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Country Assessment Report

Republic of Moldova

Black See Earthquake Safety Net-ESNET Project

Project Coordinator-

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CONTENTS

1. INTRODUCTION

The report was prepared in accordance with the requirements and schedule of the Project “Black Sea Earthquake Safety Net (work) – ESNET”, funded by the European Community. The report describes the status of monitoring of seismicity, seismic hazard assessment and seismic risk in the Republic of Moldova at the beginning of works on this project.

The Report also contains information about the National framework regarding prevention, monitoring and intervention in case of earthquake.

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2. SEISMICITY

2.1. Brief geographical and geological data

Geography. Republic of Moldova, with an area of 33 000 km2, is situated on both banks of the Dniester (Nistra) River. In the West its boundary runs across the Pruth (Prut) River. These main rivers of the country start in the Carpathians, i.e. outside the territory of the Republic. Generaly, the relief of the country is hilly and strongly divided by river valleys. On the whole, the land descends from the NE to the SE towards the Black Sea and the Danube. The climate is continental temperate with mild winters and long hot summers. Annual precipitation ranges from 340 mm in the South to 525 mm in the Nord.

The Transdniester Elevation is strongly divided by ravines and river valleys. The Codry, the highest region of Moldova, towers above the surrounding zones with separate relief elevations over 400 m above sea level. This zone, with its river valleys and elevations of 150-180 m located in close proximity, produces the impression of a mountainous countryside. The Codry is characterized by intensive landslides. The Budjac, an area of low relief, is divided by wide river valleys with gentle slopes. The Baimaclia Heights, represented by a narrow strip of elevations (up to 300 m), are sharply distinguished from the neighboring Budjac Steppe. The left bank tributaries of the Dniester River cross it with very steep, sometimes canyon-like slopes. The Dniester (River) Valley itself is a wide strip with a well-expressed floodplain terrace and widely developed estuary marshes.

Stratigraphy. All pre-Neogene rocks of the sedimentary cover and basement crop out only in a limited section of the Dniester Valley near the town of Cameca. Elsewhere, they are known only as a result of drilling, and only Miocene and Pliocene rocks are present in natural outcrops for study (A.V. Drumea, 1997).

As most of Moldova lies within the East European Precambrian Platform, two structural and/or stratigraphic layers are distinguishable - basement and cover. In the SW, Hercynian basement is overlain by a deep Mesozoic basin. Elsewhere the lower crystalline basement consists of strongly deformed Archean and Proterozoic metamorphic rocks. These rocks have been investigated mainly on the basis of borehole cores, because only one natural outcrop, in the Dniester Valley, has been discovered. The basement rocks include granites, granite gneisses and gabbro. The ancient weathered surface has been preserved in some places on the basement rocks.

The sedimentary cover, deposited on the crystalline basement, is almost undeformed and consists of Riphean, Paleozoic, Mesozoic and Cenozoic rocks. The lowermost sedimentary units consist of unfossiliferous terrigenous rocks. Their absolute age, based on K-Ar dates from glauconite, ranges from 590 to 1010 Ma. The thickness of these rocks, thoroughly investigated only in the middle Pridnestrovie (Transdniester) does not exceed 100-150 m. They are overlain discontinuously by a gravelite (conglomerate), sandstone and aleur-olite (siltstone) deposit up to 700 m in thickness with Eocambrian faunal remnants. Lower Cambrian terrigenous deposits, up to 100 m in thickness, overlie the Eocambrian strata. Ordovician rocks have been discovered only in the W part of Moldova and are represented by a 6 m thick layer of sandstone.

Silurian deposits are widespread throughout Moldova. In the N part of the country, Silurian rocks consist mainly of Llandoverian and Wenlockian carbonate deposits, while in the central part Llandoverian, Wenlock and Ludlovian clay-carbonate deposits predominate. The SW is characterized by the Tiver terrigenous sequence. The thickness of Silurian rocks is 150 m in the N, 200-400 m in the central region and over 900 m in the SW. . Devonian quartzites in SW Moldova constitute a part of the Hercynian platform basement. Elsewhere, Devonian rocks are present in a small area in the extreme southwest of the Precambrian platform and within the Predobrugian Depression, where they are unmetamorphosed and are represented by various lithological types of sediments with a total thickness of up to 1200 m. There is no valid information on Carboniferous rocks in Moldova, although the limestones and dolomites up to 200 m thick encountered in boreholes in the SW may be of this age.

Permian deposits, discovered on the South slope of the Precambrian platform and within the Predobrugian Depression, have been sampled by boreholes and are represented by argillites, sandstones and limestones as well as anhydrites. The erosional surface on top of the Paleozoic rocks in the Predobrugian Depression and the ancient platform is overlain by Triassic and Jurassic deposits. The unfossiliferous gravelites (conglomerates), sandstones, aleurolites (silt-stones) and limestones are assigned to the Triassic. These rocks reach their maximum thickness of 600 m near the town of Kahul.

No lower Jurassic rocks are known in Moldova. Middle and upper Jurassic rocks are widespread in S Moldova. They unconformably overlie the Precambrian and Hercynian platforms and in the Predobrugian Depression attain a thickness of 2000 m. Mid-Jurassic rocks include argillites, aleurolites (siltstones) and sandstones which overlie Paleozoic or Triassic deposits with angular and stratigraphic discordance. Their thickness reaches 1600 m.

Upper Jurassic sediments are represented by sandstones, limestones and argillites. Oxfordian rocks are characterized by the presence of reef limestones. To a large degree, Kimmeridgian rocks consist of red clays, sandstones, gypsums and anhydrites of lagoonal-continental origin.

Cretaceous deposits are widespread throughout Moldova except in the SW. Lower Cretaceous sediments consist mainly of terrigenous rocks. They crop out locally in S Moldova, where they attain a maximum thickness of 400 m.

Upper Cretaceous deposits overlie the whole area of the Precambrian platform, forming a sequence dipping gently towards the Dniester Estuary and the Black Sea. Their thickness increases in the same direction (from several tens of meters in N Moldova to 400 m near the Dniester Estuary) and the rocks change in character from marl and chalk in the NW to limestones in the SE.

Paleogene rocks are present in central and S Moldova and consist mainly of marine calcareous rocks with subordinate terrigenous sediments. Their thickness ranges from several tens of meters to 350-400 m in the region of the Dniester Estuary where, together with Cretaceousrocks, they form a gently sloping platform depression.

The oldest Miocene deposits in Moldova are Tortonian rocks, dominantly consisting of organic limestones, here and there forming reef bodies, with subordinate deposits of gypsum. The thickness of the latter varies greatly, usually constituting several tens of meters.

Tortonian and older rocks are overlain by Sarmatian deposits, among which calcareous rocks (including reef structures) predominate. Sarmatian deposits in W Moldova include a well-developed sequence of clayey rocks. The thickness of these deposits varies greatly and in some cases is several hundreds of meters.

In Moldova the youngest Tertiary rocks are represented only in the S of the republic as relatively thin continental and lake-river deposits. Quaternary deposits are spread all over the country and are represented by various types of continental deposits.

Tectonics. The main tectonic elements that form the structure of Moldova include the Precambrian and Hercynian platforms. These first-order tectonic units are overlain by later structural elements including the Predobrugian Depression, the Lower Dniester depression and the external wing of the Precarpathian Depression. In addition, several local folds and faults are present within the country.

The Precambrian platform - the region of Archean-Proterozoic deformation occupies all of Moldova up to the latitude of the village of Goteshti in the S. Its heterogeneous structure has been established by drilling and geophysical studies. In several places, deep fractures of various displacements are present. Near the town of Otachi and village of Cosoutsi, the Precambrian basement outcrops on the surface, while in the rest of Moldova, it was established by drilling.

In the South of the country, the basement was discovered at a depth of 1800-2000 m. The average slope of its surface is 10 m km-1 and is directed from N to S. Magnetic and gravitational data indicate the existence of deep ancient fractures with rocks different from the main formations. The surface of the crystalline basement is uneven, due both to the presence of tectonic deformations and from different degrees of ancient erosional depth. Deposits younger than the Proterozoic are practically undeformed.

After its formation the Hercynian platform was eroded, which permits the observation of a very diverse picture regarding the age, petrography and structure of the rocks. The Hercynian platform is cut by several large fractures forming a step-like structure (Fig. 435). The most significant fracture runs along the lower course of the Danube and separates the submerged part of the Hercynian platform from the Dobrugian Mountains (Romania). In the lower Pruth Valley the depth of crystalline basement is 200-600 m. The most submerged parts of the Hercynian platform are insufficiently explored since they are at great depths under younger Meso-Cenozoic sediments.

The Predobrugian Depression is an asymmetric graben structure consisting of Jurassic and, probably, more ancient rocks. Since the sediments' depth exceeds 3000 m, there is little information about its lower layers. The depression is situated at the joint of the Pre-cambrian and Hercynian platforms and stretches beyond Moldova both eastward and westward. The depression exhibits a negative Bouguer gravity anomaly.

The Lower Dneister Depression is a gently sloping structure of Upper Cretaceous and Paleogene sediments and underlying lying Precambrian basement. The depth of this depression is 500-800 m. The distribution of younger sediments reflects the configuration of the depression, as does the present land surface. Only the outermost Carpathian foredeep reaches the territory of Moldova, where it trends approximately N, i.e. parallel to the East Carpathian orogen. In the pre-Pruth area the depth of the depression is about 700 m and it is filled by Neogene deposits.

2.2. Database for Regional Seismic Hazard and Risk Studies

Earthquake related studies are guided by the quality of the available data. A special database was designed for the purpose of seismic hazard and seismic risk studies of the territories affected by the Vrancea earthquakes.

Instrumental Data. There are five recording stations in Moldova for which strong and moderate earthquake data ($4.0 \leq M_{GR} \leq 7.2$) were obtained during the 1977-2008 period. Currently, the database stores over 450 recorded ground motion recorded horizontal components from 52 events.

Macroseismic Data. Macroseismic part of the database includes information on building damages and geotechnical conditions at sites where these buildings are located. Moldova suffered heavy damage and losses as a consequence of the 1977 and 1986 Vrancea zone earthquakes. These earthquakes have provided ample damage data of the existing building stock. After the March 4, 1977 earthquake (M=7.2), 2765 (i.e. 23% of total investigated 11849) buildings were completely destroyed and 8914 (75%) were seriously damaged. Similar statistics for the August 30,1986 earthquake (M=7.0) showed 1169 (i.e. 2%) of total investigated 58538 buildings were completely destroyed and 7015 (12%) of them were seriously damaged.

Geotechnical data. Geotechnical data contain information concerning stratification of soils on 1210 sites.

Database structure. The database includes four tables for instrumental and nine tables for macroseismic data respectively. The instrumental data consists of: Catalog, Stations, Station Soil Profile Characteristics and Records. Two main tables containing macroseismic data there are: Macro (buildings location, damage degree of buildings, type of buildings, number of floors) and Geophysical Profile (soils velocity values, attenuation parameters). Additionally, the information about the geomorphology of territory, soil lithology, bedrock depth, underground water level, thickness of water saturated soil, densification capacity of soil and seismic category of soil according to current aseismic code MD SNiP II-7-81can be found.

In this way, the database provides the necessary information for investigation associated to soil-related earthquake response and structural damages.

Schematic representation of the database is shown in the Figure 2.1.

Output Example of the Elaborated Database. The data base is component part of the GIS which presents the tool that could generate ground-shaking response for a scenario seismic event, or explain properly the spectral content of seismic records on the given site, and to correlate them with the observed structural damage. The last feature – ability to produce seismic hazard and risk related maps is considered as the main advantage of the GIS- oriented database. With the help of the compiled database different procedures could be performed, such as calculation of natural periods of soil vibration, amplification functions as well as construction of various associated maps in function of specific task. The presence of the strong and moderate intensity seismic records on the given site contribute positively to the accuracy of the data and the applied methods. Besides, the variation of the depth and elastic properties of soft soil deposits resulted in significant differences of the amplification capacity for the studied sites. Utilization of database allowed constructing the maps containing information on spatial distribution of soil amplification factor. Evidently combination of different unfavorable soil conditions usually results in a strong response of the structures and higher damages during strong Carpathian (Vrancea) earthquakes. In this way, the August 30, 1986 Vrancea earthquake with magnitude M_{GR}= 7.0 and epicentral distance of ~220 km to the south-west of Chisinau resulted in a devastating damage of numerous buildings, including seismic-resistant structures in some areas of the city (Alcaz, 1999).

The correlation of buildings' damage degree d_{av} with soil amplification factor A was studied. The result of analysis is presented in Fig.2 showing coefficient of correlation 0.6. It is necessary to note that the damage data are characterized by high dispersion, but it is dear that damage degree is proportional to the amplification factor of sites.

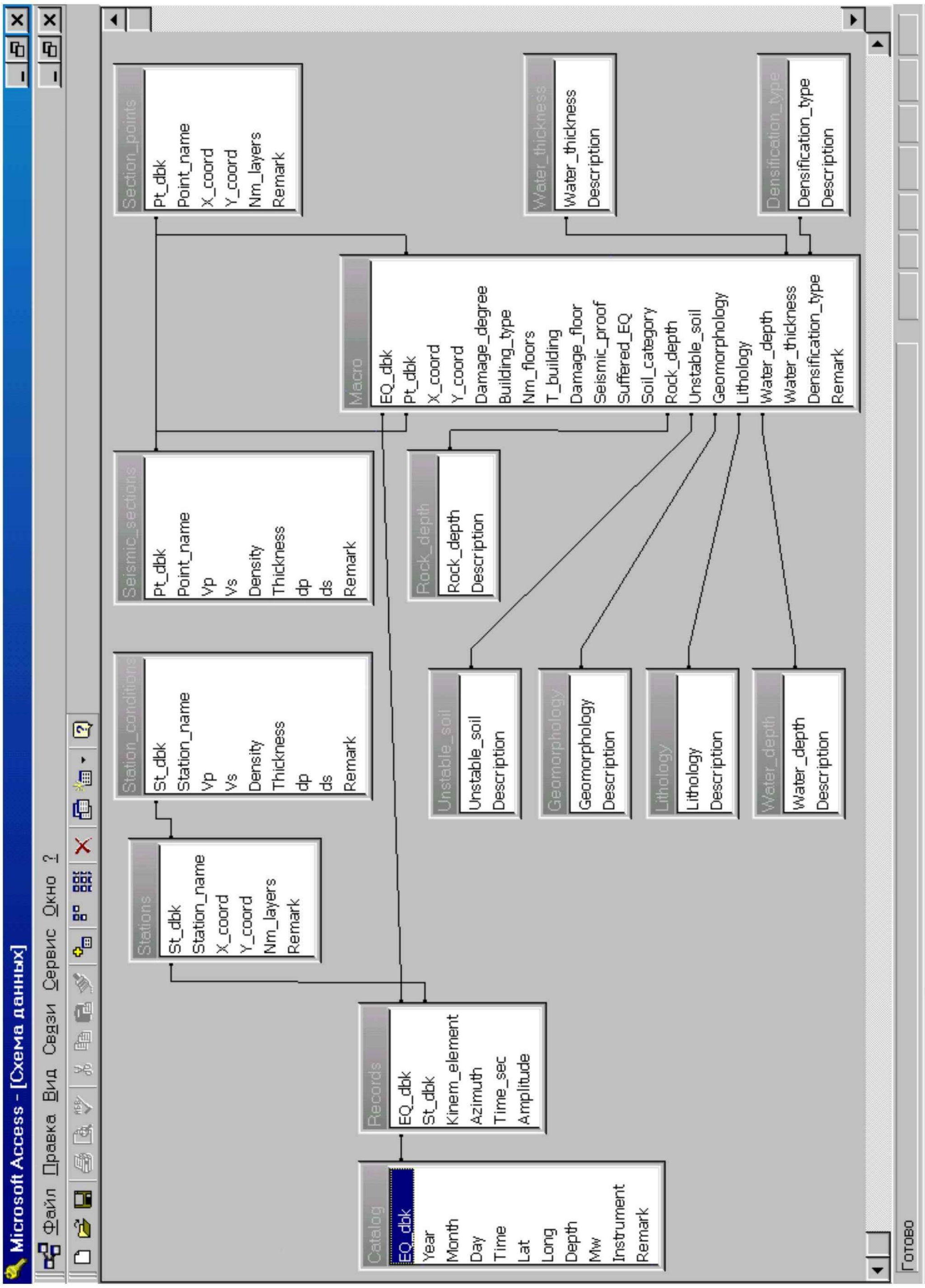


Fig.1. Schematic representation of the database

Figure 2.1. Schematic representation of the database

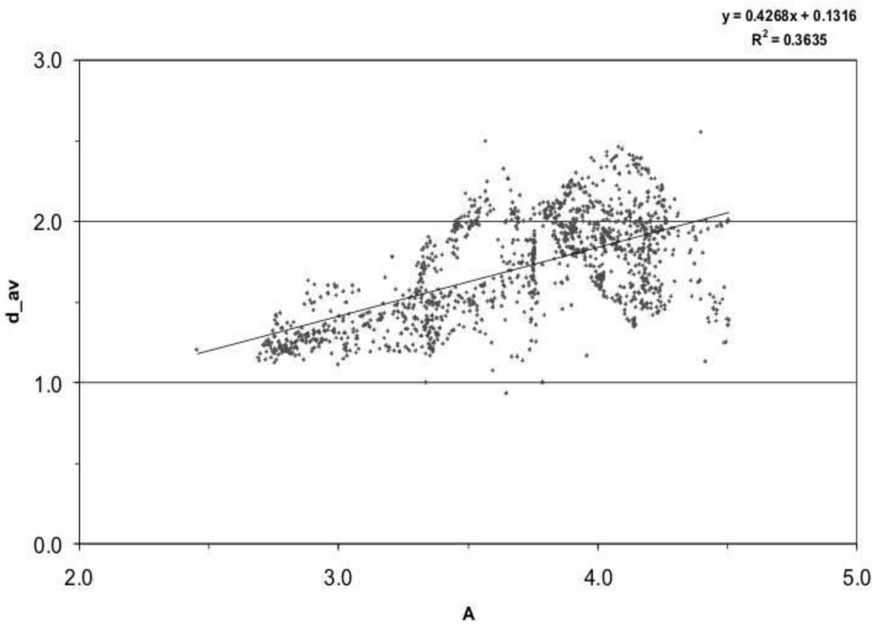


Figure 2.2. Correlation of a damage degree with site amplification factor

2.3. Seismic sources, activity, strong earthquakes

The territory of Moldova Republic is periodically subjected to the influence of strong earthquakes originating from the place where the Carpathian arc bends, known in seismological literature as Vrancea zone.

The Vrancea seismic zone is located in the Southeast of the Carpathian region and is characterized by maximal seismic activity at intermediate depths, with epicenters distributed within the ellipse domain 60×30 km2 rotated by azimuth θ ≈45◦ according to the major axis (Radu and Polonic, 1982; Constantinescu and Enescu, 1984).

The earthquakes' foci are very compact in plan (60x30km) and achieve depth of about 170km. The strongest of them are distributed in the depth interval of 80-150km, and their maximum magnitude achieves about 7.4 (M_{max}) on Richter scale according to different estimations. The resulting seismic effects from this zone are influencing a big territory till Moscow and St. Petersburg in the North, Greece in the South, the Crimean peninsula in the East and Austria and Hungary in the West.

The most significant seismic effects generated by Vrancea zone are recorded by seismic stations all over the world. Earthquakes coming from this source are of practical and theoretical interest due to the social and economical influence on the territory of the adjacent countries. The maximal seismic intensity achieves the level of 8-9 degrees according to 12-degree scale, while the territory covered by the 6-grade (in limits of the region influenced by severe ground motions and buildings' damages) includes Romania, Moldova, a big part of Bulgaria and South-Western Ukraine. The total area of the territory influenced by Vrancea earthquakes comprises 300 000 km^2, populated by not less than 25 mil. people.

Statistical information about seismic activity of Vrancea zone is available since the year 1000 and includes data on about 3000 seismic events in the region. At average, strong earthquakes of magnitude more than M=6.0 take place not less than 5 times per century (Fig. 1).

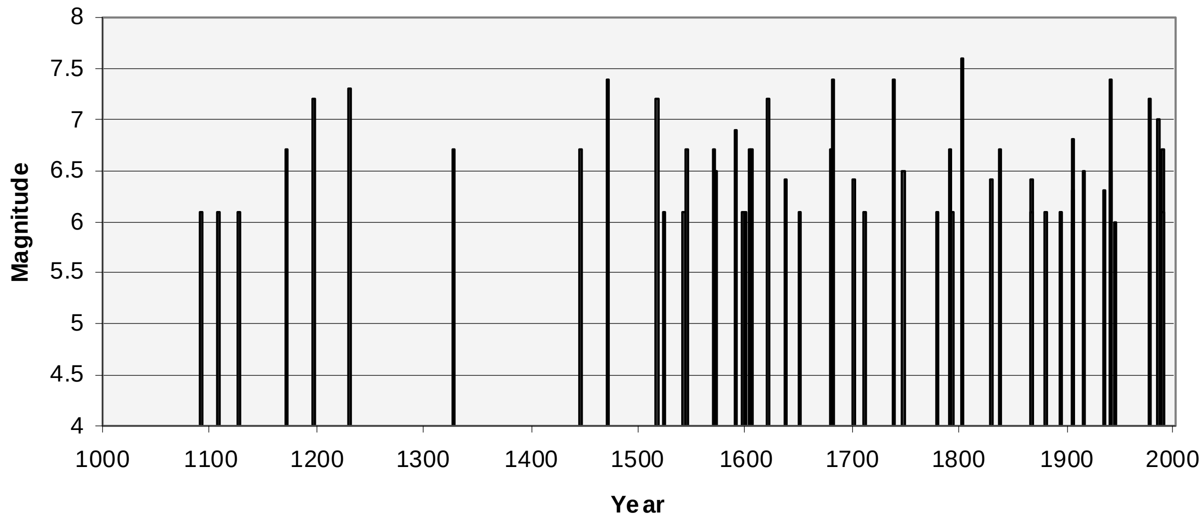


Figure 2.3. Distribution of earthquakes with magnitude M≥6.0 for the period 1000 to 2000

Here the big number of important cities is situated (including 2 national capitals), numerous industrial and energy facilities, including 2 nuclear power stations, industrial chemical facilities, gas and fuel pipelines, and a large number of bridges and dams.

The same character of seismic activity is observed in the XXth century, when instrumentally and macro seismically 5 severe (M≥6.5) earthquakes were observed, accompanied by numerous victims: November 10, 1940, September 7, 1945, March 4, 1977, August 31, 1986 and May 30, 1990. It should be mentioned that they were not the strongest of Vrancea earthquakes. It is known that on October 26, 1802 the earthquake of magnitude 7.4 (Gutenberg-Richter) according to different sources, took place, which could be considered as maximum observed for this zone. Yet, at that time its social effect was not significant due to quite clear reasons.

3. MONITORING NETWORK

3.1. Brief historical overview

Seismicity of Republic of Moldova is mainly determined by Vrancea intermediate depth (subcrustal) earthquakes, and North Dobrogean crustal earthquakes, both areas located in Romania, with some events also, occurred on the Black Sea basin area.

According to I. Ilies (I. Ilies, 2011), on the Republic of Moldova territory the earthquakes occurred also, indeed weaker. The most important of recent years was the April 2, 1988 earthquake with magnitude M=4.2, and depth 17km, located near Zaicani village, Edinet district. The macro-seismic intensity field measured in the neighboring villages to the epicenter was about 4-5 degrees of MSK intensity scale.

Monitoring of seismicity at national and international level in Republic of Moldova is carried out by the Seismic Survey Network of Institute of Geology and Seismology of the Academy of Science, which includes six seismic stations, located on Chisinau, Cahul, Leova, Soroca cities, and Milestii Mici, Giurgiulesti villages (areas, with 8, 7, and 6 degrees of MSK intensity scale). Unfortunately, the existing network has a non-uniform distribution of the stations in the area, which are located unilaterally (with almost same azimuth) to the sources of strong earthquakes affecting Republic of Moldova territory.

In Republic of Moldova the instrumental seismic survey is done from December 22, 1949, when the first seismogram has been recorded at the new station opened in Cisinau city. This may be considered as the beginning of the Seismic Survey in Moldova. The March 4, 1977 strong earthquake occurred in the Vrancea zone, magnitude M=7.4, has stimulated the development of the seismic station network in the area.

On the period 1982-1988 four new seismic stations opened in Leova, Cahul, Giurgiulesti and Soroca, with analog galvanometer recording on the photographic paper, has allowed the more detailed study of seismicity of the territory of the Republic, with more accurate earthquake epicenters locations and urgent information of the authorities about the seismic events. Seismograms for the entire period of the station's operation, are stored into the archive of the Geophysical Observatory in Chisinau city.

Figure 3.1. Seismic stations Republic of Moldova and areas were are located (8, 7, and 6 degrees of MSK seismic intensity scale)

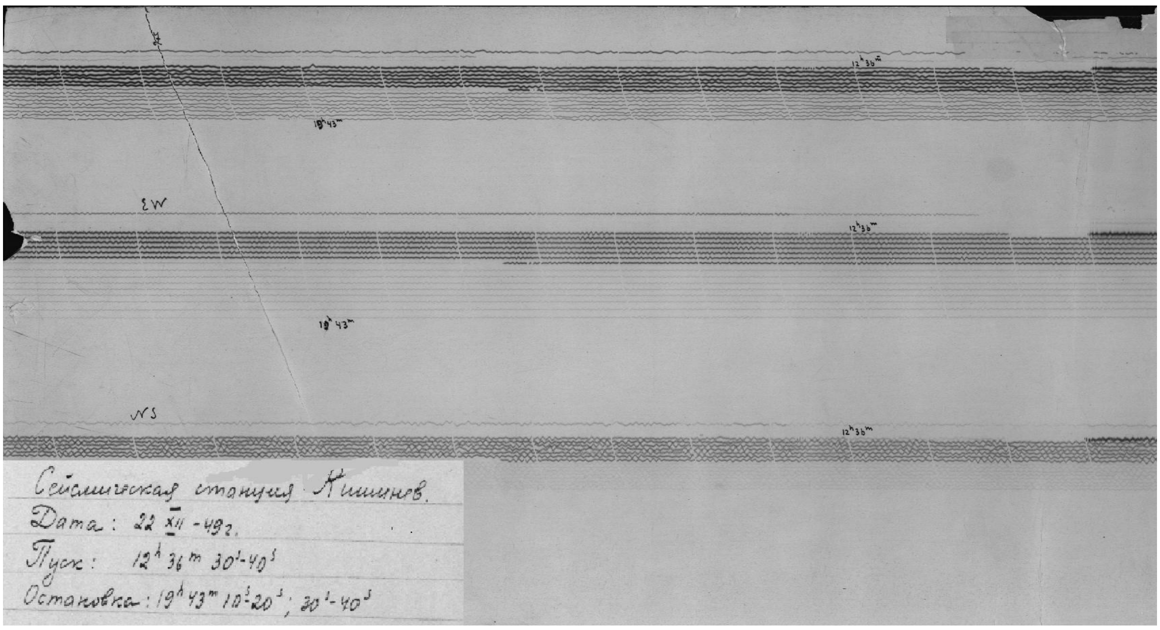


Figure 3.2. First seismogram obtained at Chisinau station: about 7 hours of quiet seismicity.

Until 1993 the network was part of the monitoring system of the former USSR, than become a national network, and some tasks have been modified in terms of requirements of the new independent state – Republic of Moldova. By Disposition No.9 of 01.25.1994 of the Presidium of the Academy of Sciences, was organized the National Seismic Service of the Republic of Moldova, in January 1994.

3.2. Technical characteristics of the system for seismic monitoring

Currently, the monitoring seismic activity in the country is managed by the Center for Experimental Seismology Institute of Geology and Seismology of ASM. At the national level the main link of the network is the Chisinau Observatory, which guarantees the functionality of the National Data Center and the whole seismic network stations in the territory. Important role in upgrading the National Seismic Network has been played by the admission in 2004 of the Institute of Geology and Seismology as a member of Euro-Mediterranean Seismology Center (EMSC-CSEM), and later (in 2008) as a member of the International Seismological Centre (ISC, United Kingdom). Through these actions, the National Network became officially an integrated part of European and World seismic network, with main goal for modern and efficient seismic data record, storage and management, including real-time purchasing techniques, secure communications (data transfer), rapid processing and exchange of any kind of data and information about the earthquakes, building and management of large data systems, publishing newsletters and seismic catalogues.

After equipping the stations with performing digital equipment in the territory in 2007-2010 the task to create a central purchasing unit for data processing and archiving, similar to those in Romania and other countries was proposed.

A modern digital seismic station includes the following performances: the hardware and programmed resources (the internal module PCMCIA PC Card memory), software that enables rapid analysis of data recording, simultaneous reading and storage of the data, an analogue to digital converter, a GPS receiver for a synchronized universal time, and three digital components (NS, EW and vertical component), with selectable recording velocity (50, 100, 200, 250 samples / second), wide dynamic range (120dB), and frequency band (0-80Hz). It provides the records of local and far (strong and weak) events (including tele-seismic ones) at each station.

The Sensor Block, which incorporates high speed sensors with the broadband (BB) – 120 sec, dynamic range ~ 145 dB, three components, robust at lock, low power consumption, it operates on wide range of temperatures without adjustments, with short period sensors, for strong ground motions (SP) – accelerometer type *force balance EpiSensor*.

The Data Acquisition Block is based on digitizers or low power acquisition systems with high resolution, interconnected into a network by 6 or 12 input channels at 135 dB dynamic range and compact multifunctional ultra-low power processor, used for storing and transmitting the data, when the communication line is open. All these achievements have been toke into account on Republican Seismic Service modernization, and it further development was done in terms of expanding the number of stations equipped with modern devices also, improve the methods of collecting and processing the seismic data.

After investigation of the seismic monitoring system and equipment for several european countries (first of all of Romania, on which territory the strong earthquake foci is located, in Vrancea, and affect the territory of Moldova) it was decided to upgrade the National Seismic Network, with similar digital devices and compatible data format. Therefore, the purchase of performance devices focus on Kinemetrics Inc. (SUA) – The Innovative World Leader In Earthquake Monitoring. In 2004, the first digital seismic station Etna-Kinemetrics was purchased and installed in Chisinau Seismic Observatory to operate under automatic seismic coupling (trigger). For the next four years have been acquired three recorders type Quantera Q330 with short period sensors ES-T, broad band sensors STS-2, and CMG-40T (Guralp U.K.). In addition to these devices three digital stations (two K2 and one Q330 Marmot, completed with seismic sensors) have been received as a donation from National Institute of Earth Physics in Bucharest, based on a Cooperation Memorandum between institutes.

These units were installed at the central seismic station in Chisinau and local stations in Leova, Giurgiulesti, Soroca. For the first time in the history of the Republic of Moldova instrumental seismometry it was possible to achieve continuous modern records, starting by June 2007. Initially, the apparatus operated under automatic coupling at strong seismic event, then data transmission from station to Central Unit in Chisinau has been provided by the Internet network connection.

Figure 3.3. The Quantera Q330 recorder at seismic station Chisinau.

Figure 3.4. Episensor ES-T and seismic sensor BB CMG-40TD at seismic station of Soroca.

In 2010 a new generation seismic station was opened in Milestii Mici, at 60 meters underground (the 5th place in the world for deep seismic recordings, according to ISC), it operates as continuous regime: recording and teal-time transmission of the seismic data.

The deep location on hard limestone rock and low noise allows the increase on sensitivity level for seismic sensors to record weak (Vrancea) or moderate (worldwide) events. It's a calibration station, all the records obtained from other stations will be compared with this one and will conclude about the role of geologic sections on the surface seismic effects.

This year (2011) it plans to open a new seismic station in the eastern part of the country (Purcari, Stefan-Voda district), which will provide information on the propagation and the attenuation phenomena of the seismic waves (generated in deep focies of Vrancea zone) in geological layers of the territory from West to East. On the same time, this point will mark as the eastern station on the Romania-Republic of Moldova seismic network, which will pioneering on records, receiving signals from the earthquakes occurred in the Alaska, Sakhalin, Kuril Islands, Japan, and Alpino-Himalayan belt (Asia system).

At the moment, the structure of National Seismic Network includes five continuous real-time digital seismic stations, six stations with accelerometers located in Chisinau, Leova, Cahul, Giurgiulesti, Soroca, Milestii Mici, and The National Center of Seismic Data (MD NDA).

Tab. 3.1. Location data of seismic stations

№	Stația	Codul stației	Anul deschiderii	φ°, N	λ°, E	H, м
1	Chişinău	KIS	1949	46.9976	28.8175	185,0
2	Cahul	KGL	1978	45.9053	28.2008	48.5
3	Leova	LEOM	1982	46.4733	28.2467	20,0
4	Soroca	SORM	1983	48.1350	28.3513	60,0
5	Giurgiuleşti	GIUM	1988	45.4850	28.2081	62.5

Tab.3.2. Technical characteristics

Denumirea si codul international	*Model stație*	*Model sensor*	*Sistemul de achiziție date*	*Transport date*	*Înregistrarea*
Chişinău KIS	3C SP	ES-T	Q330	Internet	Continuă
	3C-BB	CMG-40T			
	3C SP	CMG-5T	CMG-5TD (DM-24)	-	Regim trigherare
Leova LEOM	3C SP	ES-T	K2	Internet	Continuă
	3C-BB	CMG-40T	▪ ｶﾗﾂﾄlog ▪ ▪ □琰茝□ ▪ Ü		
Soroca SORM	3C SP	ES-T	Q330	Internet	Continuă
	3C-BB	CMG-40T			
Giurgiuleştui GIUM	3C SP	ES-T	K2	Internet	Continuă
	3C-BB	CMG-40T			
Cahul, KAG	3C SP	CMG-5T	CMG-5TD (DM-24)	-	Regim trigherare
Mileştii Mici	3C SP	ES-T	ETNA	-	Regim trigherare
Str.Trandafirilor 15, Chişinău, ISS-3	3C SP	CMG-5T	CMG-5TD (DM-24)	-	Regim trigherare
Str.Independenței 9/4, Chişinău, ISS-2	3C SP	SEIKA B1	ADS-3016	-	Regim trigherare
Bul. Ştefan cel Mare 83, Chişinău	3C SP	CMG-5T	CMG-5TD (DM-24)	-	Regim trigherare
Str. Traian 3/3, Botanica, Chişinău	3C SP	CMG-5T	CMG-5TD (DM-24)	-	Regim trigherare

3.3. The National Center of Seismic Data (MD NDA)

The Data Center placed in the Chisinau Observatory, has been renovated from the foundation. The on-line data transferring is visualized by large monitors, which describe the continuously vibrations from whole the globe on each second. It is equipped with modern devices for visualization, archiving, analysis of seismic data-transmitting and receiving information through the software applications of Source Linux PC 10.3 and SeisComp 3.2. The last one is a seismologic processor for communication, which has been developed originally for GEOPHON (Potsdam) network, later extended in the frame of MEREDIAN ("Mediteranian-European Rapid Earthquake Data Information and Archiving Network") and GITEWS ("German Indian ocean Tsunami Early Warning System") projects.

The new system installation gives the opportunity of simultaneous acquisition and real-time seismic information from five stations located in country side, listed by the international code (assigned by ISC) – KIS, LEOM, GIUM, SORM, MILM, and eleven Romanian stations, including those from epicenter area – BUC1, VRI, EFOR, MLR, TESR, PETR, ARCR, TLCR, IAS, PLOR, BUR01. In fact, this represents an integrate regional system of seismic stations Romania-Republic of Moldova, primarily designed for the Vrancea foci seismogenic potential studies – the souce, which strongly shakes the both countries territory, and other European regions.

Figure3.5. The National Seismic Center (MD NDA) the inside of the Commandment, in Chisinau.

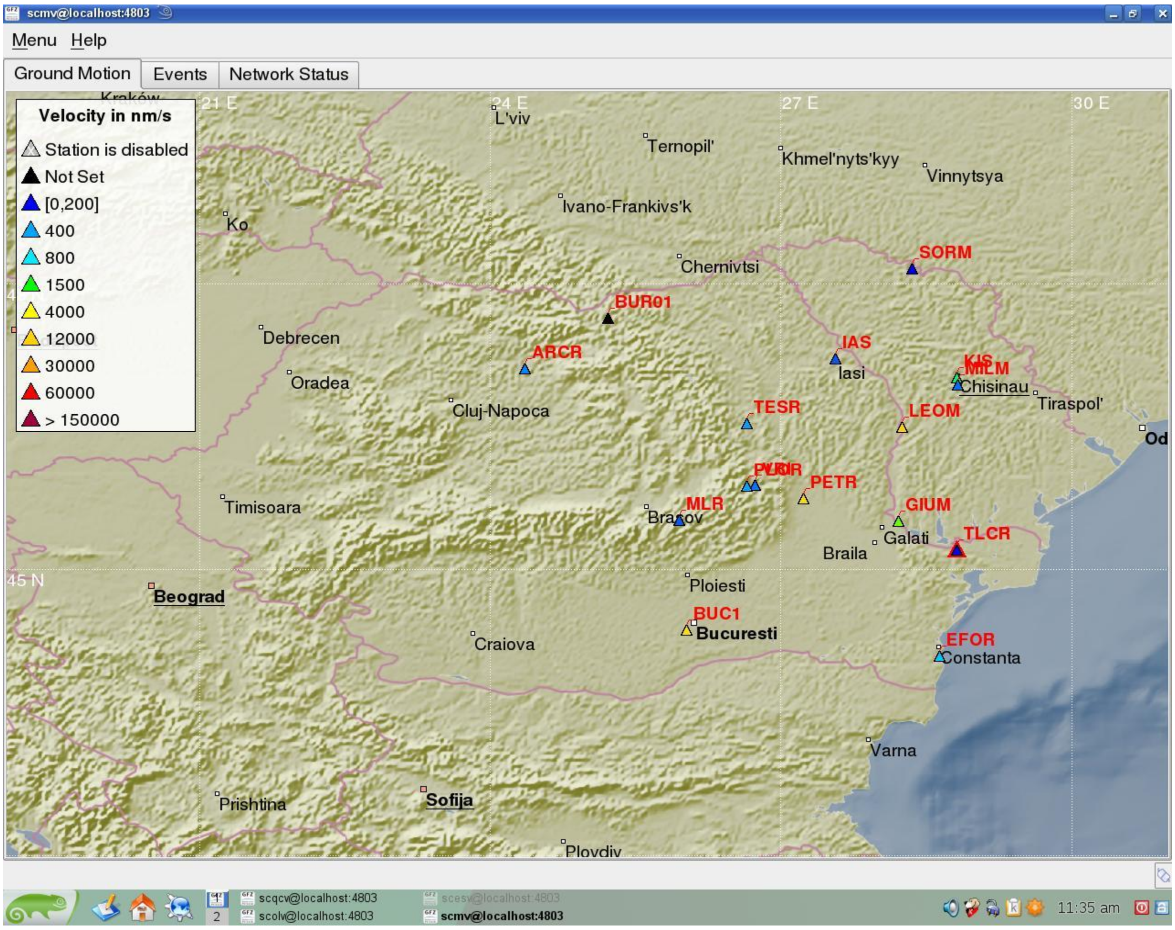


Figure.3.6. On the National Data Center Monitor it is shown the participating seismic stations at the regional instrumental investigating process.

The real-time seismic data from all stations (three components of velocity and acceleration, per each station) are recorded and stored in an industrial computer memory of 2TB, at NDC MD. In parallel, to ensure the safety of data preservations, it is saved on a memory block with the similar size of 2TB, as a data back-up. According to the sampling rate per channel (each waveform) which is 100, 80, or 20 values per second, the daily volume of information stored it is about of 1GB. The information about any event (earthquake, explosion) or interested time interval can be accessed on FTP Server of the Center. Simultaneously, the seismic data from the stations located on Moldova territory is transmitted in a real-time regime by Internet network of National Data Center (RO NDC) of the INFP, Bucharest, where used, along with other regional stations for earthquake parameters determination and seismic bulletins compositions.

MD NDC cooperates with the national and international data centers on sending and receiving information (about the earthquakes) procedures around the world, provides data about the triggered events as earthquakes or explosions, tsunamis, volcanic eruptions to the national authorities. MD NDC sent monthly the reviewed bulletins registered in the Republic of Moldova territory to the Euro-Mediterranean Seismology Center, France.

The existence of this center, similar to those in Romania, Japan and other countries, is a precondition for future participation of Moldova on a global system of seismic check for Compliance Treaty on Nuclear Test Ban (CTNTB), Vienna.

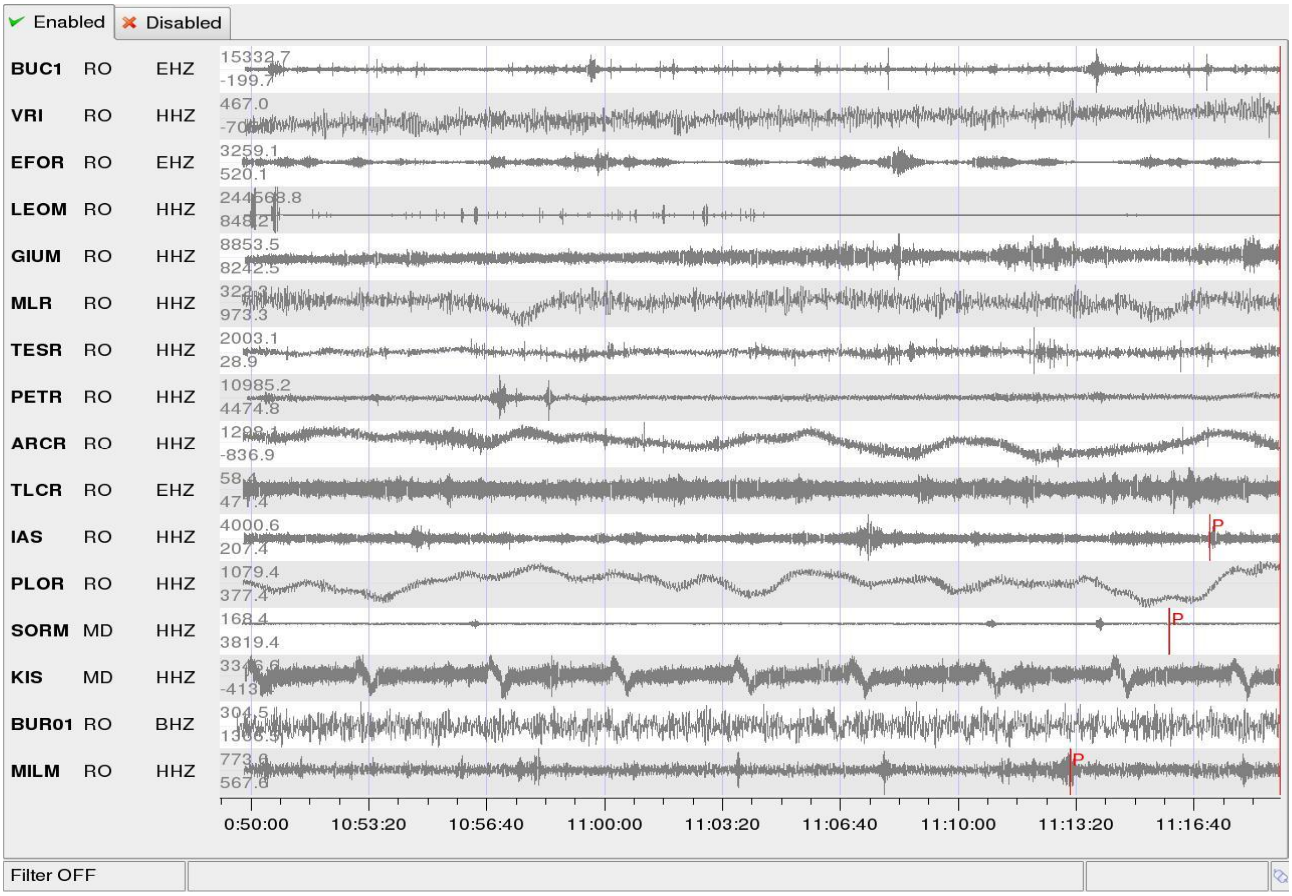


Figure 3.7. The online records of the waveforms (only vertical components Z, per each station) as the real-time visualization on the Monitor.

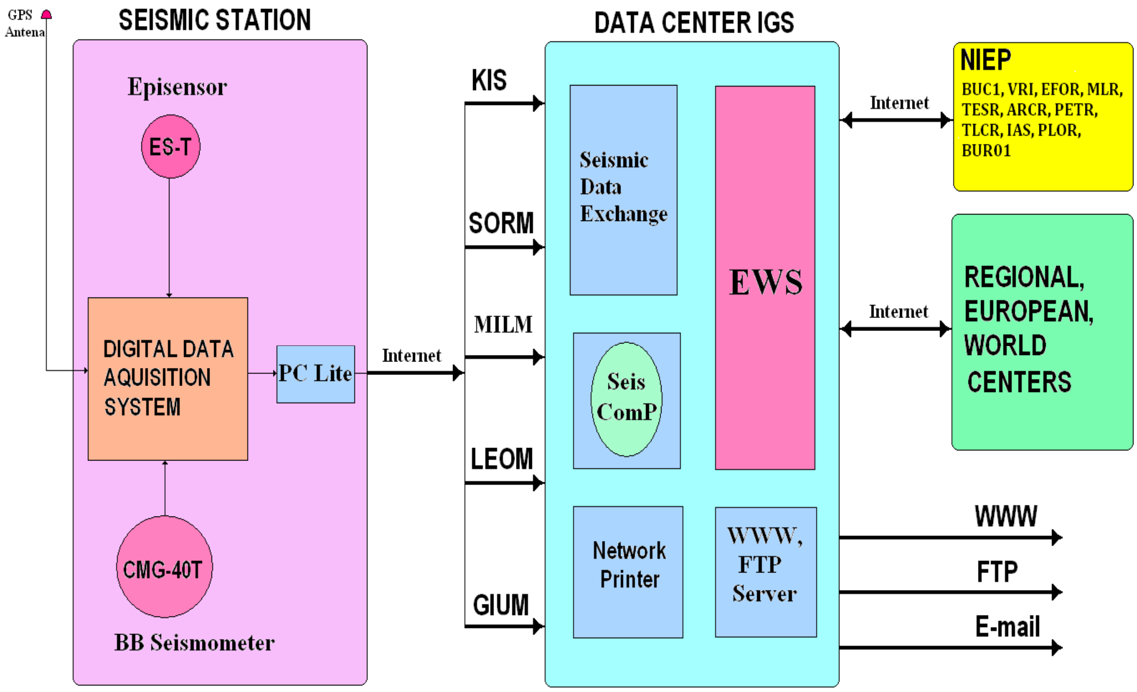


Figure3.8. The Data-Flaw Chart of the National Seismic Network of Republic of Moldova

Thus, the MD NDC will provide the access to the International Seismic Network Data on seismic monitoring of CTNTB and Internation Data Center products.

3.4. Real-time seismic warning system

The current investigation on the earthquake effects aim to reduce the seismic risk, which can de achieved by designing and building of seismoresistent constructions, strengthening buildings, planning the emergency schemes and protective undertaking measures during or after a major earthquake occurs, anti-seismic dissemination and training of population also, by enabling the seismic warning systems.

Using the modern technology of recording and data transmissions in the research have allowed successful development of modern real-time earthquake warning systems (EWS). These systems are designed to provide quick information about parameters and ground motion behaviour during an earthquake also, to process and transmit quickly the data than propagating of the devastating seismic waves (3-8km/s). Such systems have been developed in Japan, Mexico, USA, Taiwan. A similar system was developed by the

National Institute for Earth Physics (NIEP) for intermediate earthquakes threatening the Bucharest city, located at 130km away from epicenter area. This fact, allows a 25 sec seismic warning before the destructive wave arrives. This project („ The real-time seismic warning systems for Vrancea strong earthquakes") of INFP was awaeded by European Commission, with Grand IST European Prize, in 2006.

In collaboration with INFP, was designed and develloped a real-time seismic warning for Chisinau city. The warning time for the capital city of our country, due to the epicentral distance of 210-240 from Vrancea seismic zone, is definde by the difference of arrival time of P wave (at Romanian seismic stations, locatde in the epicenter area for quick signal detection) and S wave arrival in Chisinau, estimated as 37-40 sec. This time interval, although small, allows taking quick decissions on the seismic alarm before the arrival of main shock of seismic wave (S), which shakes the Chisinau city at initiated already strong earthquake.

The Earthquake Warning System (EWS) is located inside of the Experimental Seismology Center and consists by Rack 19, industrial computer PC 3GHz, alarm system MOXA with 8 levels for PGA, Laser printer, and software for real-time alarm.

On the seismic alarm decision, in case of the earthquake, this system uses the continuously recieved data via the Internet from four Romanian stations, placed in the epicentral area – VRI-Vranceoaia, MLR-Muntele Rosu, ODBI-Odobesti and PLOR-Plostina also, for local reference Moldovian stations – KIS-Chisinau, GIUM-Giurgiulesti and SORM-Soroca. The seismic information is evaluated at MD NDC, Chisinau. When the epicentral values for accelerations exceed a fixed threshold, the system will issues an alarm. This algorithm allows selecting the level of danger for Chisinau city according to the intensity of the earthquake. The intermediate Vrancea earthquake became dangerous for Chisinau city when their magnitude values on the Richter's scale exceed the 6.5.

The seismic alarm signal can be generated directly by automatic decision system, from 2-3 stations located in the immediate vecinity of the Vrancea area. The real-time transmission of the alarm signal from Vrancea and it reception in Chisinau is planned to be faster and safer by satellite connection instead of actual Internet, telephone and radio, which may give-up or fail at major seismic events.

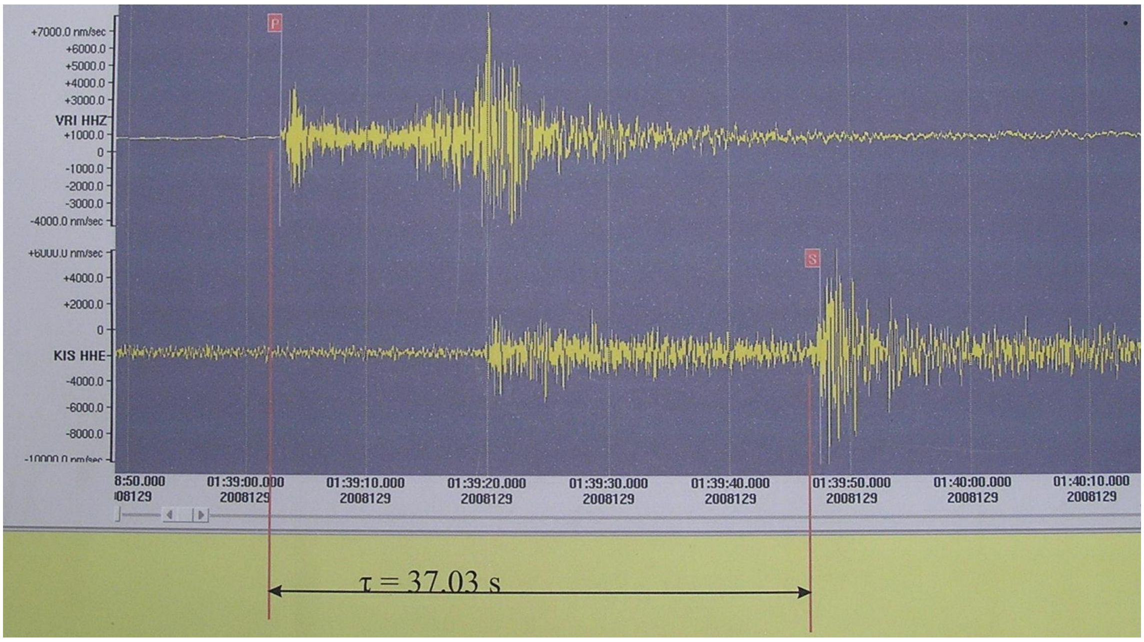


Figure 3.9. The time interval for Chisinau city estimated by EWS as the difference between direct P wave arrival time at VRI-Vrancioaia epicentral area station and S wave arrival at the KIS-Chisinau seismic station.

Figure 3.10. The Earthquake Early Warning System (EWS) at Seismic Commandment in Chisinau

This system, which is implemented at our institute also, represent one of the first steps in this regard. For the moment, the alarm signal is received via Internet, only at the Commandment in Chisinau, and for automatic transmission to other users also, the special equipment it is required to be installed, which would distribute the signal through dedicated lines as radio broadcast networks, mobile phones and other forms of media communications. Implementing this system will include all districts of the country, with all major industrial facilities to prevent and minimize the potential losses from strong earthquakes. Further development of EWS's for whole republic involving leasing satellite channels for an ultra-reliable and secure operation is possible in the frame of the future projects only, with an estimated cost of the implementation over 2 million of euro.

3.5. Seismic monitoring – an important factor in the sustainable development of the Republic of Moldova

The seismic network records from 40 to 180 earthquake per year in the Vrancea area, and around 1600 earthquakes, on average, from whole the world. The seismic network upgrade and MD NDC open, gives the opportunities for operational assessment of the seismic regime in the world, in the region and locally in the Republic of Moldova territory, informing the authorities and civil society about the occurred seismic events. The new seismic database, the digital archive created, which contains the records, Vrancea earthquake catalogs, seismic bulletins, micro-seismic and macro-seismic data, will ensure and provide data for fundamental research on the field, for interested people, institutions, and regional data for International Seismic Centers.

The design and installation of a EWS is an important (first) step towards reducing the seismic risk in Chisinau city and other districts of the country, strongly affected by the earthquakes from Vrancea intermediate seismic source. This system will be a new technically complex and useful tool for industrial infrastructure protection and population safety by the seismic prevention, the final stage of this project which are to be developed is the alarm signal reception by the users.

All these achievements of the local and regional scale seismometry are original and important for modern seismological research in our country. The records and the results obtained by their use will contribute to determine or short-term predict the seismicity in Republic of Moldova territory, and will serve to reduce the seismic risk and predictions of future earthquakes.

The seismic network modernization, in a relatively short time, was possible due to a strong and close cooperation with NIEP, under a Memorandum of Agreement for a ten year term long. Under this agreement, NIEP provides the scientific support for opening in Chisinau a NDC, similar to that in Bucharest. It donated the latest generation devices of Kinematrics production for seismic stations in Leova (K2 + CMG40T + ES-T + PC-Lite), Giurgiulesti (K2 + CMG40T + ES-T + PC-Lite) and Milestii Mici (Q330 Marmot + STS2 + ES-T) in total amount of 130,000 US$. The labor also was carried out jointly, at seismic stations in Moldova being installed the recording equipment, communication systems, seismic data acquisition systems with the operating software included. Here, a significant contribution in achieving these tasks was performed by NIEP specialists (Dr. Ionescu C. – General Manager of the National Institute of Earth Physics (NIEP), Dr. Marmureanu A., Grigore A., Parvu V., Neagoe C.), Prof. dr. eng. Marmureanu Gh., which has been awarded with Medal “Cantemir” CSSDT, provided by the ASM, to express the gratitude on collaboration research.

The successful implementation of the undertaken technical assistance is due to the Information Society Development Institute, which installed the communication systems, and provides services through the information networks of the Academy of Sciences.

The modern NDC at the opening has enjoyed by wide media coverage, became attractive not only for specialists in the research field, but also for teachers, students and pupils, for all who would like to pursue what happens, in the republic, in the region, or other parts of the world, (on every second) at larger LCD screens. So, if during their visit at Seismic Commandment by luck and coincidence some perceptible tremor at seismic station Chisinau will occur, their emotions will be unique on their kind. These visits and lessons of seismic science popularization made are actions for continuous training and education of the population to face the earthquakes, which can be at any time subject to seismic vibrations so, for this needs to prepare in advance.

4. SEISMIC HAZARD

4.1. Methodology. Seismic zoning territory Republic of Moldova

As was mentioned above, Republic of Moldova suffers heavy damage and losses as a consequence of the intermediate depth earthquakes sources located in Vrancea zone, Romania. As it is know, the design and implementation of expensive measures to providing seismic resistance of buildings and structures is performed on the basis of maps of seismic hazard.

The general characteristic of seismic risk of a certain territory is usually represented by a seismic zoning map.

Soon before 1991 the territory of the Republic of Moldova was the integral part of the former Soviet Union. Naturally its seismic zoning was done within the framework of all-union methodology of zoning map. One of the first maps of seismic zoning of the territory of USSR, based on vast for that time seismological and geological data, was compiled by the Institute of Earth Physics of the Academy of Sciences of USSR in 1957. According to that map, South-Western part of Moldova, near the boarder with Romania, was referred to seismic intensity VIII, the rest of the territory – to VII-degree zone. During the compilation of the next generation of the map CP–69, new instrumental data, from the country and neighboring states were used together with macroseismic data and the results of detailed geological investigation of the region, particularly of tectonics. That allowed introduction of certain corrections into the previous map of seismic zoning – for the Northern and North-Eastern territory of Moldova where seismic level was reduced down to 6 degrees.

The map of seismic zoning CP-78 code became a new era for seismology of that time. That was, first of all, due to number of methods for quantitative evaluation of seismic hazard, introduction of probabilistic methods for long-term forecast and emphasize on quantitative characteristics of seismic ground motion for the purposes of seismic design. It should be mentioned, that even though this map was designed as a general map, it was in fact not exactly the one, because it was compiled in fragments, in different regions, according to different methodology and on the basis of different seismological and geological data.

The core elements of methodology used during design of map CP- 78 code, common for all seismically active regions of the former USSR, were the following:

selection of seismically active zones;

compilation of earthquake catalogues;

evaluation of seismic intensity and quantitative parameters of the soil;

elaboration of geological criteria of seismicity;

analysis of deep soil structure and seismicity;

evaluation of parameters of seismic regime;

assessment of maximum possible earthquakes and seismic intensity;

evaluation of seismic hazard.

In function of certain seismological conditions of the regions of the former USSR, availability and richness of instrumental earthquake catalogues, the complete set of seismological investigations was carried out. Such, seismic zoning of the territory of Moldova in frame of the map CP-78 was based on four main methodological elements: macroseismic data, historical and instrumental catalogues, geological-geophysical, and first of all tectonic investigations, evaluation of parameters of seismic regime, including analysis of maximal possible earthquake, and calculation of seismic intensity according to methodology suggested by Y.V.Riznichenko (1979). The map of seismic zoning of the territory of the Republic of Moldova CP-78 still is the code document. The map includes isolines of seismic intensity 6,7 и 8 degrees according to scale GOST (or close to it scale MSK-64). The zone with 8-degrees intensity covers South-West of the Republic of Moldova and includes the territory of the cities Cahul, Cantemir, Vulcanesti, etc.; 7-degree intensity zone covers the majority of the country, while 6-degree intensity zone has about 40 km width and covers the eastern part of the country.

The newest earthquake hazard of Moldova Republic territory has been assessed by utilization of a probabilistic deductive approach that includes:

definition of Vrancea seismic source;

estimation of maximum credible magnitude of Vrancea source;

estimation of expected frequencies of occurrence of earthquakes of various magnitudes on Vrancea source;

determination of the macroseismic intensity attenuation changes with magnitude, distance, focal depth in the direction from Vrancea source to the site under study (Republic of Moldova);

determination of correlation of macroseismic intensity with peak ground acceleration (PGA);

application of theoretical model to the calculation of earthquake hazard.

Vrancea Source Model. Conventionally, the map of earthquake epicenters serves as a basis for delineation of earthquake source. In the present study compilation of on own earthquakes catalog was accomplished. The catalogue lists 639 Vrancea intermediate depth (60-170 km) earthquakes occurred during the period 1501-2001. It was earlier repeatedly demonstrated that high magnitude Vrancea earthquakes at intermediate depth mainly affect Republic of Moldova. Based on this, the Vrancea intermediate dept source was defined as a zone with coordinates: λ_1=26.4^0, φ_1=46.0^0; λ_2=27.2^0, φ_2=46.0^0; λ_3=25.7^0, φ_3=45.3^0; λ_4=26.5^0 φ_4=46.1^0.

Depth model for the Vrancea intermediate depth source. Applied subdivided depth model for the Vrancea intermediate depth source is given in Table 1.

Table 4.1. Depth model for the Vrancea intermediate depth source

Dept levels	Depth, km	$M_{W,Max}$	Mean Return Period, yr.
1	60-80	7.0	24
2	80-100	7.5	82
3	100-160	8.1	820
4	160-170		

Mmax. Assuming that the Vrancea foci do not reflect a simple surface of subduction, but counter a subduction lithospheric body, the maximum credible magnitude was determined as $M_{w,Max}$=8.1 (Zaicenco, A., Lungu, D., Alkaz, V., Cornea, T., 1999).

Recurrence - magnitude relationship. From regression analysis of the mentioned Catalogue of Vrancea intermediate depth earthquakes the average number N of earthquakes per year with magnitude ≥M was established ($M_{w,\ min}$ =4.0, $M_{w,\ max}$=8.1), Fig. 4.1 :

$$LgN\ (\geq M_{w\ min}) = 3.91 - 0.75 M_{w}, \qquad (4.1)$$

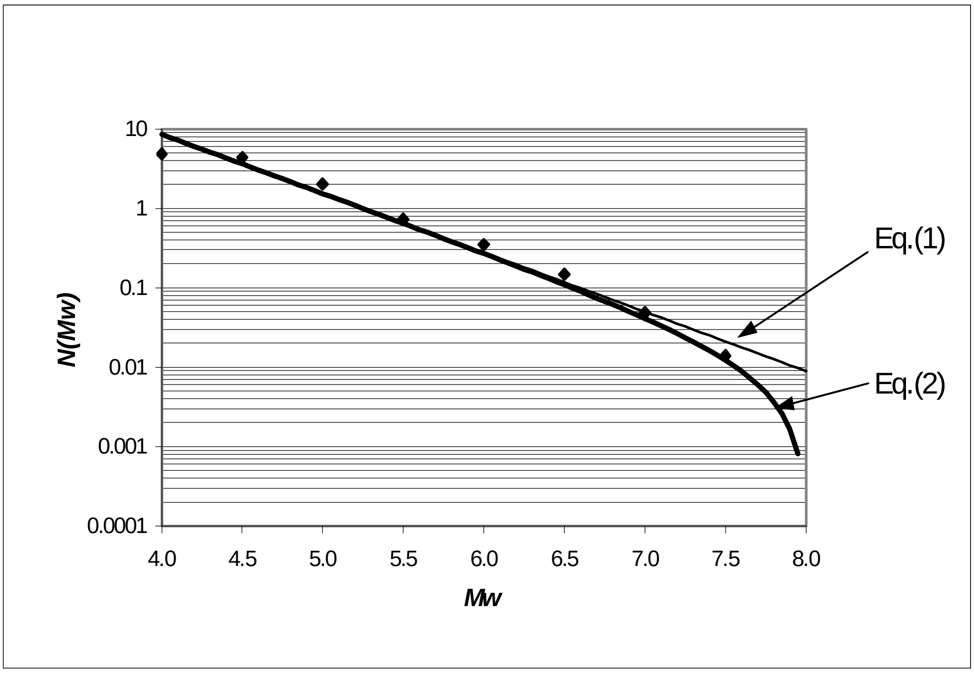


Figure 4.1. Magnitude recurrence relations for the intermediate depth earthquakes($M_w \geq 4$)

The Nwang and Huo (Hwang H.H.M., Huo J.R., 1994) modification of (4.1) is:

$$\nu(\geq m) = e^{9.012-1.72m} \frac{1 - e^{-1.72(8.1 - m)}}{1 - e^{1.72(8.1 - 4.0)}} \qquad (4.2)$$

Attenuation relationship. The new intensity attenuation relationship based on N. Shebalin model for Vrancea - Republic of Moldova azimuth was developed:

$$I=1.33M-8.41Lg\sqrt{(H^2+R^2)}+0.33P \qquad (4.3)$$

were H - is the focal depth, R - the hypocentral distance and P- the variable, equal to 0 (50% probability of non-exceedance) or 1 (84% probability of non-exceedence). MSK attenuation curves from three Vrancea earthquakes: 10.11.1940, 4.03.1977 and 30.08.1986 are given in Fig. 4.2.

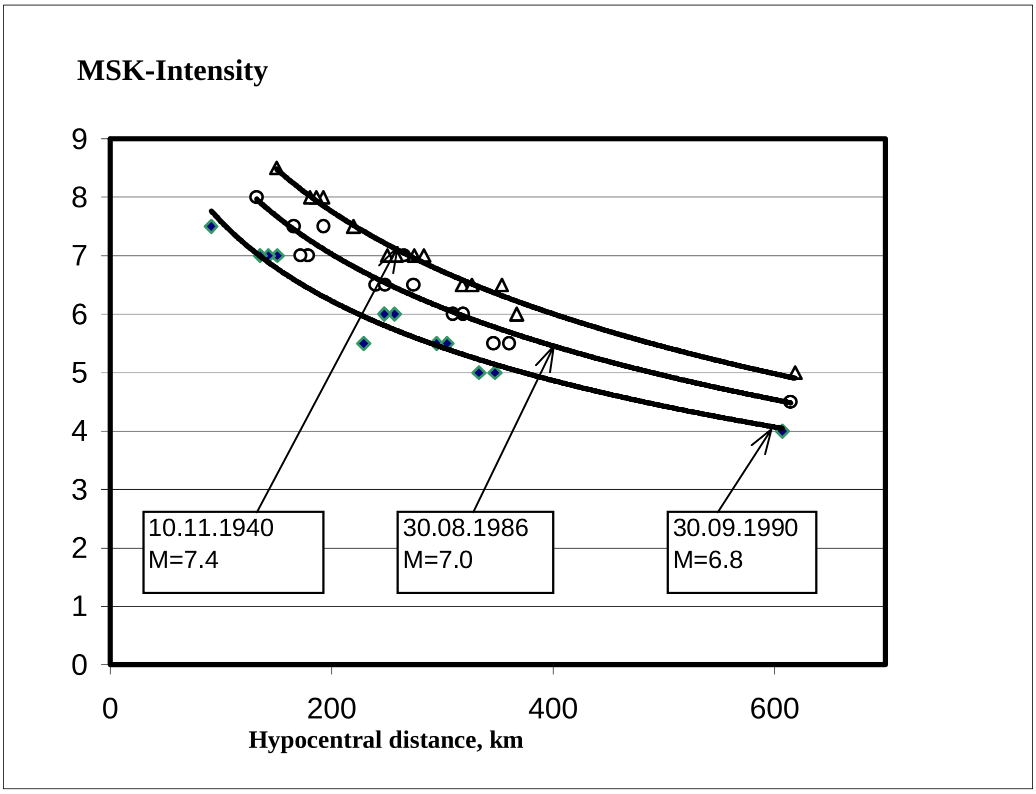


Figure 4. 2. MSK intensity attenuation from three Vrancea earthquakes

Correlation of macroseismic intensity with peak ground acceleration (PGA). Based on available data, the function representing correlation between horizontal acceleration of the ground and macroseismic intensity for Vrancea intermediate depth earthquakes was obtained (formula (4.4), fig.4.3).

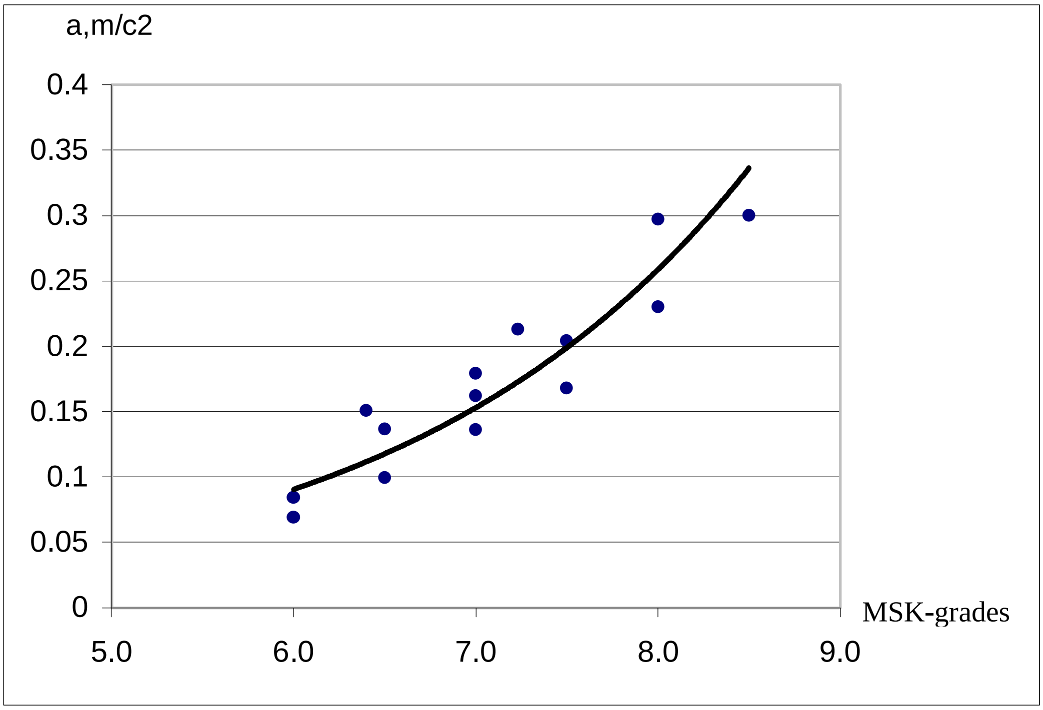
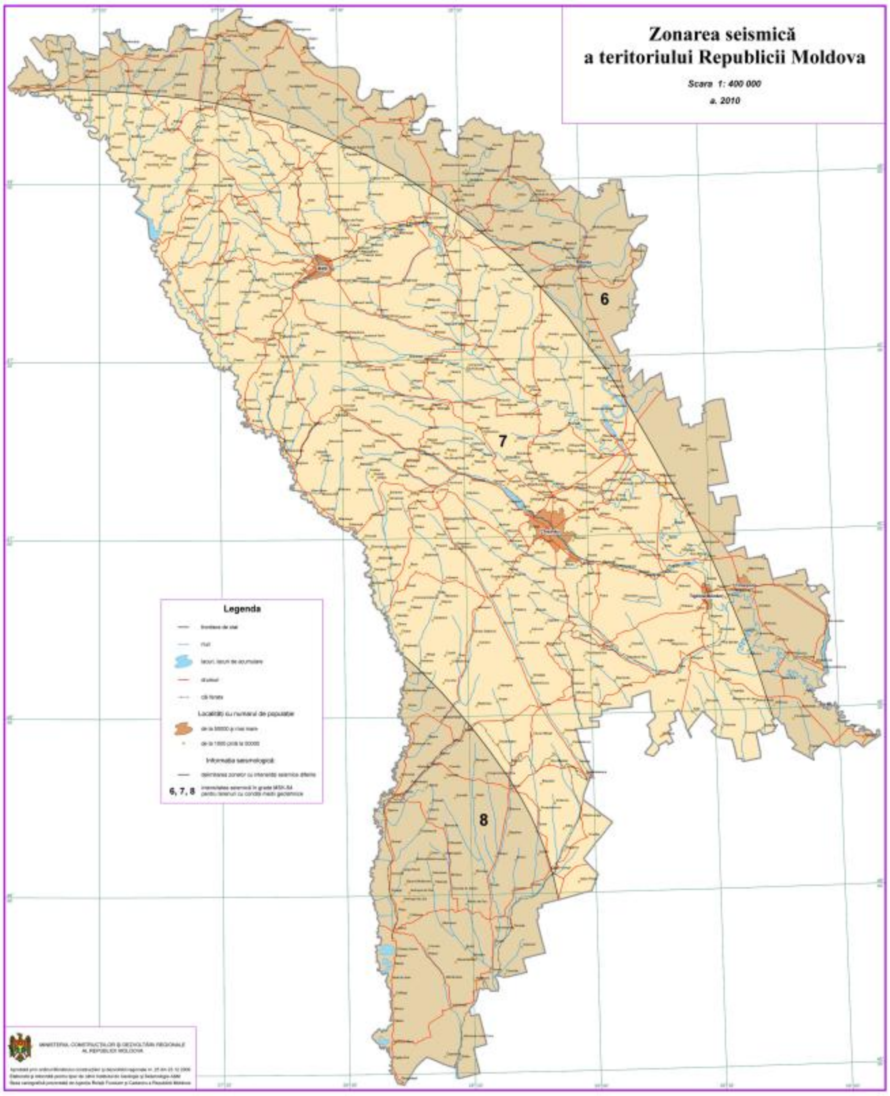


Figure4.3. Relation between MSK-intensity and PGA-acceleration for Vrancea -Moldova Republic azimuth

After calculation of the entry parameters, the Moldova Republic territory was divided into 10x10 km cells at the center of which the MSK-intensity and PGA-acceleration values for 50 years return periods were computed (Figure 4. 4).



Figre 4.4. Acting seismic zoning map territory of the Republic of Moldova

4.2. Site effects. Methodology of microzonation.

4.2.1. Site effects assessment

The study of amplification capacity of sites provided the basis for identification of zones of various seismic intensity and design of the maps of seismic microzonation.

Detailed information about site effects on the territory of Moldova Republic is given in (Alcaz et al, 2008). According to it, the empirical site response was evaluated using different techniques (sediment vs. bedrock ratio, Nakamura's method). Also, a set of analytical amplification functions for horizontal ground motion were computed on the basis of log data and 1D modeling (Ratnikova, 1984). The validation of the results was performed with the help of 2D models (Zagradnik, 1982).

In the majority of the measured points a satisfactory fit between the empirical and analytical predominant periods, as well as amplification levels was established. The site response spectra exhibit peaks between 0.5 and 8.0 Hz, and the amplification factors range from 3 to 7. Examples of soil properties used in calculations are given in tables4.2. and 4.3; examples of calculated (1D model) and empirical (Nakamura's method) transfer functions are provided in Figure 4.5. Examples of 2D structure and calculated transfer functions for specified points where the calculations were made are given in figures 4.6 and 4.7. For the same points, as a comparison, the transfer functions calculated with 1D modeling are also provided.

The results of earthquake records processing demonstrate that the increment of seismic intensity on the sites in respect to hard rock ranges from 1,5 to 2,5 on MSK-64 scale.

Ratios between horizontal and vertical response spectra of the ground motions recorded at seismic stations in Kishinev have also shown amplification for low, as well as for high frequencies, indifferently of earthquake magnitude.

Table 4.2..Soil Properties: Kishinev, Site 1

Vp, km/s	Vs, km/s	ρ, g/cm^3	H, km	Δp	Δs	Lithology
0.29	0.18	1.69	0.004	0.7	0.55	Loamy ground
0.48	0.18	1.72	0.004	0.55	0.5	Friable clay
2.00	0.24	2	0.004	0.2	0.3	Water -saturated clay
0.84	0.40	1.95	0.006	0.3	0.3	Neogene clay
0.84	0.52	2	0.021	0.3	0.25	Sands, clay
1.86	0.53	2.1	0.02	0.2	0.2	Clay, loam
1.10	0.44	1.97	0.011	0.25	0.25	Clay, sand
1.76	0.63	2.25	0.017	0.15	0.15	Clay, sand, silts
2.80	1.37	2.5				Lime-stone

Table 4.3. Soil Properties: Kishinev, Site 2

Vp, km/s	Vs, km/s	ρ, g/cm^3	H, km	Δp	Δs	Lithology
0.22	0.125	1.6	0.002	0.8	0.7	Made ground
0.38	0.20	1.7	0.002	0.65	0.4	Loam
1.5	0.26	1.9	0.008	0.6	1.2	Clay
1.6	0.48	2.1	0.008	0.25	0.25	Aleuritic clay
2.5	1.1	2.4				Limestone

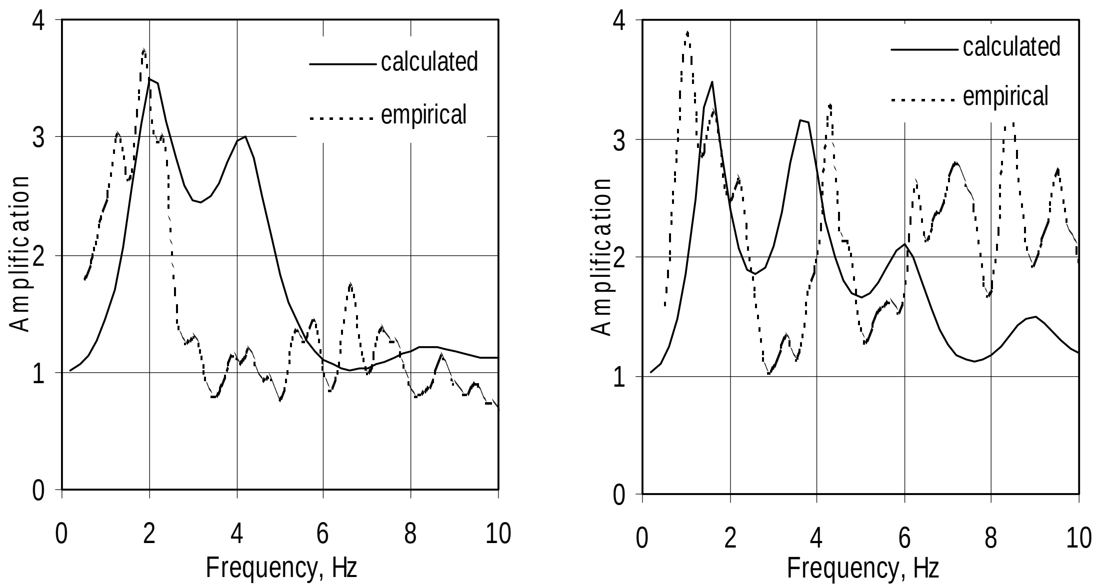


Figure4 5. Examples of empirical and calculated amplification functions for different sites within studied area: 1, 2- sites described in tables 2 and 3.

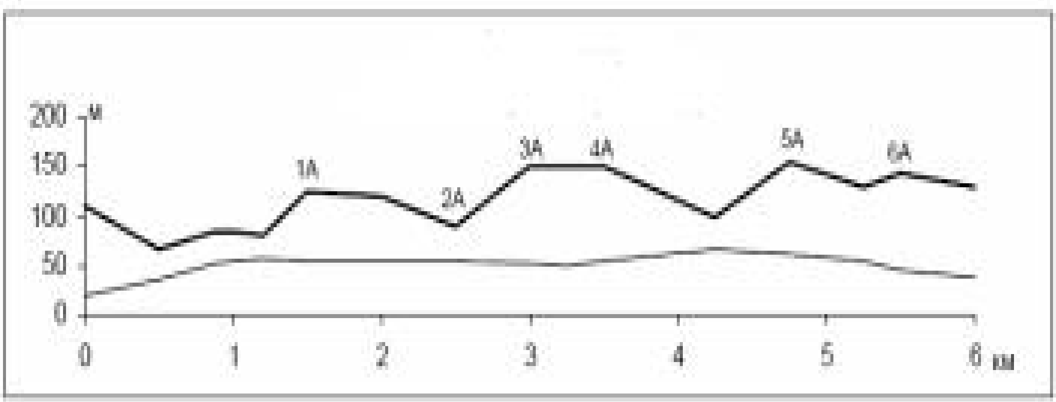


Figure 4.6. 2D geotechnical cross-section model (Figure 3) used in the assessment of the amplification capacity of soils (Zagradnik, 1982). 1A-6A -- the location of characteristic (representative) points where the calculation of amplification functions was made

Presence of geotechnical boreholes in the vicinity of the seismic stations in Kishinev allows evaluation of the influence of the local soil conditions on spectral content of seismic motions.

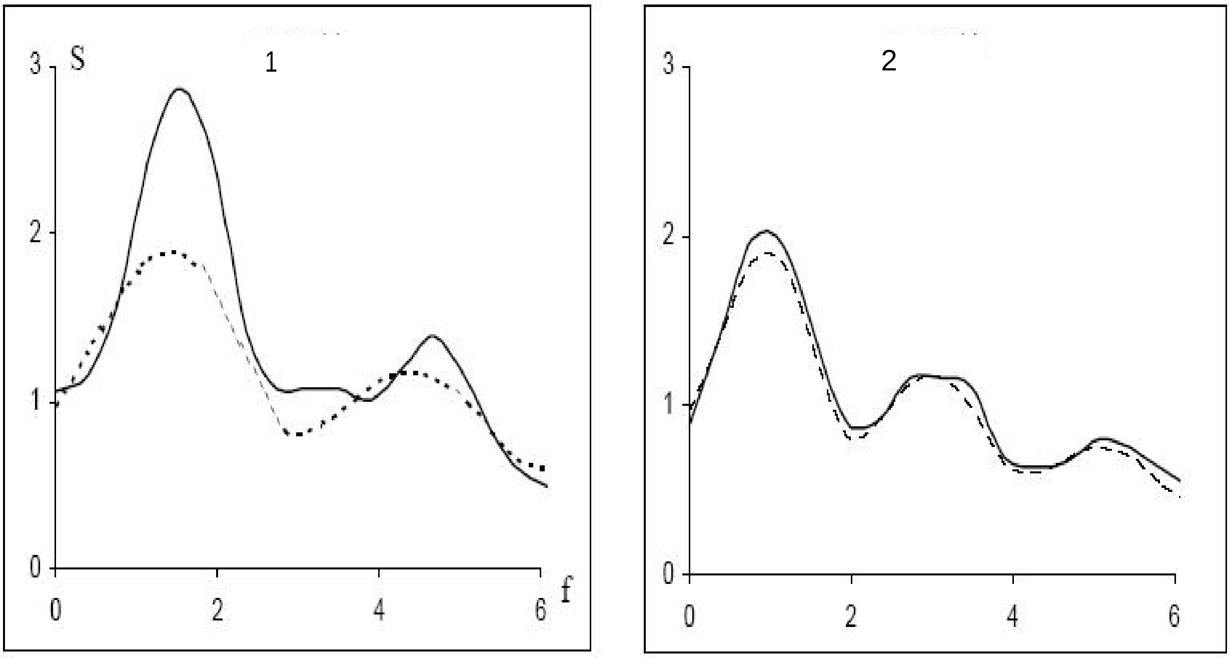


Figure 4.7. Examples of calculated amplification functions for different sites within studied area: 1, 2- sites 1A and 4A in Fig.4.6. (doted line- 1D modeling, thick line -2D modeling)

Based on the knowledge of geometry and elastic properties of soils the averaged 5-layer geotechnical model of the study area was created, Table 4.4, and average amplification factors for different sites were determined. It is noted that layers 2, 3, 4 have variable parameters determined by site location.

The map of average amplification factor for the central part of Kishinev is given in the Figure 7. The combination of different unfavorable soil conditions usually results in high values of structural response and higher damages during strong Vrancea earthquakes. For example, the August 30, 1986 Vrancea earthquake with magnitude 7.0 and epicentral distance of ~230 km to the SW of Kishinev resulted in a devastating damage of numerous buildings, including seismic-resistant structures in some areas of the city (the fault rupture propagated almost directly towards Kishinev). Figure 4. 8 shows the fragment of the map of damage distribution in the city which was prepared on the basis of macroseismic investigations (3078 buildings). The distribution of buildings investigated immediately after the earthquake in function of damage degree and number of stories is presented in Figure 4.9.

Table 4.4. Geotechnical model of the study area

	Type	Thickness, m	Density, g/cm^3	Velocity, m/s
1	Soil	0.5	1.5	120
2	Quaternary clay-sandy conglomerate	0-20	1.52-1.78	140-230
3	Quaternary clay-sandy water- saturated conglomerate	0-22	1.71-2.03	200-350
4	Neogene clay	0-200	1.86-2.17	260-450
5	Neogene limestone (bedrock)		2.45	1300

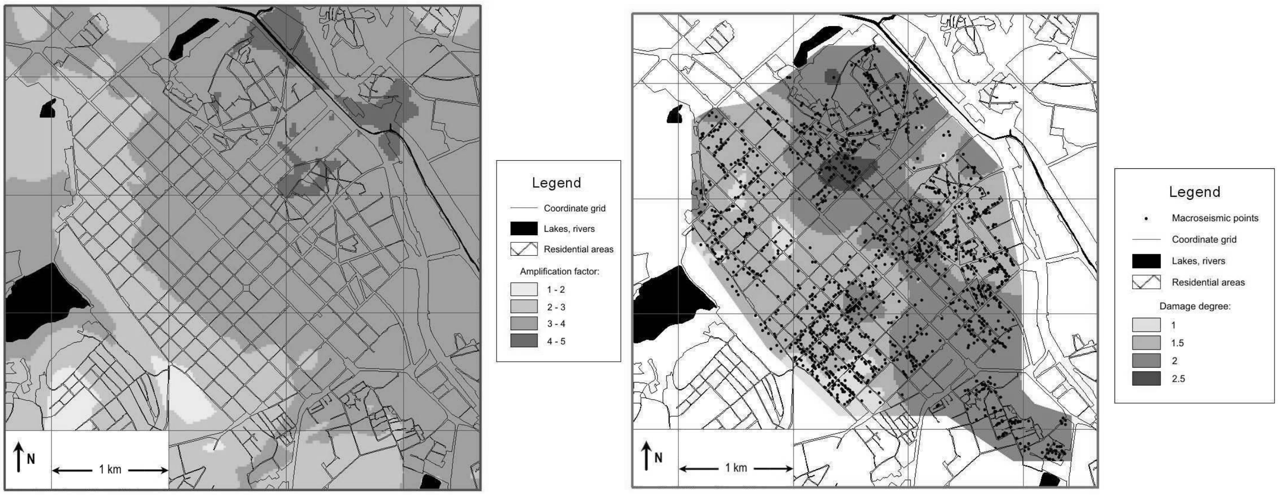


Figure 4.8. Average amplification factor for the central part of Kishinev and map of damage distribution (Kishinev center, 30/08/86 earthquake)

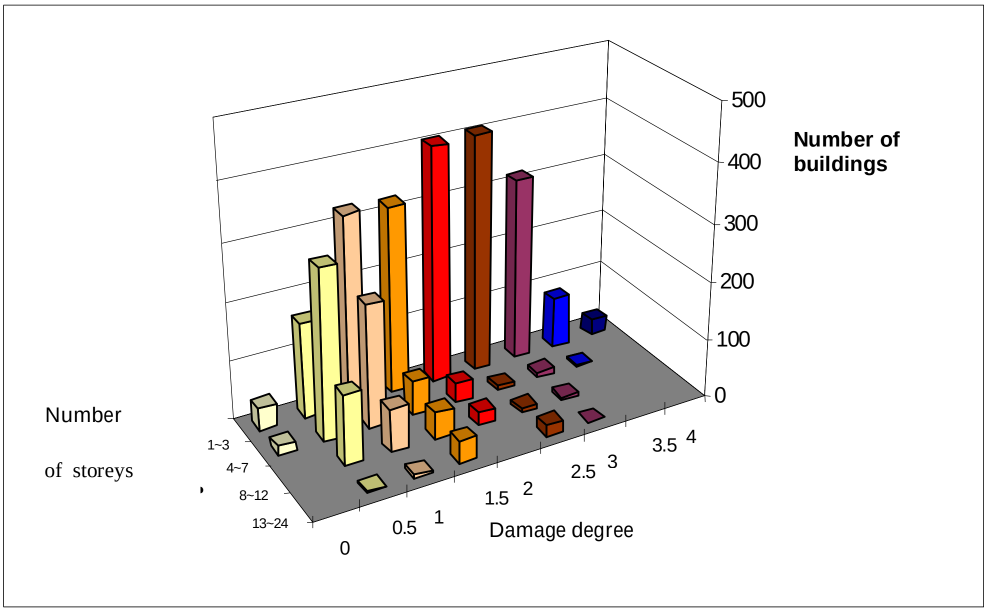


Figure 4.9. Distribution of buildings as function of number of stories and damage degree studied after 30.08.1986 Vrancea earthquake

The amplification of low frequencies by soft soils was one of the most important reasons of high damage observed in the modern high-rise buildings. Consequently, the “low frequency zones” in the city were the most “hazardous” during the August 30 1986 earthquake. The main factors controlling the damages of low-rise structures were the number of suffered earthquakes (accumulated damage) and depth of water table.

The map of amplification and map of structural damage degree for 30.08.86 earthquake were compared to validate the results obtained. In spite of high dispersion of damage degree values the coefficient of correlation ρ=0.6 with soil amplification values was obtained.

4.2.2. Seismic Microzonation of Chisinau

The quality of seismic microzonation is basically determined by the degree to which the applied methodology adequately considers the peculiarities of the region. As it was mentioned in numerous papers (Alkaz et al., 1996, 2005), the application of microzonation methods based on empirical ratios obtained for shallow earthquakes proves ineffective for Vrancea region. For intermediate-depth earthquakes the methodology should include (i) seismic properties of soils for the upper part of cross section as well as for larger depths (down to layers with $V_s \geq 1400$ m/s), (ii) distribution of shear wave velocity with depth, (iii) quantitative contribution of different soil parameters to seismic effect, (iv) expected response spectra for each intensity zone on the map of microzonation. It might be difficult to combine all these requirements in a single seismic microzonation methodology. Therefore, we used a set of methods successfully amending and complementing each other, Table 4.5.

This “combined” methodology has been applied for seismic microzonation of the territory of Kishinev. The elaboration of current map of microzonation was accompanied by a set of supplimentary maps such as map of soft soil deposit thickness, geotechnical and geomorphological maps, map of soil amplification capacity, map of dominant periods of soil (which is shown in Figure 4.10).

Table. 4.5. Methodology for seismic microzonation

Method	Output
1. Geological and geotechnical studies	map of geotechnical zonation of territory
2. Instrumental seismological studies: • earthquakes, explosions; • microtremors; • seismic logging: shallow (≤ 50 m), deep (50 – 200 m)	increment of seismic intensity ΔI; predominant periods of soil vibration velocity Vp, Vs distribution
3. Macroseismic studies	Quantitative contribution ΔI of different factors on seismic effect
4. Theoretical studies	a) transfer functions of soils; b) increment of seismic intensity ΔI c) influence of surface, internal topography; d) recorded accelerograms (response spectra).

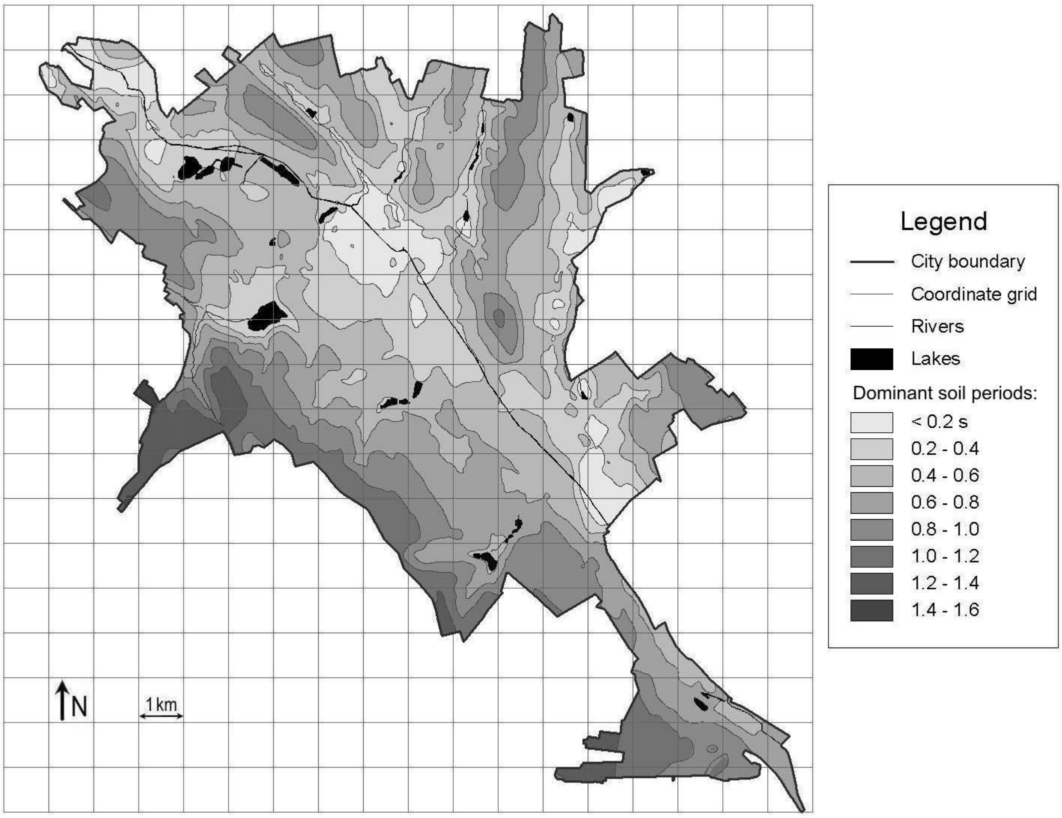


Figure 4. 10. Map of dominant periods of soil in the territory of Kishinev

The dominant periods of soil range from 0,1 to 1,6 sec and gradually increase from center to north and south of the city. Iso-period map shows zones of short predominant period in the central part of the city, and the period increases gradually to the North and South part of the city.

The assessment of amplification capacity and predominant periods of soils provided the new map of seismic microzonation of Kishinev (fig.4.11). The iso-intensity map of microzonation using MSK scale shows variations in the expected intensity distribution ranged between VII to VIII. The map of microzonation is designed for land use planning and seismic-resistant design, seismic risk assessment and elaboration of mitigation measures.

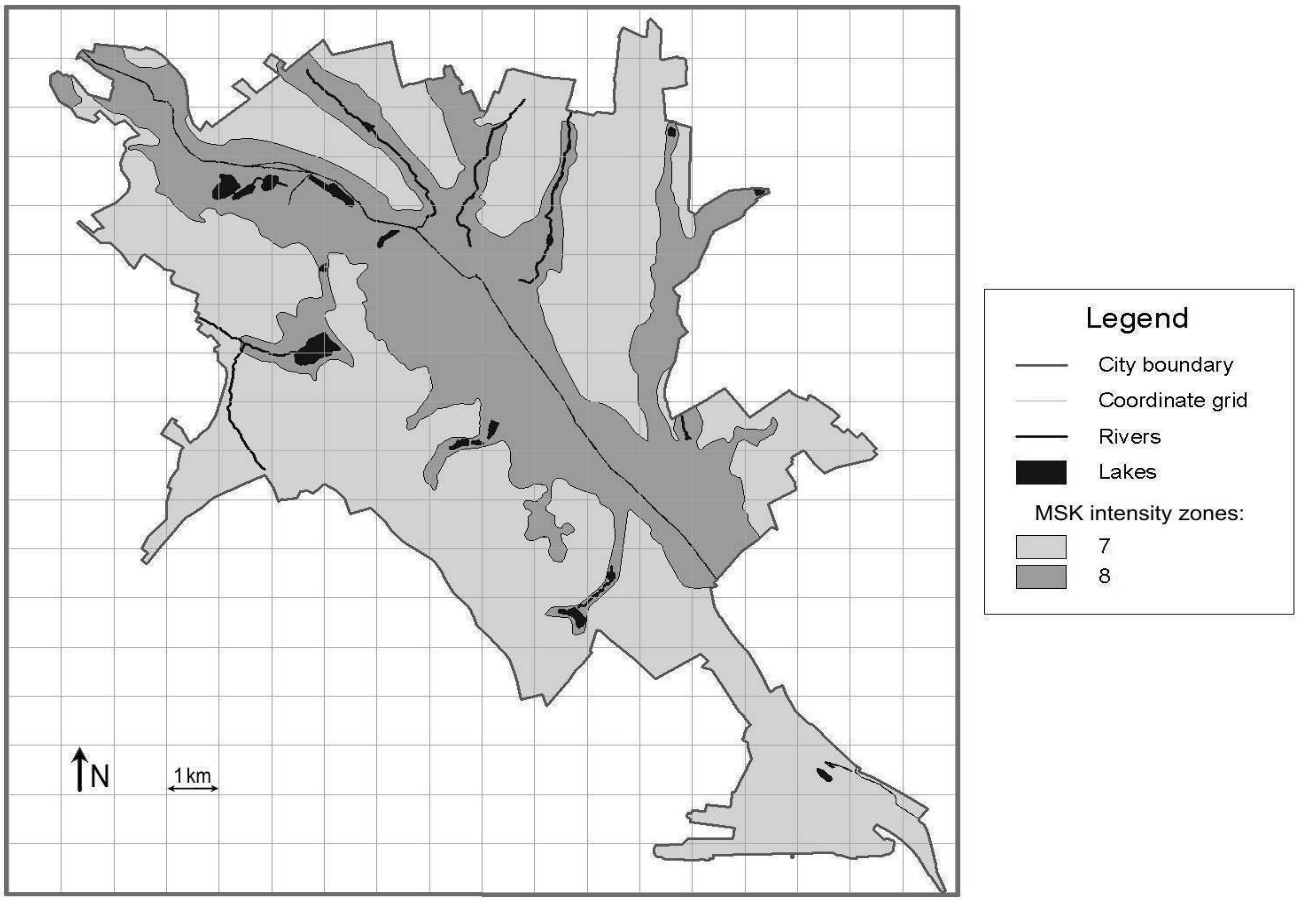


Figure 4.11. Map of seismic microzonation for the territory of Kishinev

5. EARTHQUAKE RISK

5.1. Methodology

Detailed information about the methodology of risk modeling at regional scale is given in (Alcaz et al, 2008).

During the XX century the territory Republic of Moldova has experienced several strong earthquakes. The most significant seismic events recorded in this period, *1940*, *1977,* and *1986* resulted in numerous victims and economic losses. In Table 1 some data on losses for the territory of the Republic of Moldova from the March 4, 1977 and August 31, 1986 seismic events are given (Gutenberg-Richter magnitude, respectively, 7.2 and 7.0).

Table 5.1. Republic of Moldova: losses from March 4, 1977 and August 31, 1986 seismic events

Type of construction	Total analysed (buildings)		Severely damaged, need reconstruction		Completely destroyed	
	1977	*1986*	*1977*	*1986*	*1977*	*1986*
State-owned dwellings	2821	7000	1449	1152	1372	757
Private dwellings	6984	49000	6096	4820	888	-
Schools	334	546	263	128	71	26
Pre-schooler institutions	188	562	141	88	47	33
Health care institutions	181	353	126	64	55	39
Cultural institutions	238	262	161	189	77	73
Commercial institutions	314	326	110	105	34	221
Other institutions	789	489	568	469	221	20
Total	11849	58538	8914	7015	2765	1169

Former SU state insurance companies paid population 686 mil. rubles, the state also paid allowances to the amount of 700.000 rubles, yet that did not cover the real losses population have suffered. According to estimates provided by specialists in construction domain, the sum of 800 mil USD was needed to cover the consequences of the earthquake.

It is well known that methods of risk assessment are scale-dependent. Table 2 is an example of nine different time-space combinations [Papadopoulos *et al*., 1996]. Short-, Mid- and Long-term may indicate time scales of 1, 50 and 100 years respectively. Small-, Mid- and Large-scale of space may be considered as describing areas of surface of 10, 500 and 50 000 km^2. In the present paper the earthquake risk is determined in the mid-term and large-scale sense.

Table 5.2. Conventional scale assignment for earthquake risk assessment

Space / Time	Long-term *(100 years)*	Mid-term *50 (years)*	Short-term *(1 year)*
Large scale *(50 000 km^2)*		X	
Mid scale *(500 km^2)*			
Small scale *(10 km^2)*			

The assessment of earthquake risk requires first the knowledge about factors influencing it. The earthquake (primary) and geological (secondary) hazards, vulnerability of building stock, population features and loss value have been considered as main risk factors in the area under study.

5.1.1. Earthquake (primary) hazard

As the aim of this study was the assessment of mid-term relative risk for Moldova Republic territory, the expected intensities in the future 50 years for different part of the country were considered as the main component of earthquake hazard. Besides, it has been shown in the previous studies [Alkaz, 1999, Alkaz *et al*., 1999] that for specific regional conditions such factors as thickness of soft soil, topography, hydrology play an important role in forming the amplitude level and spectral composition on ground motion.

Geologically different three models (different bedrock depth) were chosen to describe the site amplifications. Site amplifications were determined through empirical and theoretical transfer functions. [Alkaz *et al*., 1987, 1999, Alkaz, 1999].

Data from amplifications on a topographic features in the territory of Republic of Moldova as well as the data regarding the influence of hydrogeology onto the seismic effect came also from experiments, microzonation studies and numerical modeling [Alkaz *et al*., 1990, Pavlov, P., 1995].

So, Earthquake hazard has been evaluated on the basis of map, which was produced taking into account the expected intensities in the future 50 years, soil amplification capacity, topography and underground water level.

5.1.2. Geological (secondary) hazard

A high potential of landslides, densifications, liquefaction and rockfalls of the Neogene Quaternary deposits characterize the territory of Moldova Republic. To identify areas susceptible to these dynamic geological processes, necessary for geological hazard map producing, available sources of data were used: published papers, reports and maps [Stasev, 1964, Constantinova, T., et al., 1997].

5.1.3. Vulnerability of building stock

The Moldova Republic has about of 165,000 buildings. The MSK-76 scale was taken as a tool for building classification. As can be seen from Figure1, the buildings of A and *B* category are most common in this territory. To express in quantitative term the vulnerability of building stock a coefficient V_{aver} was introduced as

$$V_{aver}=(N_A+0.5N_B)/\ (N_A+N_B) \quad (5.1)$$

were N_A, N_B *is* the number of building of type *A* and type *B* (according to MSK-76 scale classification. So, only traditional buildings (*A* and *B* category), representing most of the constructions on the investigated territory, were taken into account in our analysis.

Coefficient V_{aver}, varying between 0.5 and 1.0, is a measure of the average vulnerability of structures.

5.1.4. Population features

The spatial distribution and density of the population [Palamarciuc et *al*., 2001] were considered the highly important factors, determining the population features in the investigated territory.

5.1.5. Loss value

As a measure of relative value of loss the index of economical activity each of Moldova Republic districts was assumed [Constantinova et *al*., 1997].

To draw up the earthquake, geological hazards and other necessary maps the methodologies [Blair *et al*., 1979, Mindrescu, 1990, Papadopoulos *et al*., 1996] were used.

So, the necessary steps for assessment of relative earthquake risk were as follows:

i) Defining the basic unit for calculations. The calculations were performed for a grid of 348 points with a spacing of 10 x10 km each.

ii) Determining the factors to be analyzed: earthquake hazard (earthquake source, soil amplification, topography, hydrogeology), geological hazard (landslides, densifications, liquefaction, rockfalls), vulnerability of building stock, population density and economic activity index (Table 5.3).

Quantifying relative weight: each factor was given a 3-to -40 weight representing its importance relative to the other factors. The weight was determined on 6 experts' considerations. As can be seen from Table 2, the largest weights were assigned to earthquakes, as they have the largest damaging potential; the smallest weights were assigned to the densifications and rockfalls.

iii) Potential rating of each factor (Table 5.3), from 1 to 4. For example, the earthquake were rated 1 to 3: 1 - for the VIth degree of seismic intensity (low hazard), 2 - for the VIIth (moderate hazard), and 3 - for VIIIth (high hazard).

iv) Calculating the earthquake risk for every grid cell were it is found as the convolution of earthquake hazard E_H, geological hazard G_H, buildings vulnerability V_B, population density D_P and economical activity index E_A:

$$R_i=E_H*G_H*V_B*D_P*E_A \quad (5.2)$$

Expression (1) was applied to obtain an overall number representing the score for each grid cell; the scores are ranging from 110 to 430. The relative earthquake risk, *Rri*, in each cell has been determined as

$$R_{ri}=R_i/R_m \quad (5.3)$$

were $R_m=min\{R_i\}$.

The relative earthquake risk, *Rri*, in each cell has been determined as

$$R_{ri}=R_i/R_m \quad (5.4)$$

were $R_m=min\{R_i\}$.

Table 5.3. Rating system for earthquake risk evaluation.

	Risk factors	Weight	Rating	Weight rating
	EARTQUAKE HAZARD			
1	Earthquake source	40	1	40
			2	80
			3	120
2	Soil Amplification	20	1	20
			2	40
			3	60
3	Topography	10	2	20
			3	30
4	hydrogeology	5	1	5
			2	10
	GEOLOGICAL HAZARD			
5	Landslides	5	1	5
			2	10
			3	15
6	Densifications	3	2	6
			3	9
			4	12
7	Liquefaction	5	2	10
8	Rockfalls	4	2	8
9	BUILDING VULNERABILITY	15	1	15
			2	30
			3	45

			4	60
10	POPULATION DENSITY	20	1	20
			2	40
			3	60
			4	80
11	ECONOMIC ACTIVITY INDEX	30	1	30
			2	60
			3	90
			4	120

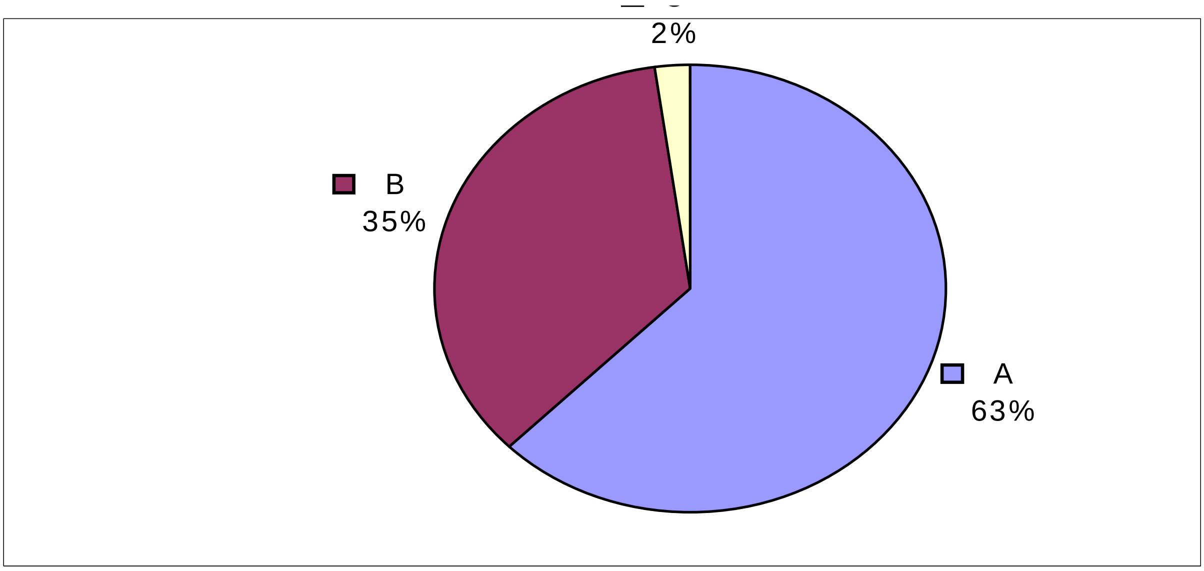


Figure 5. 1. Distribution of Moldova Republic buildings with vulnerability class.

5.3. Relative earthquake risk territory of Moldova Republic

From collected data the set of maps necessary for earthquake risk assessment were elaborated (Fig. 5.2-5.7). Then, on the basis of R_{ri} distribution, four classes of relative risk were suggested (low, moderate, high and very high) and the large-scale (1:500000) map of relative seismic risk has been performed (Fig. 5.8). As show, the earthquake risk is not consistent with earthquake hazard and reaches levels of concern in the central region of Moldova Republic were the population is denser, economy is better developed and the secondary effects of earthquakes are more likely.

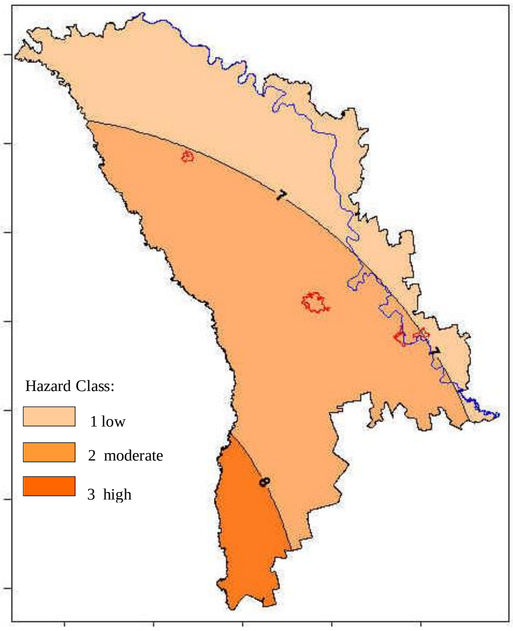


Figure 5.2. Predictive contour map (MSK) from subcrustal Vrancea source. Mean Recurrence interval =50yr

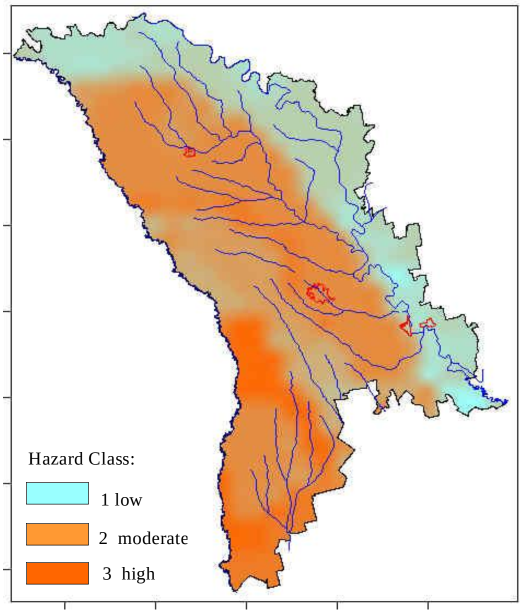


Figure 5.3. Distribution of relative earthquake hazard (earthquake source, soil amplifications, topography, hydrogeology)

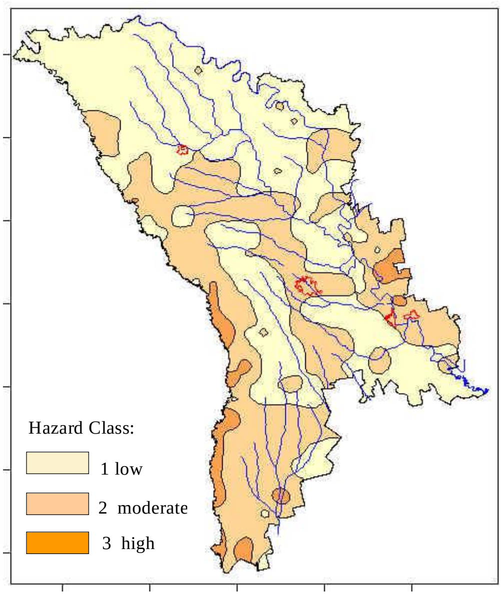


Figure 5. 4. Distribution of relative geological hazard (densifications, landslides, liquefations rockfalls)

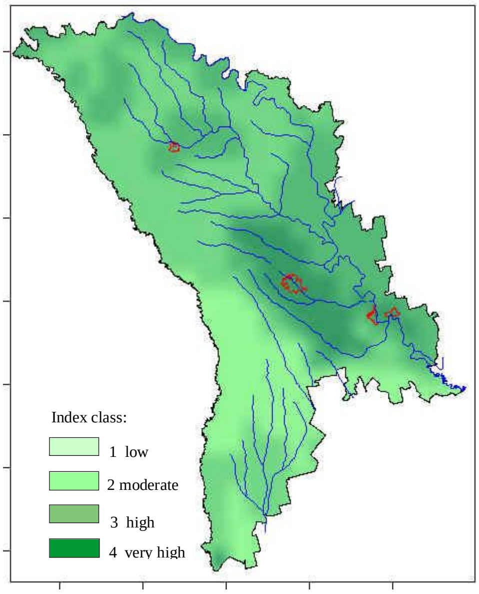


Figure 5.5. Distribution of Economical Activity Index in Republic of Moldova

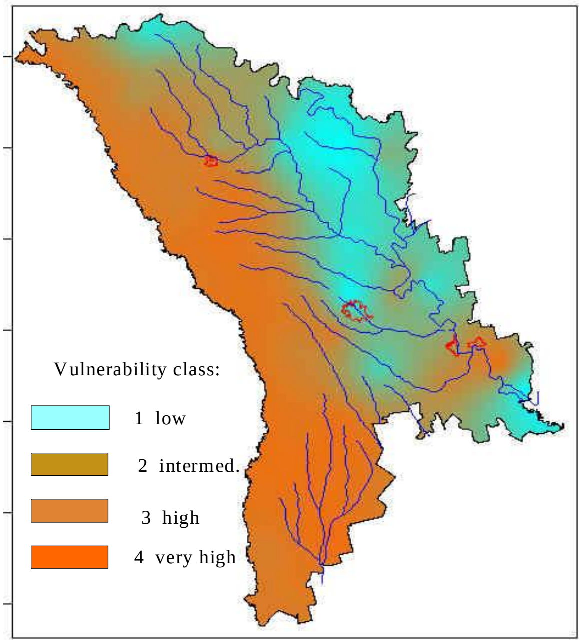


Figure 5.6. Relative vulnerability of building stock of Republic of Moldova

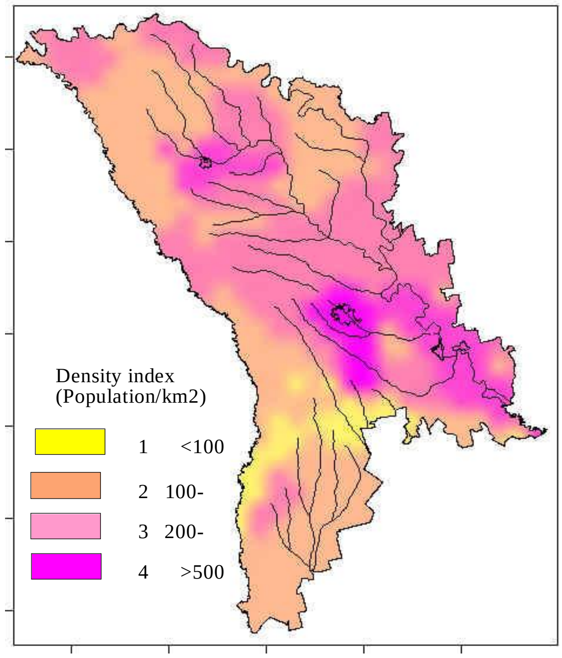


Figure 5.7. Density of population in Republic of Moldova

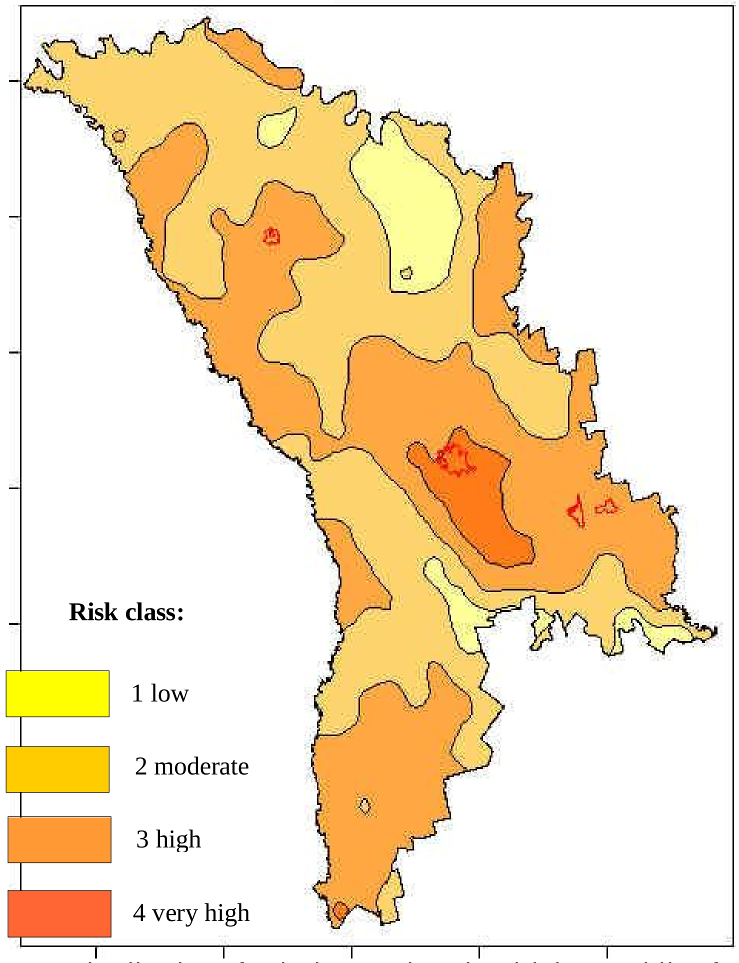


Figure 5. 8. Distribution of relative earthquake risk in Republic of Moldova

5.4. Earthquake loss assessment. Chisinau city case study

5.4.1. Methodology for earthquake loss assessment

Ground Motion Parameters. Ground motion, represented by response spectrum expected for the given site, is the demand factor determining vulnerability of buildings to seismic impact.

In current study response spectrum for the medium soil conditions is calculated on the basis of attenuation function of Peak Ground Accelerations (PGA) from Vrancea source for the sector containing Moldova [Lungu et al., 1997]:

$$\ln (PGA) = c_1 + c_2 M_w + c_3 \ln R + c_4 H + \varepsilon \qquad (5.5)$$

where: *PGA* is the peak ground acceleration at the site, M_w- the moment magnitude, *R* - the hypo-central distance to the site, *H* - the focal depth, c_1, c_2, c_3, c_4 - data dependent coefficients and ε –random variable with zero mean and standard deviation: c_1=4.150, c_2=0.913, c_3= -0.962, c_4=-0.006, ε=4.15.

Normalized response spectrum shape (ξ=0.05) compatible with Eurocode-8 format is obtained [Lungu et al., 1997] on the basis of the statistical analysis of 20 components of seismic records from the Republic of Moldova and neighboring Romanian Moldova.

Influence of local soft soil conditions is considered by convoluting bedrock spectrum with soil amplification function in frequency domain. Corresponding database of these functions is compiled for the test area.

The procedure of calculating the free-field acceleration damped response spectra, taking into account the influence of soft soil, is the following:

1. Normalized response spectrum for the target site is multiplied by the corresponding value of the *PGA* from the attenuation function, yielding spectrum for medium soil conditions at given hypocentral distance and particular earthquake magnitude. The calculated spectrum is scaled afterwards to obtain the spectrum on the bedrock;
2. Bedrock spectrum is converted into Power spectrum density function, PSD [Vanmarcke, 1997];

3. *PSD* is convoluted with the transfer function of the soft soil column in frequency domain yielding *PSD* of the free-field motion;

4. *PSD* is converted back into damped response spectrum (Figure 5.9).

5.

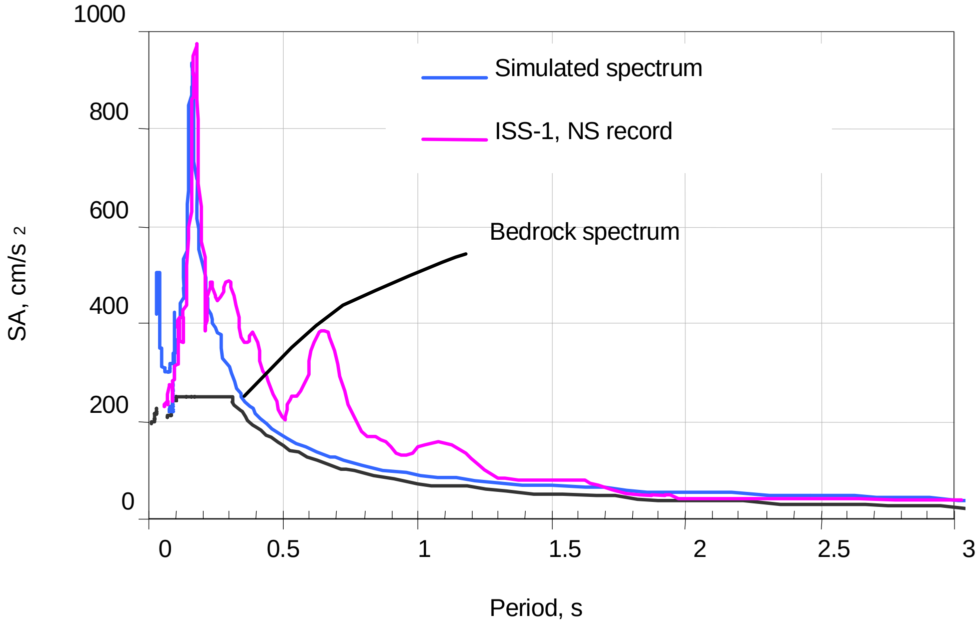


Figure 5.9. Free-field acceleration damped response spectra: simulation vs. record (August 30, 1986 Vrancea earthquake, engineering seismometric station 1- ISS-1)

The applied procedure does not yet take into consideration the non-linearity of soil dynamic behavior, which is acceptable for medium hypocentral distance of test site, when small non-linearity in soil behavior are expected for interval T=475yr.

The degree of structural damage is studied in context of the level of ground shaking expressed in terms of response spectrum, SA_{2Hz}, for the natural period of buildings.

Buldings' vulnerability. Current research uses European Macroseismic Scale, EMS-92 [Grunthal, 1993] and its buildings' damage classification for damage assessment of the existing building stock in Chisinau. The building block chosen for preliminary evaluation of seismic risk in Chisinau city is composed of various buildings. The total amount of records achieved 1870, while vulnerability class *B* (masonry) buildings, constituting ≈45% of the total, were chosen as the sample space, as providing the most reliable information both from the spatial distribution point of view as well as structural uniformity.

The fragility curves method [Kircher, 1997], taking into account the design spectra as used in the present research. Fig.5.10 provides design response spectra incorporated into the building code SNiP II-7-81 according to which the majority of structures in Moldova were designed.

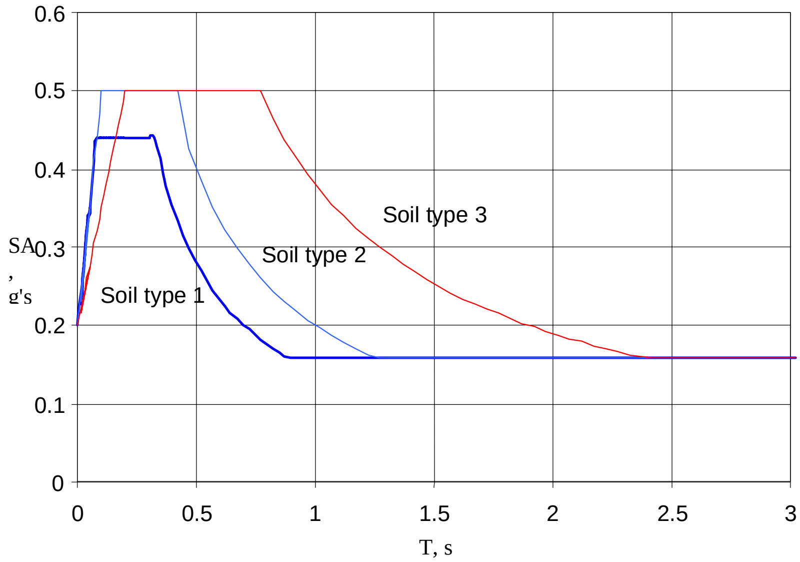


Figure5.10. Curves of spectral accelerations (g's) for intensity VIII MSK according to SNiP II-7-81

Recent update of the code did not result in considerable change of spectral shape, which was accepted with control period T_C=0.5 s.

The structural response is defined by the intersection of design spectrum and building capacity curve. The design spectrum is defined as having 5% critical damping taking into consideration attenuation law, source effects, local soil conditions, etc.

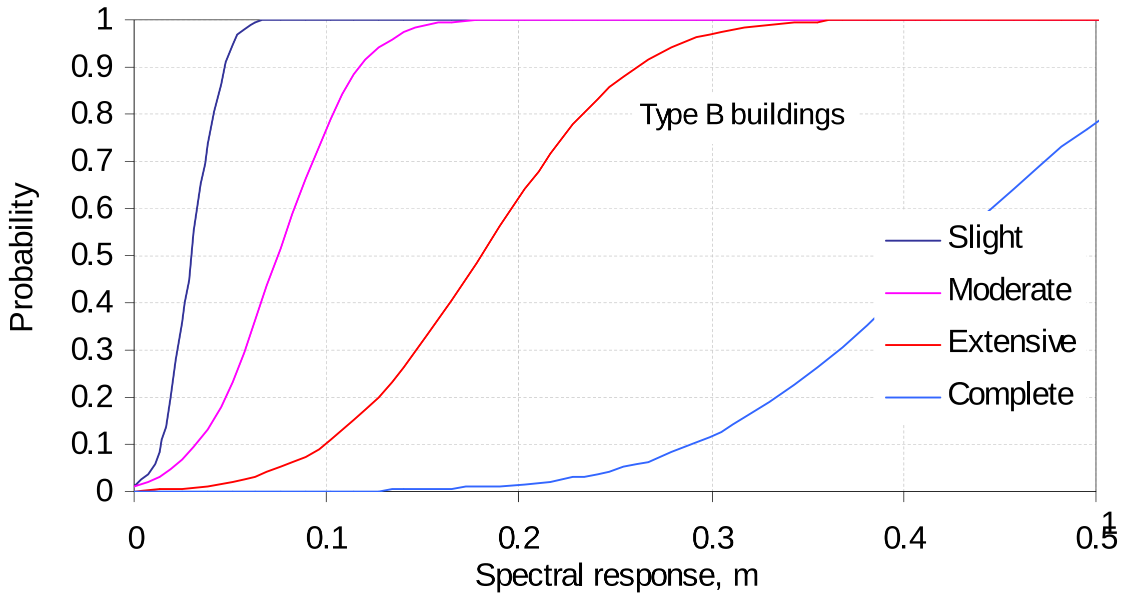


Figure 5.11. Type B buildings (classification EMS-92): fragility curves.

5.4.2. Estimating losses from future earthquakes

Damage Estimation Using Response Spectra. Simulation of free-field damped response spectra for scenario M_G=7.0 (Gutenberg-Richter) earthquakes was performed, resulting in mapping of shaking parameters. Software with GIS interface allows interpolation of selected spectral parameters for each grid point within studied area (Figure 5.12) and building damage degree calculations, d_i.(Table 5.4). The degree of structural damage is studied in context of the level of ground shaking expressed in terms of response spectrum, SA_{2Hz}, for the natural period of building's vibration. Correlation between simulation and real data is quite good: 0.89.

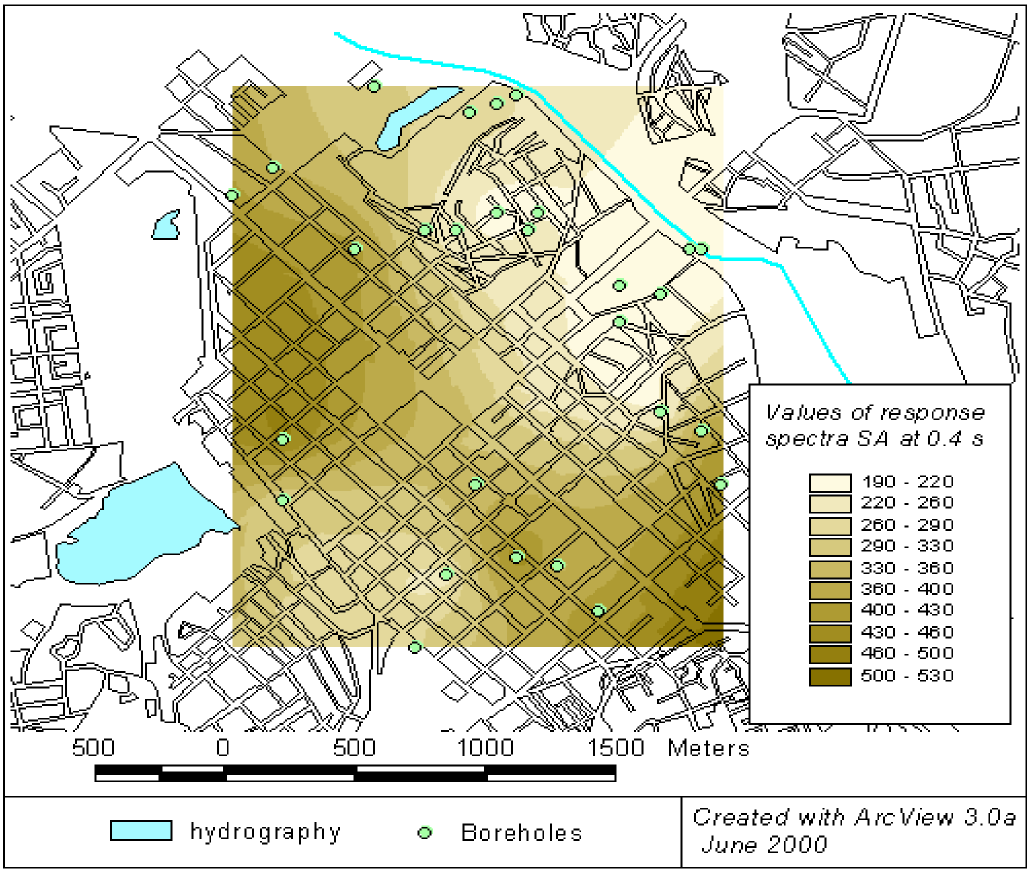


Figure 5.12. Map of simulated values of response spectra at T=0.4s for the central part of Chisinau.

Table 5.4. Simulated and recorded damages of buildings using spectral response: type B. Chisinau City Center, August 30, 1986 Vrancea Earthquake (M_G=7.0).

Damage degree	0	1	2	3	4
Simulation scenario (M_G= 7), % of buildings	7.8	32.8	41.4	11.7	6.3
Real Data, % of buildings	4.5	27.2	41.1	25.1	2.1

Damage estimation using MSK-intensity. Above, the probability of damage suffered by the structures for given level of seismic hazard is evaluated using response spectra (fragility functions). However, until now most damage estimation is done using macroseismic intensity. MSK-based software application for estimation of damage-loss and human casualties from strong Vrancea earthquakes on the territory of the Republic of Moldova has been also developed. The application evaluates damages and casualties on the base of seismic hazard assessment of Vrancea zone, taking into account directivity effects, local soil conditions and vulnerability of the existing building stock in Moldova.

i) *Directivity effects*. MSK- intensity attenuation relationship based on [Shebalin, 1997], model for Vrancea - Republic of Moldova azimuth was developed:

$$I = 1.3M - 4.6\lg\sqrt{(H^2 + R^2)} + 8.4 \qquad (5.6)$$

were: M – is the Gutenberg-Richter magnitude, H - is the focal depth, R - the epicentral distance.

ii) *Local soil conditions*. Based on the seismic attenuation law we can only get the basic intensity distribution. To take into account the influence of site geology in the methodology of forecasting of losses the map of seismic mirozonation is used. The (Central area) is given in Figure 6. According to map of seismic microzonation of Chisinau City, the basic MSK-intensity (7) has respectively 0 and 1.0 degree changes.

iii) *Vulnerability*. The functions of vulnerability used in the present study (damage matrix of buildings and matrix of casualties) are given in [Alkaz et all, 2006].

There are different ways of classification the degree of damages of buildings and structures. The offered algorithm is based on scale with 6 degrees, namely: 0 – intact, 1 – light damages, 2 – moderate damages, 3 – heavy damages, 4 – destruction and 5 – collapse.

The result of damage-loss simulation for Center test area using MSK- intensity is presented in Table 5.5.

Table 5.5. Simulated and recorded damages of buildings using MSK-intensity: type B. Chisinau City Center, August 30, 1986 Vrancea Earthquake (M_G=7.0)

Damage degree	0	1	2	3	4
Simulation scenario (M_G= 7), % of buildings	10.2	29.5	37.6	19.8	2.9
Real Data	4.5	27.2	41.1	25.1	2.1

In order to assess the efficiency of the offered methodology the comparison of predicted damage for strong of August 30, 1986 Vrancea earthquake with real observed on field was carried out. The results of comparisons are given in Tables 5.4, 5.5 and Figure5.13.

Generally, the comparison revealed a satisfactory fit between real and predicted damages by both algorithms.

Simulation of Earthquake Scenarios. Same partial evaluations of the expected loss for Chisinau City buildings from historical and scenario earthquakes were also performed using the methodology illustrated in paragraph 5.3.1. The aim of this first risk evaluation was to estimate the order of magnitude of damages and casualties expected in Chisinau City territory.

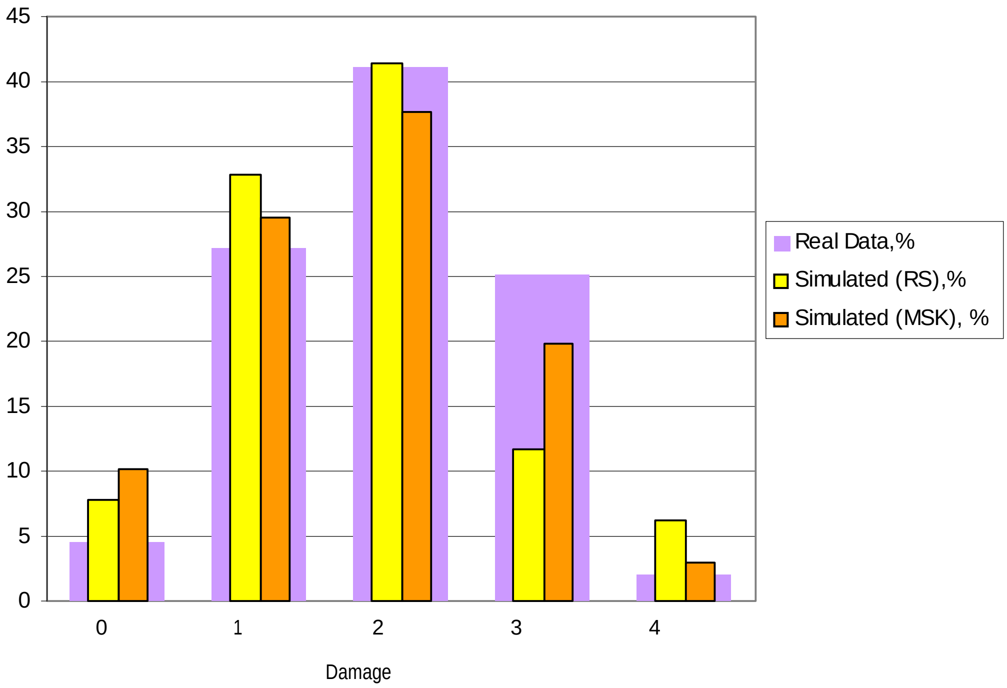


Figure 5.13. Comparison of recorded and simulated damages of buildings using different ground motion parameters (response spectra, MSK-intensity): type B, Chisinau City Center, August 30, 1986 Vrancea earthquake (M_G=7.0)

The results of calculation of expected damage-loss and human casualties from earthquake analogous to November, 1940 earthquake (M_G =7.4) are shown in Tables 5.6, 5.7 while the results from probable major Vrancea earthquake (M_G=7.8) are shown in Table 5.8 and 5.9.

Table 5.6: Expected damages from earthquake analogous to November 1940: Vrancea earthquake (M_G=7.4). Chisinau City, existent building stock

Damage degree / Number of damaged buildings	0	1	2	3	4	5
Type A	0	214	2014	3494	1878	229
Type B	267	2514	4361	2095	26	0
Type C	380	596	288	39	0	0

Table 5.7. Expected casualties from earthquake analogous to November 1940: Vrancea earthquake (M_G =7.4). Chisinau City, existent building stock

Human casualties	People			
	Buildings type A	Buildings type B	Buildings type C	Total
Injured	1938	286	586	2809
Victims	48	0	0	48
Total inhabitants	76280	190420	390600	657300

Table 9. Expected damages from probable major Vrancea earthquake (M_G=7.8). Chisinau City, existent building stock

Damage degree / Number of damaged buildings	0	1	2	3	4	5
Type A	0	31	549	2853	3509	687
Type B	38	686	3561	4380	857	0
Type C	99	487	599	117	0	0

Table 10: Expected casualties from probable major Vrancea earthquake (M_G=7.8). Chisinau City, existent building stock

Human casualties	People			
	Buildings type A	Buildings type B	Buildings type C	Total
Injured	5050	857	1758	7664
Victims	137	0	0	137
Total inhabitants	76280	190420	390600	657300

Furthermore, the methodology should be developed to ensure account of expected damages of lifelines, too.

6. NATIONAL FRAMEWORK, REGARDING PREVENTION, MONITORING AND INTERVENTION IN CASE OF EARTHQUAKE

6.1. Involved structures, main tasks

6.1.1. Governmental institutions

1. *Ministry of Regional Development and Construction*: develops and promotes the state policy in the planning, architecture, urban planning, construction, construction materials production, housing and regional development;

2. *Civil Protection and Emergency Situations Service/MIA*: protection of population, territory, environment and property in case of danger or emergency situations

6.1.2. Local public authorities

City Halls: according to the law responsible for preventing the disasters in urban and rural areas

6.1.3. Research institutions

1. *Institute of Geology and Seismology, Academy of Sciences:*

a. monitoring of seismicity of the territory of R. Moldova;

b. earthquake hazard and risk assessment;

2. Technical University of Moldova:

a. research;

b. training specialists in in the field of engineering seismology;

3. State University of Moldova:

training researchers.

6.2. Civil Protection Service and Emergency Situations

6.2.1. Structure, main tasks

- people and property protection in emergency situations;

- conducting of rescue operations and other urgent actions in the emergency situations and liquidation of its consequences;

- Organizing of prior and multilateral population preparedness, economical objectives and Civil Protection forces in order to conduct the operations in case of emergency situations.

6.2.2. Future priorities

- The national crises management centre
- The unique emergency call number 112
- Implementation of GIS technologies
- Specialized subunit for international rescue operations
- Adaptation a national CP legislation to EU

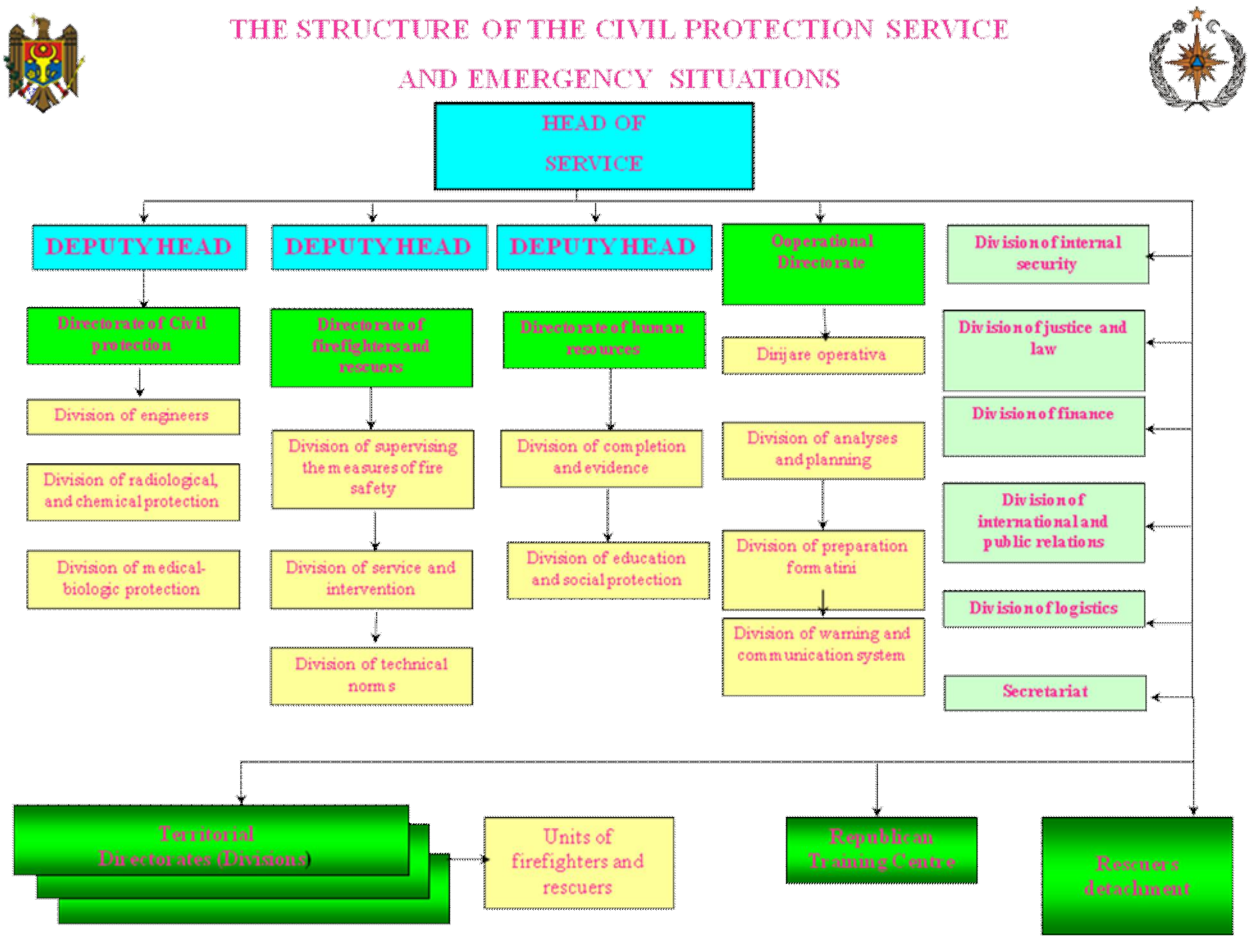


Figure 6.1. Structure of the Civil Protection Service and Emergency Situation

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