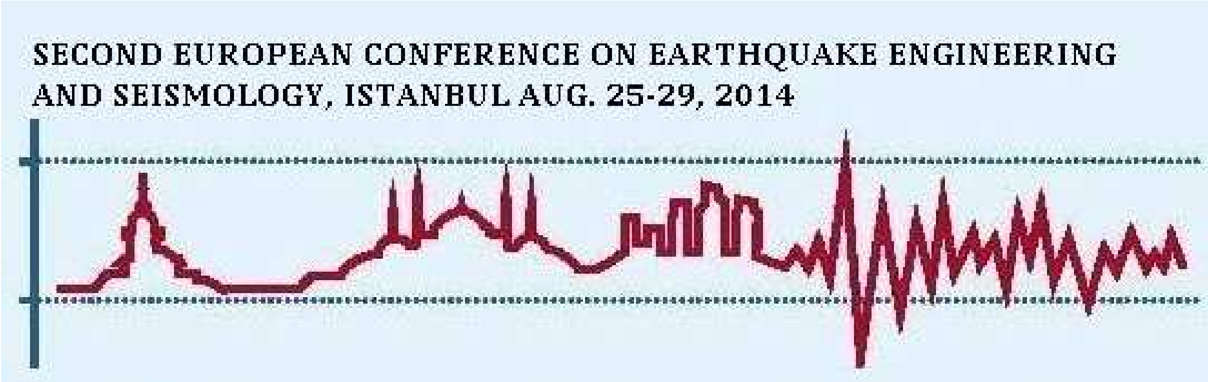

SEISMIC MONITORING OF THE SOUTHWESTERN AREAS OF THE UKRAINE AND ADJACENT AREAS

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ABSTRACT

The high level of potential seismic hazard in the southern regions of Ukraine requires the state support for the development on their territory of quite dense network of seismological and engineering seismological observations. The results of seismic micro zoning give a more accurate picture of the seismic situation in the Odessa region and Odessa city. Further development of the monitoring network is necessary to solve the problem of rather cheap, but highly effective, seismic protection of population, environmentally hazardous and economically important objects.

INTRODUCTION

Seismic danger of the territory of the Ukraine is determined by its geographical position. South-eastern areas of the country are located near a powerful seismically active belt of our planet which was formed as a result of the collision of the African, Indian and Eurasian continental plates. The major elastic energy that arises in the belt is realized in earthquakes of different intensity in the belt itself. But its considerable part is transferred to geological structures of rather quiet platforms in which dangerous local earthquakes can arise. Until the 70-es of the 20th century it was considered that larger seismic events cannot take place on the most part of the territory of the Ukraine located on a stable ancient Eastern European tectonic platform. Now it is known that catastrophic earthquakes occurred on all ancient tectonic platforms of the world, though of less strength than in seismically active belts. Strong intra-plate earthquakes can lead to big social and economic losses, due to the fact that houses and constructions remain unprepared to the earthquake attacks.

Over recent years generally felt earthquakes occurred near Ternopil – on 3.01.2002, with the magnitude of 3,2, in Luhansk region near Novo - Darevka on 11.05.2004 with the magnitude of 3,2 and on 19.04.2006 with magnitude of 3,0, in Zhytomyr region on 12.03.2006 with the magnitude of 3,6. An earthquake with the magnitude of 2.9 took place near Kharkiv region in Kupiansk on 22.11.2009. It is necessary to note that the historic 1913 earthquake with an epicenter near Kupiansk with the magnitude of 3.5 and focal depth 8 km, in which the local intensity of seismic tremors in the epicentral area reached 6.5 points on a scale MSK -64, was considered the strongest one in the eastern part of Ukraine until now.

Among latest seismic events recorded on the platform part of the territory of the Ukraine it is necessary to draw at seismic events in the Kriviy Rig iron-ore basin. Table 1 shows the seismic events in the area of Kriviy Rig recorded in the period from 2009 to 2013 on stations of the Ukrainian seismological network.

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There is also historical information about the seven-point earthquake in the north of the Kirovograd region in 1873. In addition, an earthquake with the magnitude of 3,6 took place in the area bounded by West Ingulets and Kriviy Rig- Kremenchug faults on 27.01.2006. In the area of Kriviy Rig fault a powerful earthquake with the magnitude of 3,6 occurred on 25.12.2007, on 12.06.2010 an earthquake with the magnitude of 2.8 occurred near Kriviy Rig, which was of man-made (collapse) character unlike the other events. Another tectonic earthquake with the magnitude of 3,9 took place in this area on 14.01.2011 at 07:03 local time. This earthquake was recorded by all Ukrainian stations and stations of the border countries, which is reflected on the websites of foreign seismological centres ISC; EMSC-CSEM; NEIS.

Table 1. Seismic events in the area of Kriviy Rig (2009-2013).

Date & Time	Latitude	Longitude	Mag	Depth, m
13-06-2010 03:58:17	48.02	32.35	4.3	447 - 527
18-09-2010 04:00:35	47.84	33.30	3.3	1200 - 1300
14-01-2011 05:03:12*	48.10	33.40	3.5	447 - 527
26-06-2011 04:04:30	48.02	32.99	2.5	447 - 527
22-10-2011 04:06:45	48.89	33.24	3.1	1200 - 1270
31-03-2012 04:00:42*	48.20	32.50	3.0	1200 - 1270
17-06-2012 04:03:16	47.70	33.57	3.0	1270 – 1300
28-11-2012 20:47:43*	47.787	33.341	3.1	0
23-06-2013 21:16:33*	48.04	33.42	4.6	2000

A local earthquake recorded by all Ukrainian seismic stations and more than a hundred seismic stations of the Mediterranean-European and global seismic networks occurred in Kriviy Rig on 24.06.2013. Its magnitude was estimated as 4.6. The earthquake occurred at 00:16 local time. According to public reports it was felt only by people on high floors, that according to macro-seismic MSK-64 scale and DSTU -B - B.1.1 -28:2010 "Scale of seismic intensity" corresponds to the intensity of seismic tremors of 3-4 points on the ground of seismic properties of the 2nd category. According to the Ukrainian stations and the European-Mediterranean Network the rapid assessment of the focal depth is about 2 km. However, the error of its determination due to the lack of the nearby network stations is significant, that allows Russian seismologists, for example, to estimate it as 10 ÷ 15 km. Fairly low intensity of seismic tremors in such a large magnitude can be rather an indirect evidence of the greater depth of the reservoir. Position of an earthquake will be specified by methods of macro-seismic survey of its manifestations and consequences. Local earthquakes were repeatedly observed near Odessa. Figure 1 shows the map of earthquakes that took place in Odessa and surrounding areas for the last 1000 years. Note that weak local seismicity in the area is poorly understood due to the lack of instrumental methods in a sufficiently dense network of stationary seismic stations.

According to the published data in historical times there are known cases of local earthquakes near Odessa. For example, work (S. Evseev , 1969) provides a reference to the earthquake of July 9, 1857 with an intensity I = 5 points, which was displayed as "... a local short jerk with a buzz." Another earthquake with the magnitude of 4.7 occurred at a distance 50 km from Odessa in 1864. (S. Evseev , 1969)

Seismically unsafe housing and industrial facilities in Odessa and the region are: active structures of the Southern and Eastern Carpathians interarea (Vrancea seismic zone). Earthquakes with the observed magnitudes in the range of M = 6 ÷ 7.5 are often localized in this area. At considerable depth of reservoirs of 100 ÷ 150 km, these earthquakes due to the low energy decay at distance cause earth tremors felt by population within vast areas. Estimated predictive value for the magnitude of the Vrancea zone is max = 8,0 ± 0,3. The zone is also characterized by the subcrust depth of seismic origin: 75% of all events with M ≥ 4 in the zone occurs at a depth H = 100 ÷ 170 km . Only in the last 200 years, the city of Odessa was exposed to strong subcrust Vrancea zone earthquakes with intensity

I = 6 points seven times and twice in 1802 and 1940 - of I = 7 points (E. Sagalova, 1969. A. Nikonov , 1996).

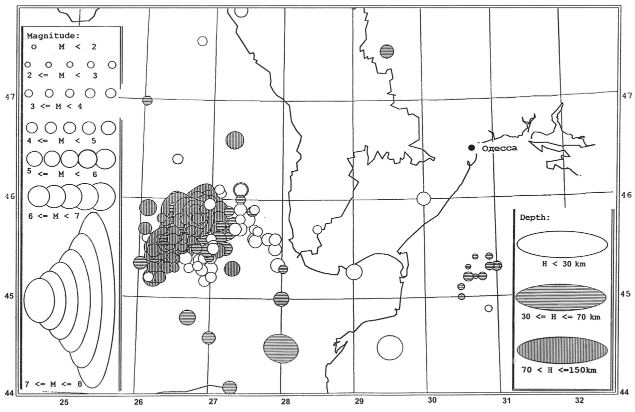

Figure 1. Map of earthquake epicenters in Odessa region and surrounding areas (B. Pustovitenko, 2004)

Table 2 provides a list of strong earthquakes of the Carpathian arc Vrancea Mountains and the intensity of their manifestations in the major cities of the Ukraine, Moldova and Russia (The seismological bulletin of Ukraine for 1992).

Table 2. Destructive earthquakes in Romanian Carpathians (Vrancea zone)

Date & Time	Mag	The intensity at the epicenter	The intensity of the earthquake in the cities					
			Kishinev	Lviv	Chernivtsi	Odessa	Kiev	Moscow
26.10.1802	7,5	9-10	7	4	7	7	5	3
26.11.1829	6,5	8	7		6	6	4-5	-
23.01.1838	7,0	9	7	4-5	6	6	4-5	-
6.10.1908	6,75	8	6	5	6	6	5	-
10.11.1940	7,3	9	7-8	5	6	7	5	4
4.03.1977	7,2	9	6-7	4	5-6	5-6	4-5	3
30.08.1986	7,0	8-9	6	4	5	5	4	-
30.05.1990	6,7	8-9	6	4	5	5	4	3

2. Seismic region of Dobrogea, where earthquakes with the maximum magnitudes up to 7.0 are possible according to calculations (B. Pustovitenko, 2000, A.Novikov, 1990). During historic times there were several earthquakes with magnitude of 3.5 ÷ 7.0 with the intensity of I >5 points (B. Pustovitenko, 2000, A.Novikov, 1990).

3. Local seismicity associated with tectonic faults in the basement of the East European Platform and shelf faulting and the continental slope of the western Black Sea.

Seismic events recorded in the period of 1961-1996 the network of highly sensitive stations in the Crimea indicate potentially high seismic activity of the shelf structures. Only in 1992 there were 12 earthquakes with the magnitude range of m = 2 ÷ 3.8 and reservoir depths of 10 km (The seismological bulletin of Ukraine for 1992).

Odessa's first seismic station "Odessa city" was founded in Odessa State Academy of Construction and Architecture to study the level of seismic danger in Odessa region. Before that such observations were conducted in the two nearby seismic stations *Stepanovka* and *Zmeiniy Island* (Snake Island). The latter station worked only from time to time due to intrinsic maintenance and operation difficulty on a remote island.

Since its work the seismic station "Odessa city" has recorded more than 100 seismic events, including 8 earthquakes with the magnitude of 4,5 ÷ 5,3 (K.Yegupov, 2013).

Figure 2 shows the vertical component of earthquake records in the subcrust Vrancea zone recorded by the seismic station "Odessa-city" on 06.10.2013(K.Yegupov, 2013).

Figure 3. shows soil conditions of the location of the seismic station "Odessa-city" in the basement housing of Odessa Academy of Civil Engineering and Architecture. Apparently, the seismic detection sensors are located on relatively hard soil, which may be considered as soil of the second category as for seismic properties, according to the table 1.1. DBN B.1.1-12: 2006

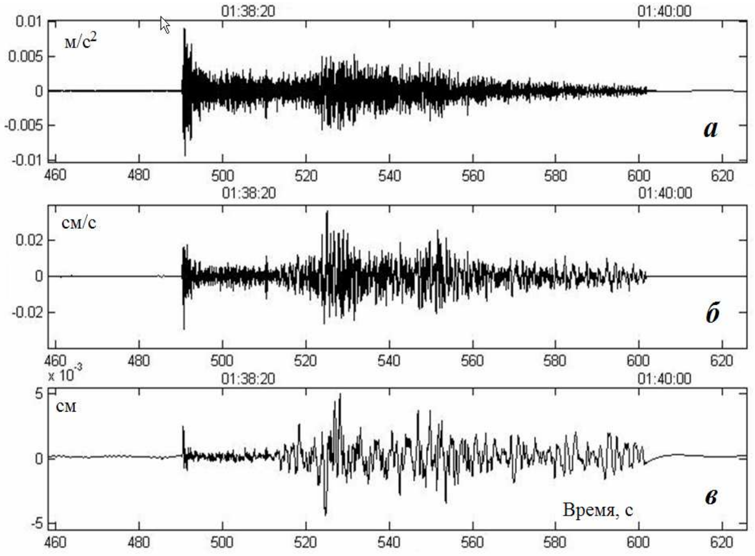

Figure 2. The vertical component of oscillations calculated by recording the earthquake 06.10.2013, of the Vrancea zone, registered by the seismic station "Odessa-city": a - acceleration, b - speed I c - offset.

Information shown in figure 3 is used to determine the relative increase (decrease) of the parameters of seismic effects on the construction and operation stages of the city with other types of soil conditions.

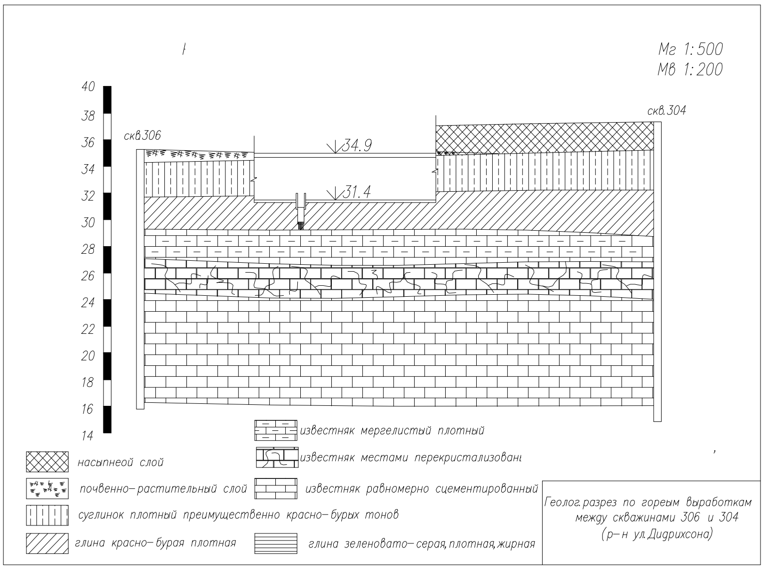

Figure 3. Seismic layout in the basement housing of Odessa Academy of Civil Engineering and Architecture.

During the work of the seismic station "Odessa-city" a series of earthquakes imperceptible to the public, which are the most dangerous for the parts of the city of Odessa and Odessa region, local source zones and the Vrancea zone was registered. Their list indicating the parameters of foci is shown in the table 3, table 3.1.

Table 3. List of seismic events with the magnitude of 4-5,3 in 2013

№	Date & Time	Latitudees	Longitude	Depth	Mag	Region name
1	2013-11-21 06:38:52.0	45.79	26.73	90	4.4	ROMANIA
2	2013-10-15 19:33:12.0	45.64	26.56	136	4.7	ROMANIA
3	2013-10-06 01:37:21.0	45.64	26.69	134	5.3	ROMANIA
4	2013-09-08 13:22:12.0	45.60	22.89	2	4.7	ROMANIA
5	2013-09-08 13:00:42.0	45.60	22.86	4	4.1	ROMANIA
6	2013-08-29 04:06:17.0	43.95	25.88	9	4.0	ROMANIA
7	2013-08-11 13:31:08.0	45.81	26.82	94	4.3	ROMANIA
8	2013-07-28 14:25:05.0	45.65	26.51	81	4.0	ROMANIA
9	2013-07-12 18:02:31.0	45.45	26.39	122	4.1	ROMANIA
10	2013-06-20 00:22:55.0	45.58	26.70	114	4.1	ROMANIA
11	2013-05-10 19:46:06.0	45.70	26.61	133	4.0	ROMANIA
12	2013-05-02 09:51:42.0	45.56	26.60	133	4.0	ROMANIA
13	2013-03-16 00:34:18.0	46.20	27.04	15	4.2	ROMANIA
14	2013-03-06 01:10:11.0	45.48	26.26	124	4.2	ROMANIA
15	2013-02-27 12:30:05.0	45.45	24.33	5	4.0	ROMANIA

Table 3.1. Seismic events with the magnitude of >4 from 2008 to 2013

Year	2008	2009	2010	2011	2012	2013
Mag	4.0-5.0	4.0-5.3	4.5	4.0-4.8	4.0-4.6	4.0-5.3
Number of events	8	8	2	8	14	15

Clarifying the seismic risk of buildings, design engineers and builders are interested in the question of their behaviour during earthquakes, which level of seismic hazard which is given by the intensity of seismic tremors in points of the macroseismic scale, or in form of anticipated, with a specified probability of not exceeding at a given time period, physical quantities characterizing the seismic vibrations in future earthquakes.

Carrying out calculations of a building or a construction on seismic effects, it is necessary to consider a number of the major characteristics of an earthquake, such as the speed of distribution of a seismic wave, three-dimensional nature of the effect, its orientation in space, wave nature of soil movement, the prevailing period of soil fluctuation. The fullest information on seismic effect can be gained when using real or synthesized accelerograms of earthquakes as a result of seismic micro zoning.

Seismic micro zoning represents the section of the engineering seismology which subject is the specification of the data of seismic zoning for territories or sites under construction taking into consideration the local ground, hydrological conditions and the landscape. Seismic micro zoning became a regular practice of engineering research in the Ukraine according to the requirements of the Ukrainian national construction regulation B.1.1.-12:2006.

Main objective of the research using seismic micro zoning is the quantitative assessment of rated seismicity in terms of seismic force and physical parameters of eventual seismic effects, taking into account the influence of local geotechnical conditions of a project construction site.

For mass civil and industrial engineering venues, that make the majority of the project buildings in Odessa and Odessa region, the background seismicity according to the 1.1.1 of the Ukrainian national construction regulation has to be accepted with a tolerant seismic risk of 10% (frequency of 500 years). However, the maps of the general seismic zoning do not take into account local soil conditions, although it is known that geotechnological, geomorphological, hydrogeological and geotectonic features of a building site can significantly influence the size of local seismic manifestations that have to be taken into consideration according to the 1.1.2 of the requirements of the Ukrainian national construction regulation.

Works on seismic micro zoning of building and operational sites in Odessa and Odessa region actualizes the data base organization of geotechnological and seismological data for the region, and also the method development of obtaining quantitative assessment of rated seismicity, focused on the use of empirical regularities of the field of seismic fluctuations under the conditions of the city of Odessa, obtained according to the data of the instrumental surveys.

Records of strong earthquakes of hazardous for the site of seismogenic zones registered directly on it can provide the most complete information about the magnitude and the nature of the ground motion on the test site during potentially possible maximal earthquakes. However, because large earthquakes are rare, one usually fails to get their records in such a limited period of time for geological and geophysical studies of construction sites. Therefore, synthetic rated accelerograms were calculated for modeling of seismic ground motion calculated on the construction site.

A semi-empirical approach based on the use of the theoretical calculation of the amplitude spectra of the accelerograms and their empirical phase spectra (A.Kendzera, 2008) was used. The spectral density of the resulting impact was calculated on regional (for the Vrancea zone) and the world average (for local source zones) dependencies between the position of the characteristic points of the amplitude spectrum of acceleration, the magnitude of a rated earthquake magnitude and the epicentral distance. Influence of soil conditions on the site was taken into account by using generalized theoretical models of the frequency characteristics of the geological environment under the platform.

For each construction site three rated three-component accelerograms were provided, which were modelling predicted seismic oscillations of the free surface of the ground during earthquakes in the Vrancea zone and three ones – in the local reservoir zones. While generating there were used different combinations of theoretical spectra envelopes of the rated accelerograms, normed frequency characteristics of the medium and phase spectra obtained for various posts of real earthquakes.

In the course of work on seismic microzoning "Seysmobud " and the Subbotin Institute of Geophysics studied about 30 construction sites in Odessa region to clarify the calculation of seismicity. In the course of research three-component rated accelerograms (Fig. 4) present time functions, modelling the components of acceleration of seismic movements in the surface soil at the construction site during earthquakes, which can be realized on it once in 500 years. For practical use we propose two types of rated accelerograms corresponding earthquake focal zone of Vrancea and local focal zones of possible occurrence of earthquakes (A.Kendzera, 2008).

Figure 5 shows the three dimensional orientation of the vector components of the total seismic oscillations shown in Fig. 4: vertical - Z, «North-South» - NS, «East-West» - EW, radial - R (facing away from the construction site towards the reservoir) and tangential - T (perpendicular to the radial).

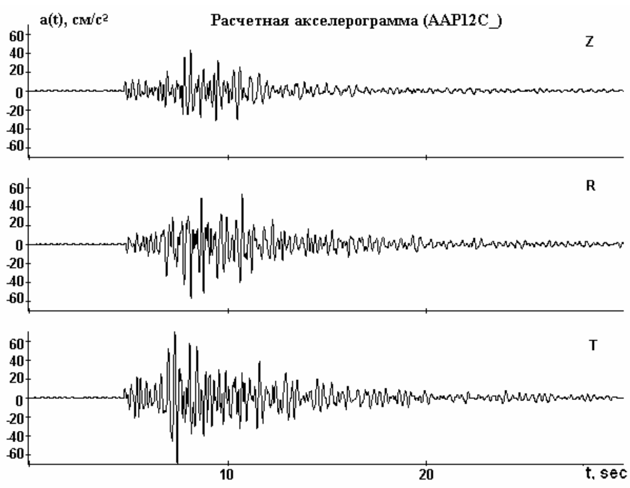

Figure 4. Example of the three-component rated accelerograms, modelling rated earthquake of local focal zone on the free surface of the ground one of the sites in the city of Odessa.

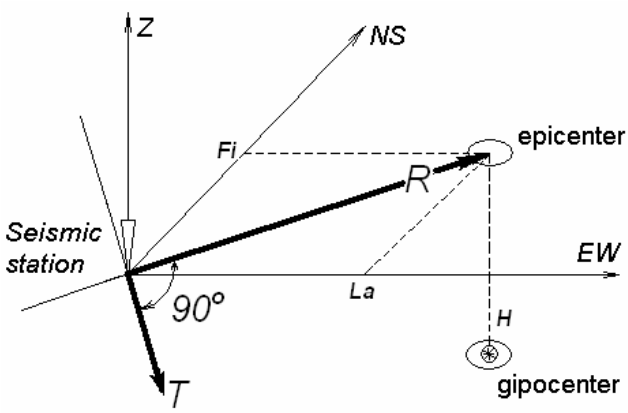

Figure 5. Direction of vector components of the total seismic vibrations.

Figure 6 shows the response spectra of individual oscillators T - component of the rated accelerograms shown in Figure 4.

The dominant oscillation frequency oscillators with 2, 5 and 10 percent level of intrinsic attenuation were determined according to the spectra of the reaction. Under the predominant frequencies we understand oscillation frequency, at which response spectra have the intensitiy greater than half of its maximum value.

In the course of construction works the base of engineering and geological information and the basic parameters of the synthesized accelerograms (see table 4) have been formed. The set of accelerograms is supplemented by a computer program for visualizing of the accelerograms and their preprocessing. The program allows to plot accelerogram charts, analyze in detail their individual plots, calculate the spectra, build response spectra, graphics oscillation frequency and duration of different intensity(A.Kendzera, 2008).

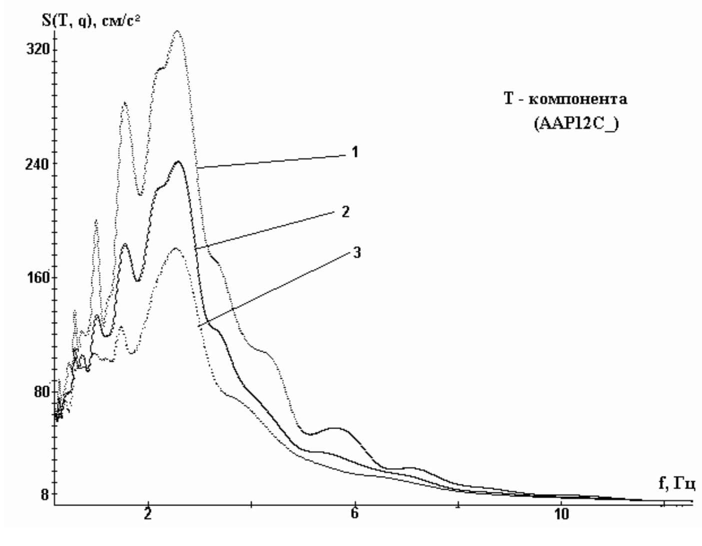

Figure 6. Linear response spectra of individual oscillators accelerogram shown in figure 4. Figures 1, 2, 3 correspond with intrinsic attenuation of single oscillators: 2, 5 and 10 percent of critical, f - the angular frequency and T = 1 / f.

Table 4. Example of the basic parameters of the synthesized ternary rated accelerograms shown in figure 4.

Component	Acceleration, a, см/с2	Dominant frequency, Hz	Oscillation time	
			a>0,9a	a>0,5a
T	69.5	1.8- 5.6	0.4	2.5
R	57.0	1.6- 6.1	0.8	4.1
Z	43.1	1.9- 6.1	0.4	2.9

A map of the location of the studied sites in Odessa and the Odessa region was prepared, their classification according to soil conditions was made, the data describing the frequency parameters, the predominant periods and amplitudes of the three-component accelerograms synthesized for modelling seismic waves from earthquakes of the Vrancea zone and local focal zones was collected.

Addresses of the construction sites are shown in table 5, where the research the seismic zoning, indicating an updated seismic hazard - IRN, obtained seismic intensity increments - ΔIM and totals calculated intensities IR, was conducted.

Table 5. List of works performed by seismic microzoning.

№ п/п	Address of the construction site	IR intensity rated value for site
1	Zatonsky.	IR=IRN + ΔIM =6.51 + 0.69 = 7.20 points
2	Bocharov St., 35, 53	IR =IRN + ΔIM =6.51+ 0.22 = 6.73 points a
3	Bocharov St., 45a	IR =IRN + ΔIM =6.51 + 0.33 =6.84 points
4	Primorskaya St., 2 ,Kryzhanovka	IR =IRN + ΔIM = 6.50 + 0.63 = 7.13 points
5	Deribasovskaya St., 25	IR =IRN + ΔIM = 6.51 + 0.66 = 7.17 points
6	Nechiporenko St., 4	IR =IRN + ΔIM = 6.51 + 0.72 = 7.23 points
7	Zaslavsky St, 9	IR =IRN + ΔIM = 6.51 + 0.10 = 6.61 points
8	Kowalewski St., 5, 5a	IR =IRN + ΔIM = 6.51 + 0.43 = 6.94 points
9	Dyukovskaya St., 6	IR =IRN + ΔIM = 6.51 + 0.96 = 7.47 points
10	Balkovskaya St., 139	IR =IRN + ΔIM = 6.51 + 0.31 = 6.82 points
11	Bugayevskaya St., 3/1, 3/2	IR = IRN + ΔIM = 6.51 + 0.83 =7.34 points
12	Bugayevskaya St., 3	IR =IRN + ΔIM = 6.51 + 0.67 = 7.18 points
13	Gen. Tsvetaev St., 11	IR =IRN + ΔIM = 6.51 + 0.95 = 7.46 points
14	Breus St., 63	IR =IRN + ΔIM = 6.51 + 0.45 = 6.96 points
15	Srednefontanskaya St, 30	IR =IRN + ΔIM = 6.51 + 0.81 = 7.32 points
16	Armeyskaya St., 8б	IR =IRN + ΔIM = 6.51 + 0.40 = 6.91 points
17	Marshal Malinovsky St.	IR =IRN + ΔIM = 6.51 + 0.78 = 7.29 points
18	Frantsuzsky Boulevard, 60\1	IR =IRN + ΔIM =6.51 + 0.31 =6.82 points
19	Vanny Lane, 1	IR =IRN + ΔIM = 6.51 + 0.33 = 6.94 points
20	Fontanskaya St., 165	IR =IRN + ΔIM = 6.51 + 0.31 = 6.82 points
21	Academician Williams, 44, 45	IR =IRN+ΔIM = 6.51+ 0.09 = 6.60 points
22	Academician Glushko,17-a	IR =IRN + ΔIM = 6.51 + 0.93 = 7.44 points
23	Levitan St., 118б, д. 1	IR =IRN + ΔIM = 6.52 + 0.30 = 6.82 points
24	Levitan St., 118б д. 2	IR =IRN + ΔIM = 6.52 + 0.42 = 6.94 points
25	Levitan St., 118б, д. 3, 4	IR =IRN + ΔIM = 6.52 + 0.29 = 6.81 points
26	Mizikevich St.№1 (д. 3, 6, 7) №2 (д. 1,2,4,5,8)	IR1 =IRN + ΔIM = 6,51 + 0.03 =6.54 points IR2 = IRN + ΔIM =6.51 + 0.52 =7.03 points

Above day (free) records of the accelerograms of the ground were introduced, but the data on the oscillations of the buildings during an earthquake indicate that additional pressure on the ground from the weight of buildings and structures also significantly affect the intensity of seismic ground motion base and the degree of transmission of seismic effects from soil towards the construction (A.Tamrazan, 2003). In this respects many scientists have been recently paying attention to taking into consideration the effect of pressure of constructions on the maximum amplitude of the accelerograms of the ground work oscillations (Ju.Nemchynov, 2008)

Currently, a seismometric station is being founded to assess the response of real buildings (building of Odessa State Academy of Building and Architecture) on seismic effects, taking into account soil conditions. The equipment for recording vibrations on the free surface of the soil is being installed in the basement of the building on the isolated pedestal on the ground work, as well as on the second and eighth floors. Seismic equipment will record the time-synchronized oscillations.

Further processing and analysis of materials of instrumental observations allow to quantify the impact on the character of the observed seismic waves, a particular building first, and also other buildings and structures in the future, to study the dependence of their parameters on the position of the observation points in the geological environment and the building. This opens the possibility of improving and developing methods of rated accelerograms of the maximal predicted earthquakes not only on the free surface of a construction site, but also for buildings and structures, taking into account location of their points of application .

CONCLUSIONS

International experience shows that the negative social consequences and losses from natural disasters, including earthquakes and accompanying hazardous secondary phenomena can be significantly reduced with appropriate technical and organizational preparation for them. Information on what should be protected can be provided by a government only, guaranteeing national seismic monitoring a number of seismological monitoring local networks of seismic observations. Taking into consideration the high level of potential seismic hazard in the southern regions of the Ukraine, it is necessary to develop a dense network of seismological and engineering seismological stations to solve the problem of relatively cheap but highly effective seismic protection of environmentally hazardous and economically important objects.

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