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THE IMPACT OF GRIVA EARTHQUAKES ON STRUCTURES DAMAGE

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ABSTRACT

Earthquakes that occurred in Griva, northern part of Greece, within the period from 21.12 to 26.12.1990 were intensively felt in the towns of Gevgelija, Valandovo and Dojran, causing significant damage on various building structures. The earthquake with magnitude M=5.5, as well as some aftershocks were recorded on three instruments type SMA-1, located at Capacitors factory in Gevgelija, Hotel Ograzden in Dojran and seismological station in Valandovo.
This paper presents the earthquake parameters (magnitude, location, hypocentral depth, focal mechanism) obtained through analysis of the data from various stations in the region.
The recorded strong motion data will be also analyzed and presented in graphical and analytical form. Numerical values of the accelerations, velocities and displacements, together with their response spectra will be given. The main parameters of each component, such as maximal values of the acceleration, velocity and displacement, along with the frequency limit of the chosen filters will be discussed.
Five registrations, three of the main events and two of the two aftershocks, were obtained. Maximal acceleration of 0.058g was recorded in the Valandovo seismological station. Due to the small relative distance between Gevgelija and Valandovo and Dojran and Valandovo, same level of acceleration was observed in those two towns.
After the earthquakes, team of experts made a field inspection and damage evaluation of the buildings in Gevgelija and the surroundings. A brief presentation of damages inflicted on various structural types will also be given.

Keywords: magnitude, focal mechanism, acceleration, response spectra, damage

1. INTRODUCTION

In December 1990, the area between Gevgelija and Gumendza was affected by a high seismic activity, namely a swarm of earthquakes that lasted until September 1991. The main shock took place on 21.12. 1990 at 06:57 GMT originating from a focus in Northern Greece, in the east foothill of Pajak Mountain. The earthquake epicenter was defined based on instrumental data obtained at 18 seismological stations. The earthquake was located in the vicinity of Griva village, at a distance of about 25 km south from Gevgelija. Due to the intensity of this earthquake, its destructive effects were observed at a distance of 30 to 40 and partially up to 50 km from the epicenter, covering the entire territory of the municipality of Gevgelija and the larger part of the territory of the municipality of

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Valandovo. The earthquake caused considerable damage to structures and panic among the citizens. In addition to the panic as well as two heavily injured and several slightly injured persons, the earthquake did not cause any loss of human lives. From the information communicated from Greece, a person was killed and at least 60 persons from the Edene-Kerkira region were injured.

2. PROCESSING OF INSTRUMENTAL AND MACROSEISMIC DATA

2.1 Instrumental data

The M_L5.5 main shock of the 1990 Griva earthquake sequence was recorded on the seismological stations Skopje (SKO), Ohrid (OHR) and Valandovo (VAY), which then were equipped with three-component short-period Lehner-Griffith seismometers with galvanometric registration on photographic paper. The seismogram from the Valandovo station was not usable due to the exceeded dynamic range of the three-component short-period Lehner-Griffith seismometer with galvanometric registration on photographic paper working there at the time. Figure 1 presents two obtained seismograms, one from the N-S middle-period mechanical seismometer Conrad at the Skopje station and the other from the vertical component short-period Lehner-Griffith seismometer with galvanometric registration on photographic paper at the Ohrid station.

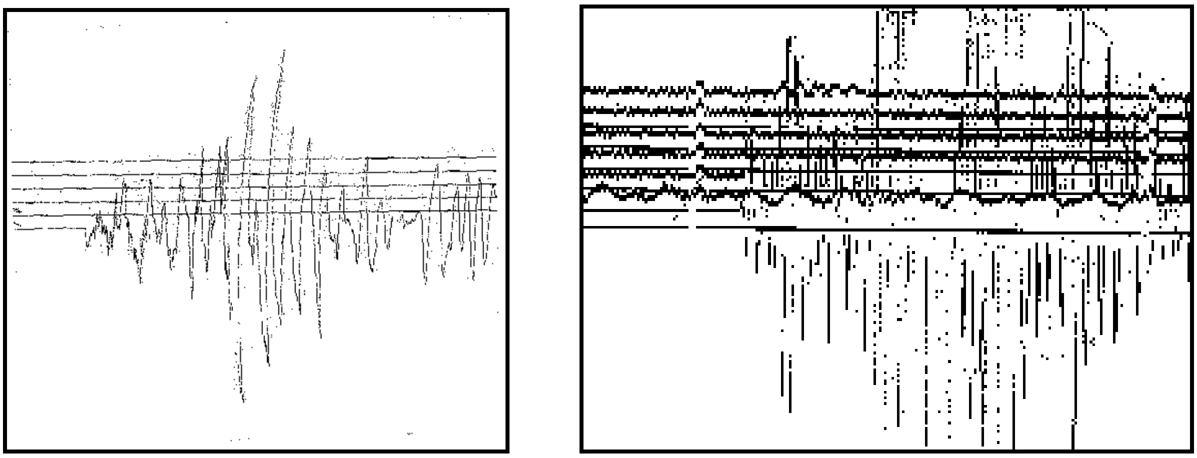

Figure 1. Seismograms from Skopje and Ohrid stations

Hypocentral parameters of the main shock (Table 1) were determined using the instrumental data of the 43 stations within epicentral distance of 900 km. Aftershocks activity, with 365 located earthquakes, lasted until September 1991. The distribution of the epicenters (Cejkovska et al., 2016) of the aftershocks is shown on Figure 2.

Table 1. Hypocentral parameters of the 1990 Griva M_L5.5 earthquake

Date	**Hypocentral time UTC**			**Longitude (°)**	**Latitude (°)**	**Depth (km)**	**Magnitude M_{LgH}**
	(h	**min**	**s)**				
21 December 1990	06	57	43.9	41.02	22.40	15	5.5

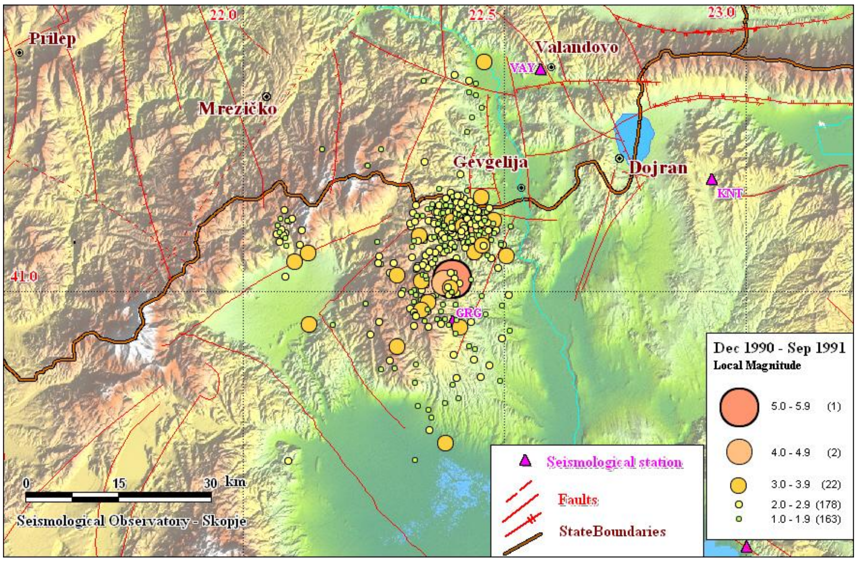

Figure 2. Distribution of aftershocks of the 1990 Griva M_L5.5 earthquake
(from December 1990 to September 1991)

2.2 Macroseismic data

The evaluation of the macroseismic effects of the 1990 Griva M_L5.5 earthquake is taken from the book of Cejkovska et al., 1996, where it is based on the analysis of the questionnaires answered by population, as well as of the reports of the media and special terrain teams of the Seismological Observatory an Institute of Earthquake Engineering and Engineering Seismology in Skopje.
According to the macroseismic data, the maximal intensity of the 1990 Griva M_L5.5 earthquake is $I_0 = \text{VIII}$ MSK-64 degrees, its epicentre is located at $40.99^o\,\text{N}$ and $22.39^o\,\text{E}$ and its hypocentre at depth of 18 km (Figure 3).

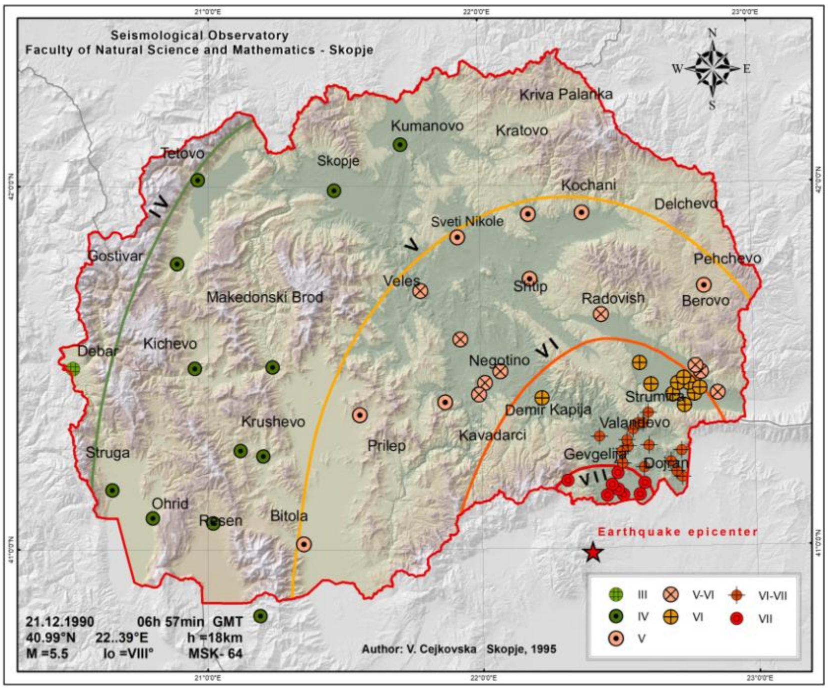

Figure 3. Isoseismal map of the 1990 M_L5.5 earthquake

2.3. Source mechanism

We present here the P-nodal solution of the 1990 Griva M_L5.5 earthquake obtained in the book of Cejkovska et al., 1996. The corresponding source parameters and beach ball are here presented in the Table 2 and Figure 4. According to the comparison with the macroseismic data and tectonic data, Cejkovska et al., 1996, concluded that the earthquake had been caused by a normal left lateral motion of the hanging wall of a fault plane striking toward 66^{o}ENE and dipping under an angle of 84^{o}SSE, that that fault plane can be associated with the south-east border of the Kozuf mountain, as well as that the whole aftershock activity is due to this fault.

Table 2. Source parameters of the 1990 Griva M_L5.5 earthquake (Cejkovska et al., 1996)

Main shock parameters					P – **nodal plane I**				P – **nodal plane II**			
Date 21.12.1990.	Lat.	Long	Focal depth	Local magni-tude	Strike azimuth	Dip angle	Slip angle	Type of faulting	Strike azimuth	Dip angle	Slip angle	Type of faulting
Hypocentral time 06:57:43.9	41.02	22.40	15	5.5	**66 ENE**	**84 SSE**	**-46**	**n-l-l** (normal left lateral)	162 SSE	44 WSW	-171	n-r-l (normal right lateral)

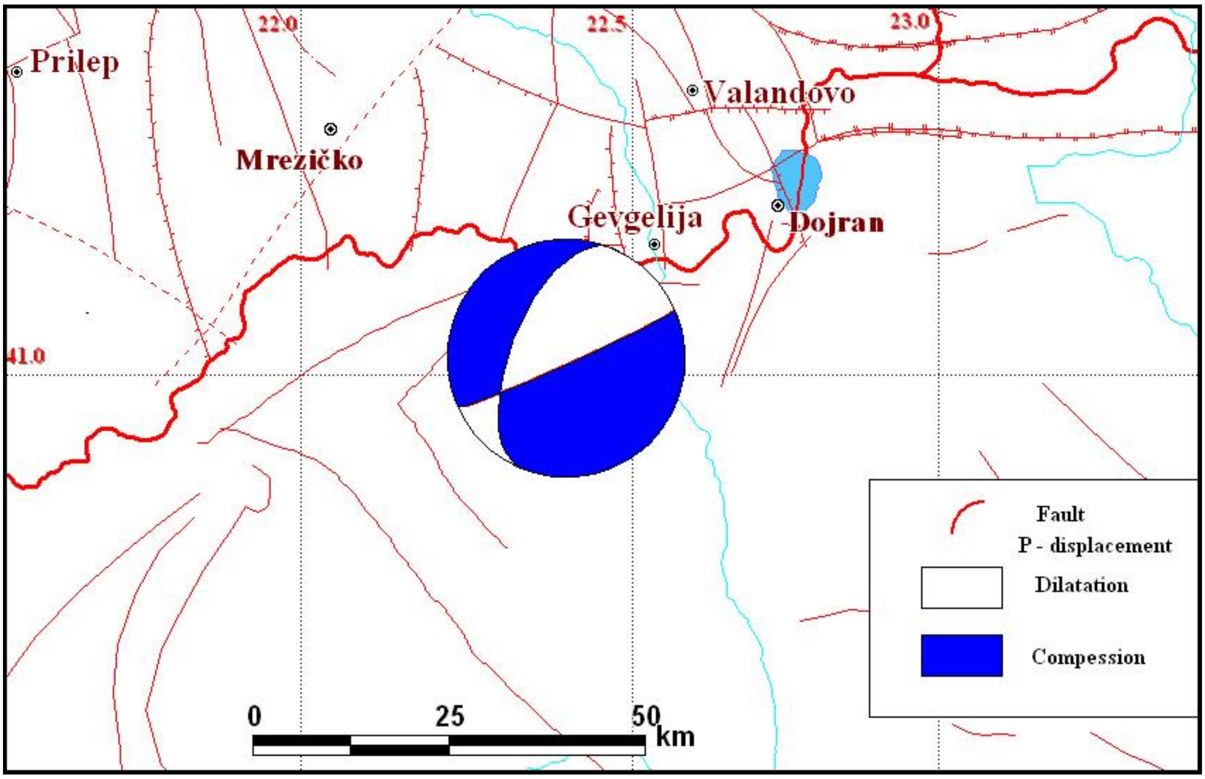

Figure 4. Source mechanism (beach ball) of the 1990 M_L5.5 earthquake (Cejkovska et al., 1996)

3. SEISMIC ACTIVITY AND COMPARISON OF THE RESULTS WITH TECTONIC DATA

The seismic impact of these earthquakes was considerable. The earthquake sequence lasted from 21.12.1990 until September 1991. Significant among all the aftershocks are two strongest ones, namely on 21.12.1990 at 16:19 with a magnitude of 4.1 and maximum intensity of I_o = V – VI^0 MSK-64 and the one on 24.12.1990 at 02:34 with a magnitude of 4.0 and maximum intensity I_o = VI^0 MSK-64. These aftershocks did not cause any significant damage to the structures in Gevgelija and its surrounding.
The main shock caused changes in the yield of the springs in Negorski Spa, Smrdliva Voda and Novo Konsko, or temporary disappearance of surface and well waters, occurrence of cracks in the soil with and without bursting of sand upon the surface, liquefaction and rockfalls.

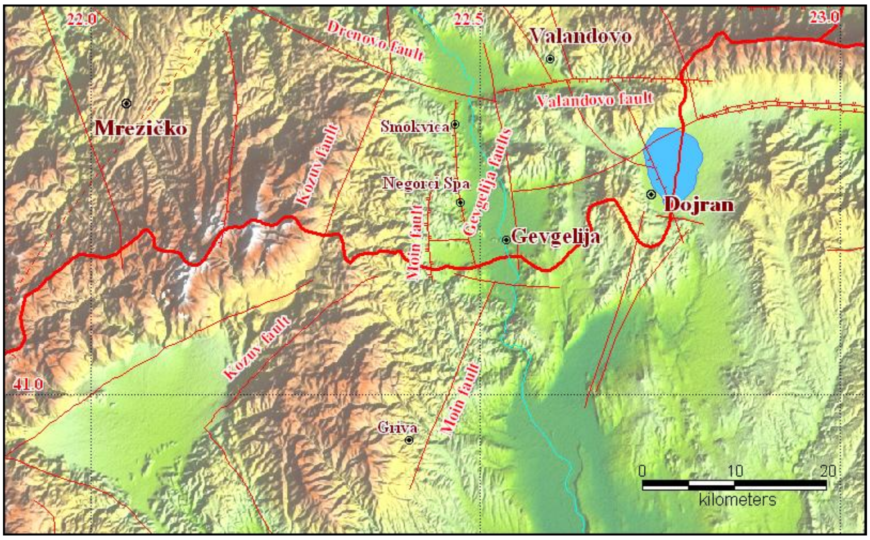

Figure 5. Faults in the affected region

The earthquake originated from an active Moin fault (Figure 5) stretching in the meridian direction through the territory of Northern Greece, entering the territory west from Gevgelija. The fault passes through Negorski Spa and northwest from Smokvica, it collides with the Drenovo-Valandovo fault. Based on seismotectonic investigations that have been performed, the maximum earthquake that may occur along this fault is with an evaluated magnitude of M_{max} = 6.5^o according to Richter. This points out that the earthquake that occurred on 21.12.1990 is not the strongest earthquake that can be recorded along the activated fault. In accordance with our and world experience in the field of tectonics, there is a little probability that the fault be activated along its whole length and generate an earthquake with the theoretically estimated magnitude. The motion of the mentioned fault conditioned disturbance of the stress state of the blocks along the near faults in the part of the Kozhuv-Strumica area.

4. ANALYSIS OF STRONG GROUND MOTION RECORDS OBTAINED FROM GEVGELIJA, DOJRAN AND VALANDOVO

During the main shock of 21.12.1990 and the later aftershocks, three instruments type SMA-1 were activated, located at the Capacitors Factory in Gevgelija, Ograzhden Hotel in Dojran and Valandovo Seismological Station. A total of five records of three earthquakes were obtained: three from the main shock and one of each of the later earthquakes (Table 3). This paper shows the detailed processing and analysis of the obtained records and results shown in graphic and tabular form. According to the data obtained from Greece, the earthquake was also recorded by an instrument located in the city of Edessa in their territory.

Table 3. List of recorded data

Designation	Location	Inst. no.	Earthquake data					
			Date	Time	M	Lat.	Long.	Location
Capacitors Factory	Gevgelija	712	21.12.1990	06.57	5.5	$41^0$02’	$22^0$40’	Griva, Greece
Hotel Ograzhden	Dojran	656	21.12.1990	06.57	5.5	$41^0$02’	$22^0$40’	Griva, Greece
Seismolo-gical Station	Valandovo	2845	21.12.1990	06.57	5.5	$41^0$02’	$22^0$40’	Griva, Greece
Capacitors Factory	Gevgelija	712	22.12.1990	23.40	3.6			
Capacitors Factory	Gevgelija	712	26.12.1990	14.06	3.5			

4.1. Standard Procedure for Data Processing

The procedure for processing of strong motion records was developed at IZIIS and it represents a standard method based on a concept generally accepted worldwide. The process consists of several phases: (1) digitization by a standard digitization step of 0.01 s, i.e., ultimate frequency of 50 Hz; (2) obtaining of uncorrected data; (3) obtaining of corrected data with correction and removal of the long periodic noises, with correction and drawing of a zero axis of the record and scaling of the data to real physical measuring units of accelerations; (4) instrumental correction that eliminates the effect of the instrument itself that has a transferable characteristic and may essentially modify the input signal depending on the frequency range: (5) computation of velocities, accelerations and displacements through filtration of the time history of acceleration with previously defined filters for the purpose of eliminating noises. By integration of acceleration, the velocity is obtained. By integration of velocity, the displacement is obtained.
Computation of response spectra is the most important data for seismic design in engineering practice. They represent the maximum value of the response of a single-degree-of-freedom system for a pre-defined period and damping, whereat the acceleration computed in the previous phase is used as an input excitation. The following response spectra are computed: acceleration, velocity and component displacement response spectra for damping of 0, 2, 5, 10 and 20%.
The new processing software uses an algorithm that processes the signal much faster than the previously used software. When comparing the obtained results, there are minor differences in high frequencies, while in the intense part of the signal there are no significant differences in the results obtained from the record processing.

4.2. Obtained Results

Table 4 shows the most important parameters of each individual component of the five records, i.e., the peak values of acceleration, velocity and displacement as well as the ultimate frequencies of filters used in the course of data processing. F1 and F2 define the high band pass filter, while F3 and F4 define the low band pass filter, meaning that the records contain harmonics in the range between F2 and F3 frequencies. From this data, it is clear that the earthquake of 21.12.1990 caused intensive ground motion in Gevgelija, causing a great number of damages followed by failure of structures. Considerably lower are the obtained values of the same quantities in Valandovo which is the result of the greater distance from the earthquake epicenter as well as the local soil characteristics (rock) and the place of recording the earthquake.

Table 4. Obtained maximal values

No.	Designation	Component	Absolute max.corrected:			Boundary frequencies			
			acc.	vel.	displ.	High pass filter		Low pass filter	
			cm/s^2	cm/s	cm	F1	F2	F3	F4
1	Capacitors Factory	L	141.6	7.268	0.903	0.20	0.40	25.00	27.00
		T	205.2	8.099	0.554	0.20	0.40	25.00	27.00
		V	100.4	5.284	0.714	0.20	0.40	25.00	27.00
2	Hotel Ograzhden	L	27.6	1.652	0.185	0.36	0.56	25.00	27.00
		T	32.0	2.187	0.227	0.62	0.82	25.00	27.00
		V	20.6	1.541	0.246	0.31	0.51	25.00	27.00
3	Seismological Station	L	55.2	3.443	0.401	0.30	0.50	25.00	27.00
		T	58.6	3.777	0.316	0.27	0.47	25.00	27.00
		V	16.4	1.533	0.188	0.37	0.57	25.00	27.00
4	Capacitors Factory	L	10.8	0.258	0.009	2.70	2.90	25.00	27.00
		T	30.0	0.649	0.021	1.77	1.97	25.00	27.00
		V	16.1	0.279	0.007	2.60	2.80	25.00	27.00
5	Capacitors Factory	L	26.3	0.386	0.013	1.75	1.95	25.00	27.00
		T	23.3	0.530	0.016	1.54	1.74	25.00	27.00
		V	19.5	0.297	0.010	2.00	2.20	25.00	27.00

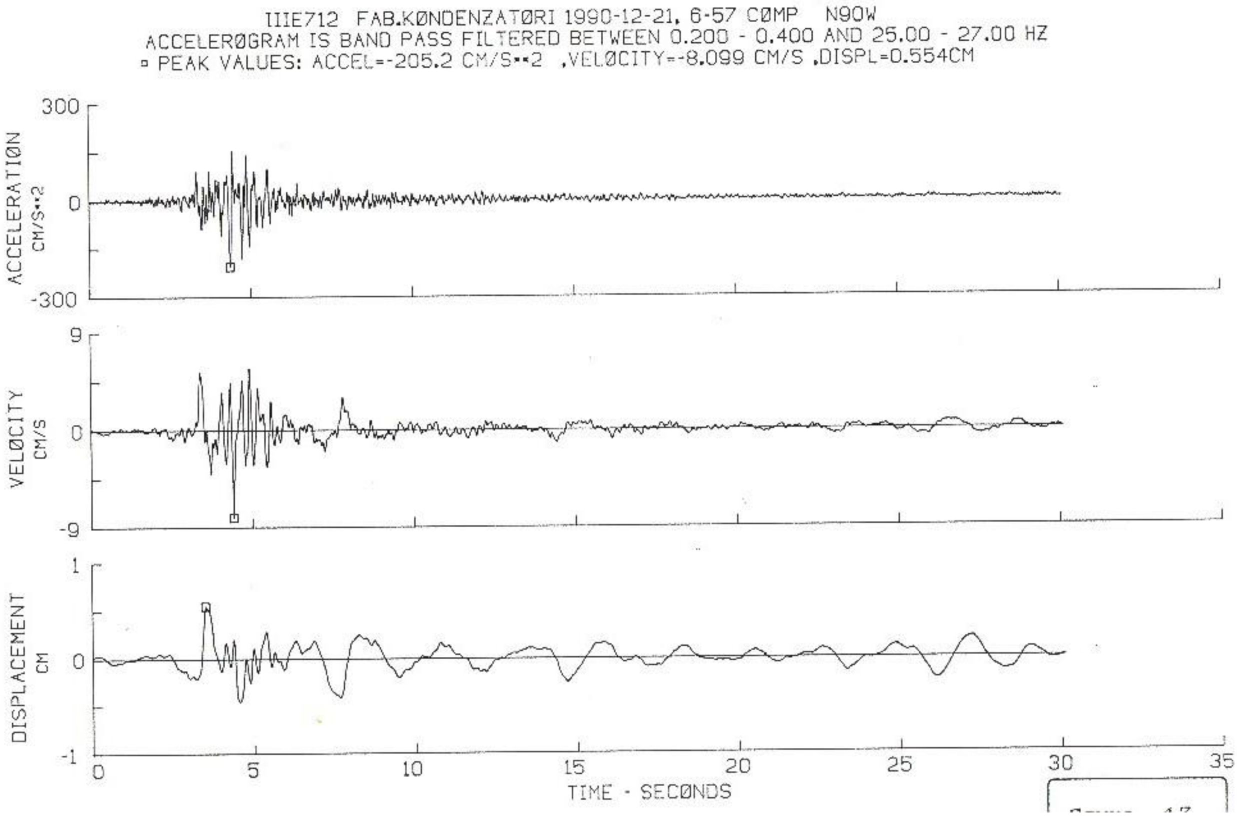

Figure 6. Time history of acceleration, velocity and displacement for N90W component.

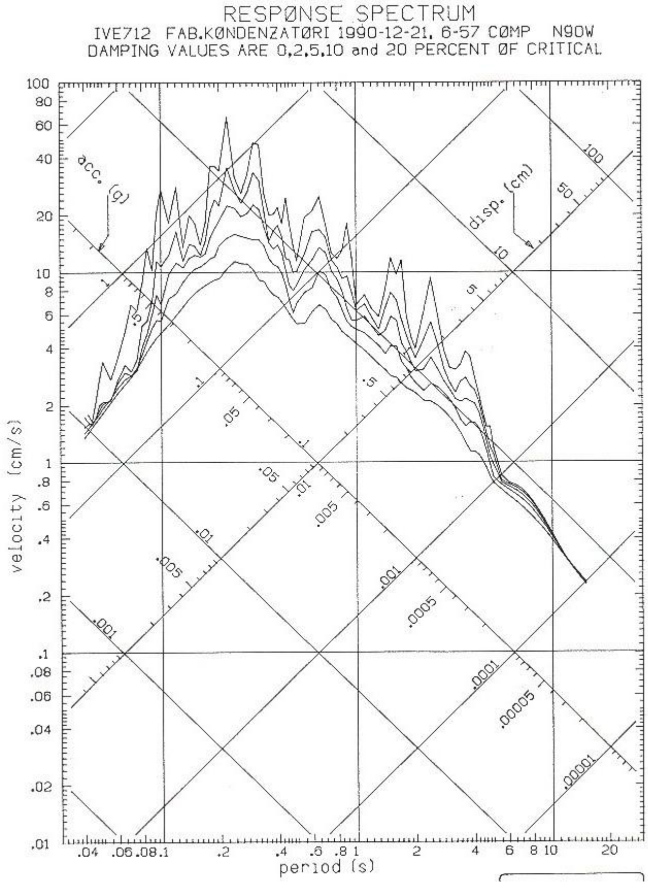

Figure 7. Response spectrum for N90W component.

Figure 7 shows the acceleration, velocity and component displacement response spectra for damping of 0, 2, 5, 10 and 20% of the strongest component recorded at the Capacitors factory in Gevgelija.

5. ANALYSIS OF DAMAGED STRUCTURES

From the obtained results, it can be concluded that the main shock on the location of the Factory for Capacitors in Gevgelija cause considerable accelerations (0.2 g shear component). From the special geomechanical analyses of the soil where the instrument was placed, a relatively soft soil is at stake, meaning that the level of this acceleration extraordinarily affects the local soil structure. Soft soils generally amplify input acceleration. For a realistic insight into the level of acceleration caused by the earthquake, it is necessary that the instrument is placed on a hard soil or the so called bedrock. Such location, in this case, is the Valandovo Seismological station where peak acceleration of 0.058 g, shear component, was measured. Since the relative distance between Valandovo and Gevgelija and between Dojran and Valandovo is very small compared to the epicentral distance, it can approximately be considered that the same acceleration level at bedrock occurred also in Gevgelija and Dojran. The response spectra graphs show that the spectral content of the time record of acceleration is mainly concentrated in the interval of 0.04 seconds to 2 seconds, corresponding to 0.5 to 25 Hz. On the other hand, the displacements are quite harmonic, with a fundamental period of vibration of about two seconds. This was felt by a large number of citizens.

In cooperation with relevant institutions for evaluation of damage due to disasters, inspection and classification of damages to engineering structures in the territory of the most affected municipalities of Gevgelija and Valandovo were performed.

Classification of the extent of damage and usability of structures is done through classification and marking of structures into 5 categories. The first category accounts for structures without visible damage, the second category involves structures with cracks in mortar, the third category involves structural damage, and the fourth category is characterized by large cracks with or without separation of walls (temporarily unusable structures) and the fifth category accounts for structures suffering damage to structural elements and joints. The structures belonging to the fifth category are not safe due to the possibility of collapse.

Damages are mainly manifested on masonry structures built of unbaked brick (NT), solid brick (ZT) without horizontal and vertical belt courses, with considerably lesser damage to masonry structures with horizontal and vertical belt courses and reinforced concrete structures, stone masonry structures (KZ), masonry structures with concrete blocks (ZB) and reinforced concrete structures (AB).

Damages occurred as a consequence of non-connection of the bearing walls in both orthogonal directions, high gable walls and relatively weak connection of the walls with the floor structures constructed of wood, Table 5 and 6.

Damaged structures are with a fundamental period of vibration of 0.1 to 0.3 s coinciding with the records obtained by the strong motion network.

Exceptions are some damages to reinforced concrete structures with a cantilever outlet and a mushroom floor structure. In the Valandovo region, due to the greater distance from the epicenter, the damages were considerably reduced, but still the main types of damages were observed on the same types of structures, Table 7.

Table 5. Number of damaged structures in private ownership in Gevgelija

Struc. type	**Extent of damage**					**Total**
	1	**2**	**3**	**4**	**5**	
AZB, AB	87	116	35	6	2	246
ZB	1	15	3	0	0	19
KZ	9	261	320	95	20	705
ZT	12	162	84	22	2	282
NT	21	221	234	101	62	639
Total:	**130**	**775**	**676**	**224**	**86**	**1891**

Table 6. Number of damaged structures in private ownership in Gevgelija

Struc. type	**Extent of damage**					**Total**
	1	**2**	**3**	**4**	**5**	
AZB	1	16	3	1	0	21
AB	34	45	4	2	0	85
ZB	0	1	2	0	0	3
KZ	0	2	4	4	0	10
ZT	1	15	22	2	7	47
NT	0	4	4	0	1	9
Total:	**36**	**83**	**39**	**9**	**8**	**175**

Table 7. Number of damaged structures in private and public ownership in Valandovo

Struc. type	**Extent of damage**					**Total**
	1	**2**	**3**	**4**	**5**	
AZB, AB	6	25	1	0	0	32
ZB	1	2	0	0	0	3
KZ	13	107	36	4	0	160
ZT	3	44	13	1	0	61
NT	0	14	7	1	0	22
Total:	**23**	**192**	**57**	**6**	**0**	**278**

The effect of the damages due to this earthquake was increased in those structures in Gevgelija and the surrounding places damaged by the Thessaloniki earthquake that occurred in 1978 and the Valandovo area (Udovo) damaged by the Negotino earthquake that took place in 1985. In both cases, these were structures that did not undergo any interventions after these earthquakes or were retrofitted, but not adequately strengthened in accordance with the valid technical regulations for design and construction of structures in seismically active regions.

6. CONCLUSIONS

The pure seismological investigation of the 1990 Griva M_L5.5 earthquake showed that it had been caused by a normal left lateral motion of the hanging wall of a fault plane striking toward 66^oENE and dipping under an angle of 84^oSSE, that that fault plane can be associated with the south-east border of the Kozuf mountain, as well as that the whole aftershock activity (with 365 located shocks) was due to this fault.

The earthquakes that occurred in the period 21.12.1990 to 26.12.1990 in the northern part of Greece were felt in Gevgelija, Dojran and Valandovo, causing considerable damage to a larger number of structures.

There was confirmed the necessity for taking prevention measures for the individual structures with a small number of storeys (ground floor and storey), i.e. construction of a bearing structural system that represents an integrity of vertical and horizontal structural elements capable of sustaining and transferring seismic effects without considerable damage. For example, that can be frame systems and systems of masonry structures strengthened by vertical and horizontal belt courses with a rigid RC floor structure.

Given the damages, it is necessary to instrument the type of structures that suffer the most damage under such and similar earthquakes, in order to obtain the real response of a characteristic structural system for the purpose of taking prevention measures for protection.

Avoiding to apply recommended measures for repair and strengthening of structures damaged by occurred earthquake could result with considerable damage to the structures in a case of future earthquake even if it has lower seismic intensity (magnitude).

7. REFERENCES

Cejkovska V., Pekevski L., Cernih D., Hristovski B., Vasilevski N., Jordanovski, Lj. (1996). *Gevgelija Earthquake of 21 December 1990 at 06h 57min GMT and Its effect on the Territory of Republic of Macedonia*, Ss. Cyril and Methodius University, Faculty of Natural Sciences and Mathematics, Seismological Observatory, Skopje.

Cejkovska V., Pekevski L., Drogreska., K., Najdovska J. (2016). *A report on the project "National Annexes to the Eurocodes",* Ss. Cyril and Methodius University, Faculty of Natural Sciences and Mathematics, Seismological Observatory, Skopje.

Milutinovic Z., Gavrilovic P., et al. (1991), Evaluation of Damage to Engineering Structures in Private and Public Ownership in the Territory of Gevgelija Municipality Due to the Earthquakes of 21.12.1990, Volume 1: Global Evaluation of the Natural and Value Indicators of Damage to Populated Places, Institute of Earthquake Engineering and Engineering Seismology, Ss. Cyril and Methodius University, Skopje, IZIIS Report 91-14/1, Skopje.

Milutinovic Z., Gavrilovic P., et al. (1991). Processing and Analysis of Records Obtained by the Existing SMA-1 Strong Motion Instrument Network in the Period 21-26.12.1990, Institute of Earthquake Engineering and Engineering Seismology, Ss. Cyril and Methodius University, Skopje, IZIIS Report 91-15, Skopje.

Milutinovic Z., Gavrilovic P., et al. (1991), Evaluation of Damage to Engineering Structures Owned by Citizens and Legal Entities in the territory of Valandovo Municipality due to the Earthquakes of 21.12.1990, Volume 2: Summary Assessment of Natural and Value Indicators of Damages for the

Valandovo Municipality, Institute of Earthquake Engineering and Engineering Seismology, Ss. Cyril and Methodius University, Skopje, IZIIS Report 91-18/2, Skopje.