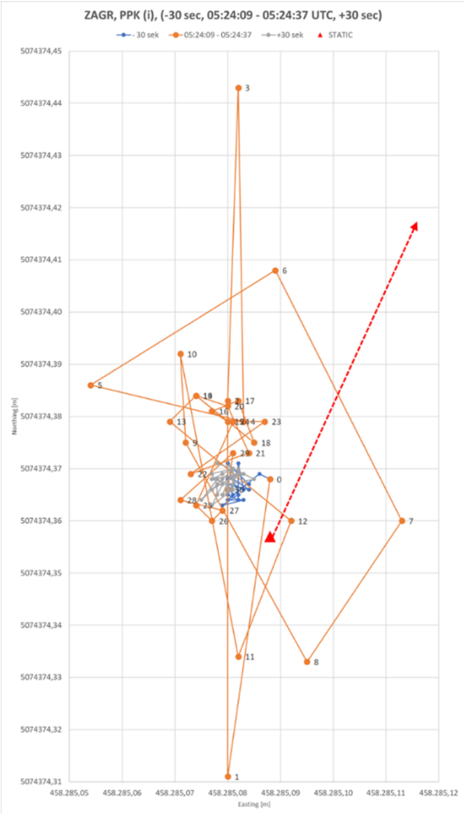

Figure 1. Kinematic effects of the M5.5 earthquake on CROPOS ZAGR station derived from PPK results on 22nd March 2020, 05:24 UTC [4]

The research in this case is of great benefit to the developers who will be rebuilding Zagreb in understanding the movement of buildings and the impact on their static. Both examples also show that despite the state of shock, it is possible and necessary to provide quality information and applications as soon as possible in support of rescue and remediation services, i.e. for informing citizens.

2. PETRINJA EARTHQUAKE ON DECEMBER 29th 2020 - USE OF EO AND GI TECHNOLOGIES

Three days before end of the year, on 28th December 2020 at 6:28h CET there was a strong earthquake with magnitude ML=5.0 near Petrinja. In addition to the epicentral area of Petrinja, Sisak, Glina and its surroundings, the earthquake was also felt throughout central Croatia. A series of aftershocks followed. The very next day, 29th December 2020, a devastating earthquake of magnitude ML=6.2 occurred in the same area at 12:19h CET. In addition to significant material damage, this quake also took seven human casualties

[5]. This quake was followed by strong aftershocks in the mentioned epicentre, which continued into 2021. Material damage caused by the Banija earthquakes even bigger. Estimates suggest that 64,000 buildings were destroyed [6]. Therefore, from the first moment it was extremely important to establish communication services for rescuers and citizens in order to provide assistance to the affected as soon as possible, and to start remediating the situation. In understanding what happened on 28th and 29th December 2021, an important role was played by geodetic experts, especially from the Faculty of Geodesy University of Zagreb, who, taught by the Zagreb Earthquake, immediately reacted and provided a range of information, i.e. established vital services to assist citizens and rescuers.

Already on December 30th Faculty of Geodesy has, in cooperation with Croatian OpenStreetMap community and OpenIT company, established ushahidi-platform – digital interactive map with standardized categories for easy input of supply and need for assistance in an earthquake-threatened area called Earthquake 2020 available at https://potres2020.openit.hr/. In this interactive map, shown in Figure 2, georeferenced information can be easily added to several standardized categories: 'I offer assistance', 'I seek help', 'Search for the missing', 'Caring for people and animals', 'Supply point', 'Accommodation', 'Gas-water-electricity-telecommunications', 'Traffic-parking', 'Emergency services' which facilitates the coordination of volunteers and professional services. As visible in Figure 2, thousands of users used this plafrom and exchanged infromation about the needed and offered assistance. The volunteers from the OpenStreetMap community and Faculty of Geodesy staff and students have voluntarily vectored 48,000 houses and 1,500 kilometers of roads and access roads within a radius 30 kilometers from the epicentre, measuring 2826 sq km, facilitating access to remote areas and vulnerable residents in need [7].

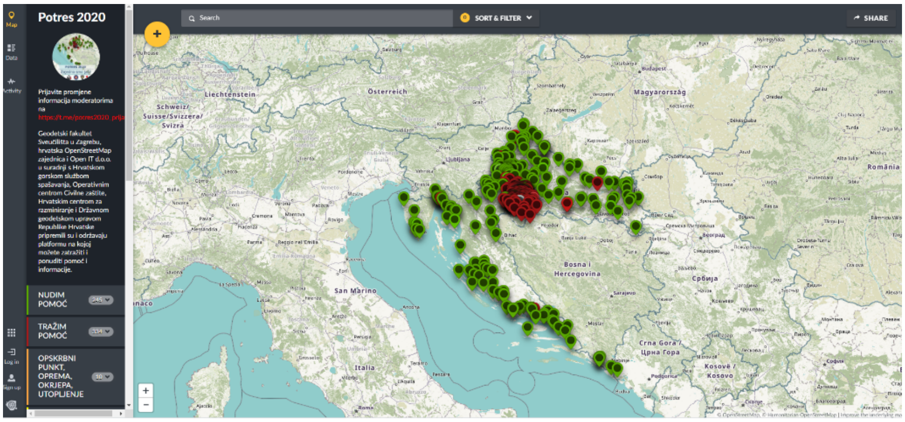

Figure 2. Ushahidi platform "Earthquake2020" - interactive map [7]

Following the Earthquake 2020 platform, another network application was created in collaboration with OpenStreetMap community developers named „Oton“ for assessing the condition of roofing in the Banija area. Digital orthophoto images made before (aerophotogrammetrically) and after (using drones) earthquakes were used to create the application [7]. The result of those activities were summarized in the first preliminary visual assessment map of the roofing condition generated by the use of the Oton application shown in Figure 3.

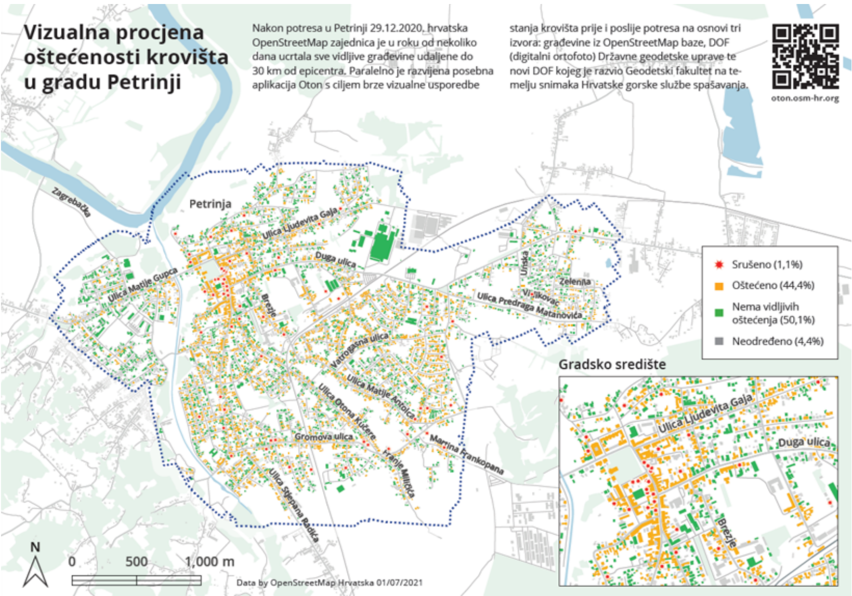

Figure 3. Visual assessment of roof damage in the city of Petrinja using Oton application [7]

Using satellite radar altimetry data from Copernicus Sentinel 1 satellite, already on December 31st, Marin Govorčin from the Faculty of Geodesy carried out the data processing and published a map of surface displacements obtained by satellite radar interferometry for the Petrinja earthquake, Figure 4. Two observations of the Sentinel-1 satellite mission were used, an observation before and the other after the earthquake, on the basis of which the ground displacement caused by the earthquake was gained. The terrain displacement is shown in blue-red cycles, where each cycle represents a shift of 2.8 cm in direction and at the angle of observation of the satellite. The results indicated that the west wing of the epicentre moved about 35 cm towards the satellite (in a north-west direction), and the east wing moved about 28 cm away from the satellite (in the south-east direction) [8].

Also, many other professionals and research teams from Croatia and abroad have in those days published information and computation results related to the Petrinja earthquakes contributing to better understanding of the disaster and the situation created. In particular, the first results of satellite radar interferometry that detected significant surface displacements indicated the need for further research into what happened in the epicentral area and what consequences this has created. It has resulted in the processing of Global Satellite Navigation Systems (GNSS) data for the purpose of accurately determining surface displacement.

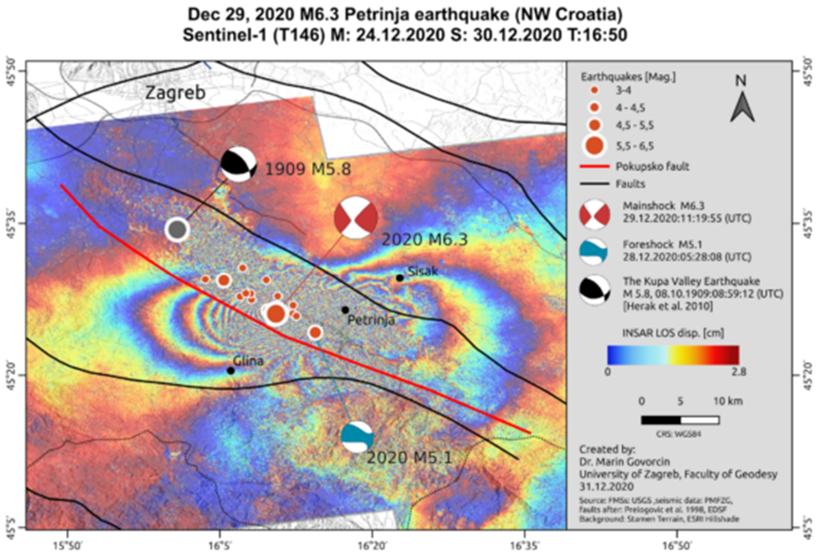

Figure 4: Ground displacement in the epicentre of Petrinja earthquakes computed from Copernicus Sentinel 1 satellite radar altimetry data [8]

3. USE OF SATELLITE POSITIONING TECHNOLOGY

The Seismological Service of Croatia, using several test systems of the automatic location of earthquakes, registered a total of 574 earthquakes in the period of 9 days after the first shock on 28th December 2020. The number of earthquakes with corresponding magnitudes is given in Table 1, source [9].

Table 1. Number of earthquakes with corresponding magnitudes in the epicentre area of Petrinja in the period 28.12.2020. – 06.01.2021.

Magnitude	No of earthquakes
M < 2	194
2 ≤ M < 3	321
3 ≤ M < 4	50
4 ≤ M < 5	7
5 ≤ M < 6	1
6 ≤ M < 7	1

The stated number of earthquakes and their magnitude, especially the devastating earthquake of 29th December 2020 (the main earthquake) that occurred in the specified epicentre area, as well as the previously published interferograms, imposed the need to check the possible impact of the earthquake more accurately on ground displacements in

the epicentre area. In this context, it was necessary to first check the possible impact of the earthquake on the stability of CROPOS permanent GNSS station in Sisak (CORS SISA), located at a distance of 15 km northeast of the epicenter of the devastating earthquake, and then the displacement of the ground throughout the epicentre area.
Assist Prof. Danijel Šugar and Prof. Željko Bačić from the Chair of Satellite Geodesy of the Faculty of Geodesy carried out preliminary calculations in the days following the earthquake and published on 13th January 2021 the results of the CORS SISA [9] offset. For this purpose, daily static solutions for the specified point for the 11-day period were calculated, from 27th December 2020 (the day before the first strong earthquake) to 06th January 01.2021. Taking over CROPOS GPPS data observations of 24-hour sessions for CORS SISA with storage interval 15 seconds 10 out of possible 11 daily solutions were calculated, because for 30.12.2020 there were only 13 epochs registered out of a possible 5760. Based on the available observation data, daily solutions (24-hour sessions) were calculated, which together with the fixed coordinates of CORS SISA are shown in Figure 5.

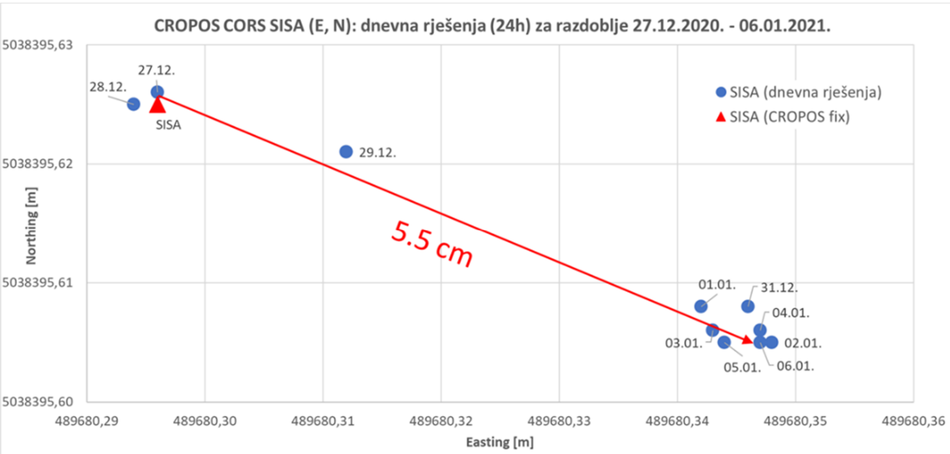

Figure 5. Daily static solutions (E, N) of CORS SISA station for the period 27.12.2020. – 06.01.2021.

Preliminary analysis of daily solutions of static observations showed that in the period considered there was a positional shift of 5.5 cm CORS SISA station in the direction of the southeast. The first two daily solutions (27th and 28th December 2020) show good stacking with fixed coordinates (2 mm), while the daily solution (29th December 2020), which includes data before and after the earthquake, already shows a displacement of 17 mm. The daily solution for 30th December 2020 could not be calculated, while the daily solutions for the following days, i.e. from 31st December 2020 to 06th January 2021. show a shift of approximately 5.5 cm in the direction of the southeast. It is not possible to discern from these preliminary results whether the progress identified is due to the displacement of the object on which the CORS SISA GNSS antenna is located, or if the soil has shifted due to the effect of the earthquake. A similar analysis was done for the height of the GNSS antenna, from which it can be concluded that there was a shrug (decrease in height) estimated at approximately 2 cm (Figure 6).

Further, in the period from 4th to 28th January 2021, the State Geodetic Administration of the Republic of Croatia (SGA) carried out preparatory work and precise control GNSS measurements in the area of the towns of Glina, Petrinja and Sisak. Based on the obtained results and analysis of the coordinates of the geodetic points before and after the earthquake, it was found that the largest shift is shown by points in the Petrinja area, with mean displacement values of 45 cm in the direction of the southeast, while the mean displacement values for Glina area are 10 cm in the direction of the northwest and 10 cm in the east direction for the Sisak area [10], see Figure 6.

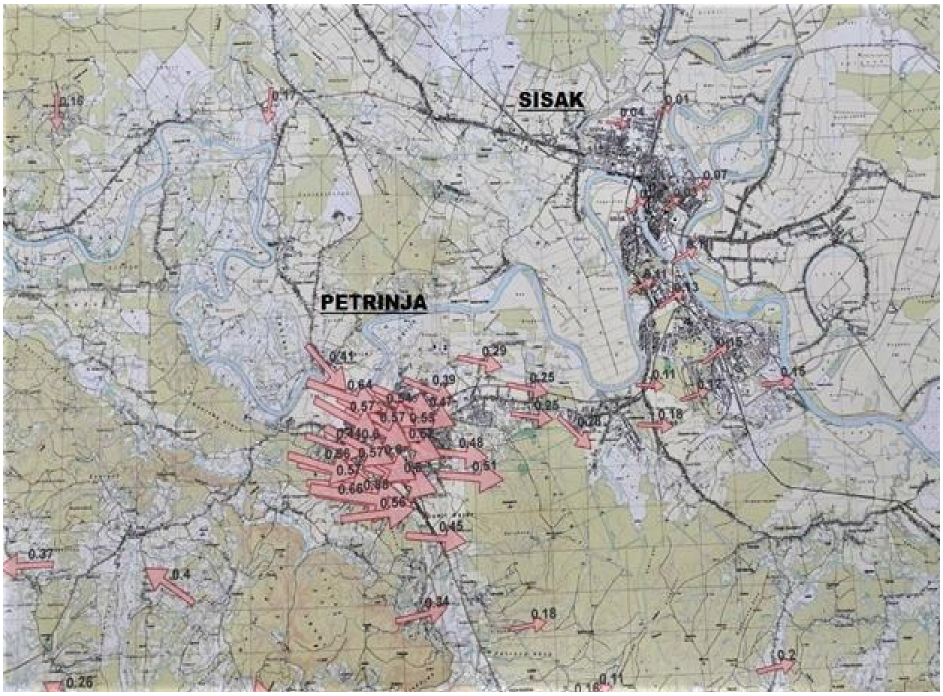

Figure 6. Horizontal changes of geodetic network points in Petrinja and Sisak [10]

The obtained results provided a detailed insight into the displacement of the surface in the epicentre area, which enabled the actions of the competent services to be taken, i.e. the elaboration of plans for the resolution of the state of play, with remediation not only related to buildings and infrastructure, but also to all other segments of the functioning of the company. Thus, in the coming period, the SGA will approach cadastral measures of the epicentre of Petrinja, Sisak and Glina in order to spatially correct the cadastral operating for the displacements of the surface caused by the earthquake, i.e. content for the changes that will result from the reconstruction [10].

4. CONCLUSION

The earthquakes that hit central Croatia in 2020 with epicenters near Zagreb and Petrinja showed great importance of a quick reaction of experts in establishing services that enable efficient communication between the aid provider and recipients, i.e. the implementation of damage-finding activities in case of such disasters. On the experience gained from the Zagreb Earthquake in March 2020, experts of the Faculty of Geodesy, in cooperation with partners, reacted immediately after the Petrinja earthquakes in December 2020 and established such applications, i.e. performed analyses based on satellite technologies (Earth observation and satellite positioning) that provided a number of useful information. Public reaction, use of developed applications and interest in data on the aftermath of earthquakes (damage records and static and kinematic surface movement) clearly showed how necessary and justified such engagement of experts is. In synergy with the results delivered by other professions, conditions have been created for better and more efficient management of disaster consequences, i.e. remediation of the situation in the affected areas. Geodetic experts, starting from the establishment of the online service for coordinating the provision of aid and rescue in the field, establishment the servise for assessment of damage caused by the earthquake on the buildings and infrastructure, and ending up with the estimation of surface displacement by satellite methods (InSAR, GNSS), have shown a great contribution in a disaster management and recovery.

REFERENCES

[1] Markušić, S., Stanko, D., Korbar, T., Belić, N., Penava, D., Kordić, B.: The Zagreb (Croatia) M5.5 Earthquake on 22 March 2020. *Geoscience*, 10 (2020), 252, 21
[2] Bocardo, P, Pasquali, P.: Web mapping Services in a Crowsource Environment for Disaster Management: State-Of and Further Development. ISPRS International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XXXIX-B4, 2012, pp.543-548
[3] https://direktno.hr/zagreb/zagrepcani-stetu-od-potresa-mogu-prijaviti-putem-ove-mobilne-aplikacije-187388/, download 25.02.2020
[4] Šugar, D., Bačić, Ž.: Kinematic Effects of M5.5 Zagreb Earthquake Assessed by GNSS Method Supported by Galileo Satellite System. Proceedings of 1st Croatian Conference on Earth Engineering - 1. CroCEE Zagreb, March 22nd – 24th, 2021. In print.
[5] https://www.pmf.unizg.hr/geof/seizmoloska_sluzba/izvjesca_o_potresima?@=1m6aj, download 25.02.2021, Prevolnik, S.: Potresi kod Petrinje nakon 28. prosinca 2020.
[6] https://www.vecernji.hr/vijesti/najnoviji-podaci-potres-je-unistio-vise-od-64-000-objekata-stete-ima-u-zagrebu-gorici-1461679, download 18.01.2021
[7] https://www.geof.unizg.hr/potres2020/, download 18.01.2021
[8] https://www.geof.unizg.hr/novosti/karta-povrsinskih-pomaka-dobivena-satelitskom-radarskom-interferometrijom-za-petrinjski-potres-magnitude-6-3/, download accessed on 3.01.2021.
[9] science.geof.unizg.hr/satgeo/zurnal79.htm, download 13.01.2021. Šugar, D.: Utjecaj potresa na CROPOS stanicu Sisak – prethodno priopćenje
[10] https://www.cropos.hr, download 31.01.2021. Prvi službeni rezultati satelitskih mjerenja na potresom pogođenom području

БРЗА ПРИМЈЕНА САТЕЛИТСКИХ И “G” ТЕХНОЛОГИЈА НАКОН ПОТРЕСА – ПЕТРИЊА 29.12.2020.

Резиме: *Шире подручје Баније погодио је 29. 12. 2020. године снажан потрес јакости 6.2 ступња по Рицхтеровој скали с епицентром у близини Петриње. Потрес, који се осјетио и изван граница Хрватске, узроковао је смрт седам особа и велика разарања. Више тисућа објеката је разрушено и неупотребљиво, као и значајни дијелови комуналне инфраструктуре. Такођер, уочени су и видљиви трагови помицања тла. Прије и након главном потреса епицентрално подручје погодило је више стотина потреса од којих и неколико јачих од 4,5 ступња по Рицхтеровој скали.*

Прије тога, 22. 03. 2020. такођер је Загреб погодио снажан потрес јакости 5.5 ступња по Рицхтеровој скали. Већ је након Загребачког потреса уочена велика потреба за просторном интерпретацијом догађаја и његових посљедица. Стога је након потреса у Петрињи услиједила брза реакција геодетских стручњака, који су користећи модерне сателитске и геоинформацијске (ГИ) технологије пружили информације о насталим посљедицама. У неколико дана развијене су ГИС апликације за доставу помоћи угроженим грађанима и евидентирање штета, као и пружене информације о распростирању потреса односно помицању тла у епицентралном подручју. Синергија различитих метода и брзина реакције, односно квалитетне информације и апликације у великом су помогле организацији управљања кризном ситуацијом, информирања служби и грађана и бољем разумијевању настале ситуације те планирању санације и обнове.

У овом раду дан је преглед кориштених сустава, сензора и података, њихове обраде и добивених резултата односно, приказане су апликације развијене за потребе управљања кризном ситуацијом. Посебно су истакнути резултати помака тла добивени кориштењем податак перманентних ГНСС станица које су обрадили аутори овог рада и који показују да је у Сиску дошло до хоризонталног помицања од cca 5,5 cм и слијегања од cca 2 cм.

Кључне ријечи: *Потреси, сателитске и геоинформацијске технологије, ГИС апликације помицање тла*