SEISMIC RISK MITIGATION - THE BASIS OF A SUSTAINABLE DEVELOPMENT

Aurelia BRADU[1], Adrian Alexandru CIOBANU[1], Constantin MIRON[1], Monica CHERECHEȘ[2], Florina FILIP[3]
[1] PhD. Eng, NIRD URBAN INCERC, Iaşi Branch,
[2] PhD. Phys, NIRD URBAN INCERC, Iaşi Branch
[3] Eng, NIRD URBAN INCERC, Iaşi Branch
[aurelia.bradu, adrian.ciobanu, constantin.miron, monica.chereches, filip.florina]@incd.ro

ABSTRACT

The notion of seismic risk is employed to describe the effects of earthquakes on social, economic and environmental aspects over a certain period of time and can be defined as the interaction of three parameters: seismic hazard, exposure time and structure vulnerability. A high seismic risk does not involve a high seismic hazard and vice versa. Disaster risk management is quantified by the application of appropriate policies and strategies necessary to prevent and reduce the risk, manage residual risk, thereby enhancing the resilience of the system. There are two strategic ways to reduce seismic risk: the improvement of emergency response and the adequate design of structures. Prevention is the most cost-effective solution and can play even the role of a driver for economic growth, and it is granted more attention in the disaster management cycle. Performance based seismic design involves the development of safety criteria in which the hazard is determined probabilistically as a function of the potential consequences of failure. Even if earthquakes cannot be accurately predicted, the disastrous consequences produced by human loss, economic and social damage can be minimized. In this paper, models of seismic risk mitigation programs for Turkey, Greece and Romania are presented.

Keywords: seismic risk mitigation; earthquakes; disaster management.

REZUMAT

Noțiunea de risc seismic este utilizată, de regulă, pentru a descrie urmările cutremurelor asupra aspectelor sociale, economice și de mediu într-o anumită perioadă de timp. Aceasta poate fi definită ca o interacțiune a trei parametri: hazardul seismic, expunerea și vulnerabilitatea structurală. Un risc seismic sporit nu implică un hazard seismic ridicat și invers. Managementul riscului de dezastru este cuantificat prin aplicarea politicilor şi strategiilor adecvate necesare pentru prevenirea și reducerea riscului, gestionarea riscului rezidual, sporind astfel reziliența sistemului. Există două modalități strategice de reducere a riscului seismic: îmbunătățirea capacității de răspuns în situații de urgență și proiectarea adecvată a structurilor. Prevenirea reprezintă cea mai eficientă soluție, putând avea chiar şi rolul de stimulent al creşterii economice; prevenirii i se acordă o atenţie sporită în ciclul de management al dezastrelor. Proiectarea seismică bazată pe performanţă implică dezvoltarea unor criterii de siguranță, în cadrul cărora hazardul este determinat probabilistic, ca o funcţie de consecinţele potenţiale ale cedării. Chiar dacă seismele nu pot fi prezise cu precizie, consecințele lor dezastruoase, traduse prin pierderi de vieţi omeneşti şi pagube economice şi sociale pot fi minimizate. În acest articol sunt prezentate modele de programe de reducere a riscurilor seismice pentru Turcia, Grecia și România.

Cuvinte cheie: reducerea riscului seismic; cutremure; managementul dezastrelor

1. INTRODUCTION

Seismic hazard represents the intrinsic natural occurrence of earthquakes in a given geographic area, over a specific period of time, with a ground motion intensity exceeding a certain level - for example, a ground motion with 15 percent probability of exceedance in 50 years. The estimation of seismic hazard derives through two parameters: the assessment of the seismic action and the estimation of the seismic risk.

An appropriate assessment of the seismic hazard involves good knowledge of historical and recent seismicity, including notions about the neotectonic regime, seismogenic faults, geological structure of the site etc (Choudhury *et al*., 2018).

The main purpose of seismic hazard analysis is to provide the necessary data for seismic risk assessment. In order to prevent the confusion with seismic hazard, which describes the natural phenomenon or the properties of an earthquake, the notion of seismic risk is employed to describe the effects of earthquakes on the social, economic and environmental aspects over a certain period of time (Georgescu, 2010).

The risk mitigation demands considerable human effort; risk evaluation represents a key factor of disaster risk management. This activity involves the identification, assessment, and prioritization of risks by national authorities and/or governmental agencies at different levels: local, regional or country, according the pursued policies and mandates (Šipoš and Hadzima, 2017).

The comprehension of the risk is extremely important because it gives the way to expound and analyze the necessary measures which should to be taken to protect society from disastrous consequences. The concept of seismic risk is much broader and more complex than seismic hazard. Even though seismic risk can generally be defined as the probability of destructive consequences occurrence to society, it can be interpreted differently by varied stakeholders. For example, in earthquake engineering it is important the pursuit of the probability of exceedance of a certain level of ground motion, in a specified location, over a given period. At the same time, insurance companies are more interested in following the probability that losses in a region or site exceed a defined level over a certain period of time (Raganelliab, 2017).

Concluding the above, seismic risk can be defined as the interaction of three parameters: seismic hazard (e.g. an earthquake of magnitude 7.0 or greater with a recurrence interval of 50 years), exposure time (e.g. design life of a bridge is 100 years) and vulnerability (e.g. cost of collapse of a particular building) as show in Fig.1.

The importance of the seismic hazard in the assessment of the seismic risk is given by expression (1) (Jia, 2017):

$$P(R_i) = \sum_{j=1}^{J} P(R_i|S_j)P(S_j) \qquad (1)$$

where:

$P(R_i)$ - the probability that the system is at state *i* with a total *j* states;

S_j - the seismic hazard is at level *j*;

$P(S_j)$ - probability that the seismic hazard is at seismic level *j*;

- the probability that the system is at the behavior state R_i, given that the seismic hazard *Sj* takes place.

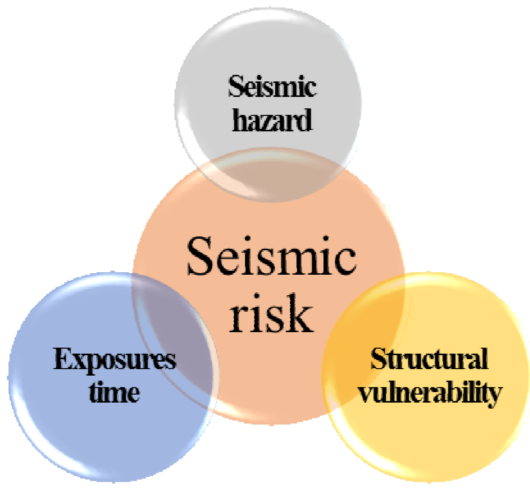

Fig. 1. Seismic risk

A high seismic risk does not involve a high seismic hazard and vice-versa. The lack of preventive measures in regions with low seismicity leads to an increased vulnerability of the infrastructure, which induces the increase of seismic risk level. The concept of "acceptable risk" is provided by many seismic provisions in order to balance the cost of seismic-resistant structures, beside the possibility of appearance of unacceptable losses in future earthquakes. An appropriate and widely-adopted method to account for the seismic risk in the assessment of infrastructure protection is to develop safety criteria in which the hazard is determined probabilistically as a function of the potential consequences of failure.

The establishment of the seismic risk level for a building is based on combination of the main parameters: bedrock properties, ground acceleration, control period of the response spectrum, exposure level and other factors mentioned in seismic design codes and guidelines.

2. SEISMIC RISK ASSESSMENT

The strongest earthquakes in Europe occur due to tectonic plate movements. The tectonic fault lines extend from Iceland, located in the north of Europe, on the Mid-Atlantic-Ridge, down to the southeast zone, to the North-Anatolian Fault (Turkey) as illustrated in Fig. 2. The effects of earthquakes are much more disastrous for countries with high population density, such as those in the Mediterranean area, including Turkey, and the Balkans.

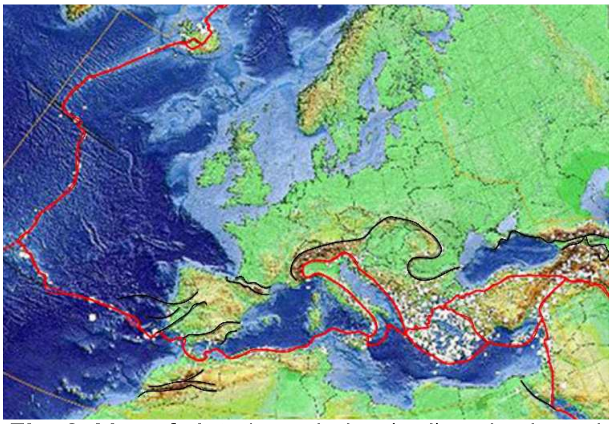

Fig. 2. Map of plate boundaries (red) and selected first order fault (black) in the European region (Oskin, 2012)

For example, the earthquake in Iceland, produced in 1784, with an estimated moment magnitude of 7.2 M_w, has caused serious damage to farmhouses, generating three human losses. At the same time, one of the recent earthquakes in central Italy, produced in august 2016, with the magnitude of 6.2 M_w, resulted in 299 deaths, serious damage to an entire city, leaving 4500 homeless. In the last decades, the disasters produced by the earthquakes recorded in Southern Europe and Turkey have caused the death of thousands of people.

The notion of disaster risk expresses the potential loss of human lives, economic crushes and other consequences that can occur in a community within a certain timeframe. Disaster risk assessment describes a qualitative approach of this phenomenon, with the aim to determine the nature of the event and estimate the magnitude of the consequences on society through a meticulous analysis of the existing conditions of manifestation. Disaster risk management is quantified by the application of appropriate policies and strategies required to prevent and reduce disaster risk, manage residual risk, thereby enhance the resilience of the system (Jaramillo *et al*., 2016).

European policies on disaster management have the purpose to achieve a high level of mitigation, to protect people, environment and property. This goal can be attained only through cooperation among countries, together with local authorities, in order to elaborate prevention, preparedness and response actions. As well-known, the prevention is the most cost-effective and can play even the role of a driver for economic growth, and it is granted more attention in the disaster management cycle.

According to the statements issued by the Union Civil Protection Mechanism, the earthquakes are the fourth most common hazard after flooding, extreme weather and forest fires, 19 European countries having performed seismic risk assessment actions. The Balkans, Italy, Greece, Romania, Bulgaria and Turkey are among the most exposed to earthquake regions of Europe.

There are two strategic ways to reduce seismic risk: improvement of emergency response and adequate design of structures in affected areas (Gountromichou *et al*., 2014).

Improving emergency response capability can be achieved by: training people about preparedness, planning and response in disaster, developing an appropriate infrastructure to ensure that emergency services have access to affected areas and implement modern early warning technologies.

Population training must be carried out from school institutions through various national programs, including various simulations, to avoid panic amongst the participants.

The development and implementation of a sustainable infrastructure is the task of local / regional authorities, which must take into account area specificity, population density and development prospects.

The modern technologies aimed to early warning transmit almost instantaneously a triggered earthquake. The difference between the arrival time of longitudinal waves and of destructive transversal waves provides a period of time for safe evacuation. The application of early warning systems requires the existence of a seismic monitoring network across the whole vulnerable territory, for a faster identification of the epicenter and of the wave propagation direction. The human and automated systems can use this short time delay to take the necessary measures for life and property protection.

This set of actions is indispensable to organize the efficient emergency management, as well as to put forward relevant seismic risk mitigation measures to improve the degree of preparedness and to ensure the resilience of the urban system.

Performance based seismic engineering both reduces the risk of human loss and improves the efficiency of structures in seismic areas. The main way to take performance-based decisions consists in assuming that risk and safety are by-products of design.

It is relevant to highlight the essentiality of building codes in order to achieve a sustainable design, and the difficulty to enforce on extended areas. The performance level of the standards is linked to the effective development of the region, as it involves major investment in research.

The European codes EN (Eurocode), comprise 10 standards, EN 1990 - EN 1999, which provide a common conceptualization about civil engineering design, and demonstrated to be a reliable mechanism for mitigating seismic risk (Follesa *et al.*, 2018).

3. EXAMPLES OF SEISMIC RISK MITIGATION PROGRAMS

Even if earthquakes cannot be accurately predicted, the disastrous consequences produced by human loss, economic and social damage can be minimized with the implementation of an appropriate infrastructure and with the establishment of a set of requirements for seismic design. Furthermore, warning people about earthquake risk and getting proper emergency response can have positive results. An earthquake risk mitigation plan is a vital investment for every seismic region. In this paper, models of seismic risk mitigation programs for Turkey, Greece and Romania are presented.

3.1. Turkey

Turkey sits on one of the most seismically active zone in the world due the location at the junction of African, Arabian and Eurasian plates. Its territory is situated above the Anatolian plate, and border with East and North Anatolian Fault zone. The last has a length over of 1,400 kilometers and is moving with a rate of 24 millimeters per year. Likewise, the country is adjacent to the Aegean-Cyprian Arc and the Dead Sea fault zone (Kayabali and Akin, 2003). The seismic map of Turkey in terms of peak ground accelerations is represented in Fig. 3

It has been estimated that 81% of Turkey's population is exposed to least two hazards types, such as earthquakes, floods or landslides. Earthquakes have the greatest impact on people lives and cause material damage.

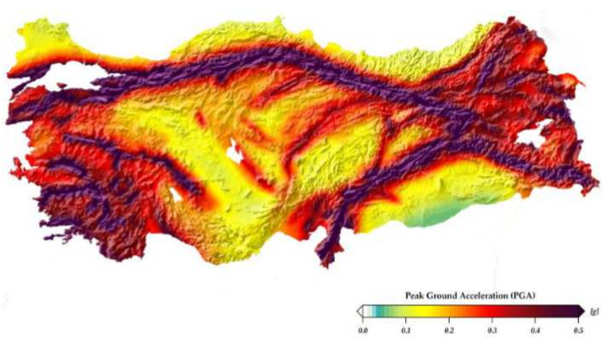

Fig. 3. Seismic map of Turkey (Akkar *et al.*, 2017)

The most recent destructive earthquake produced in the North Anatolian fault area occurred in the Marmara region, near Izmit, on 17 august in 1999, at 03:02 local, with a magnitude Mw = 7.4 and a depth of 17 km. The earthquake lasted 45 seconds causing over 17,480 human losses, about 44,000 people injured and approximately 300,000 homes seriously damaged or collapsed. A similar earthquake occurring near Istanbul would be catastrophic, according to seismic scenarios; it could cause more than 50,000 deaths and of more than $ 60-70 billion economic losses.

The seismic hazard of Tukey led to indispensable risk mitigation programs. A first step of implementation was the development of a dense seismic network of 240 stations, able to record strong ground movements. For example, the metropolitan area of Istanbul is monitored by more than 100 accelerometers with dial-up transmission of information, generating a fast response. The entire network constitutes the Early Warning and Quick Response System.

Another approach of seismic risk mitigation programs provides the necessary measures which should be taken to retrofit and reconstruct public buildings from education and health sectors, these being considered as a priority by the importance in a post-disaster phase.

An important factor was the improvement of communication systems, information management systems and the ability to manage emergency situations.

The framework of the seismic risk mitigation program is outlined in Fig. 4.

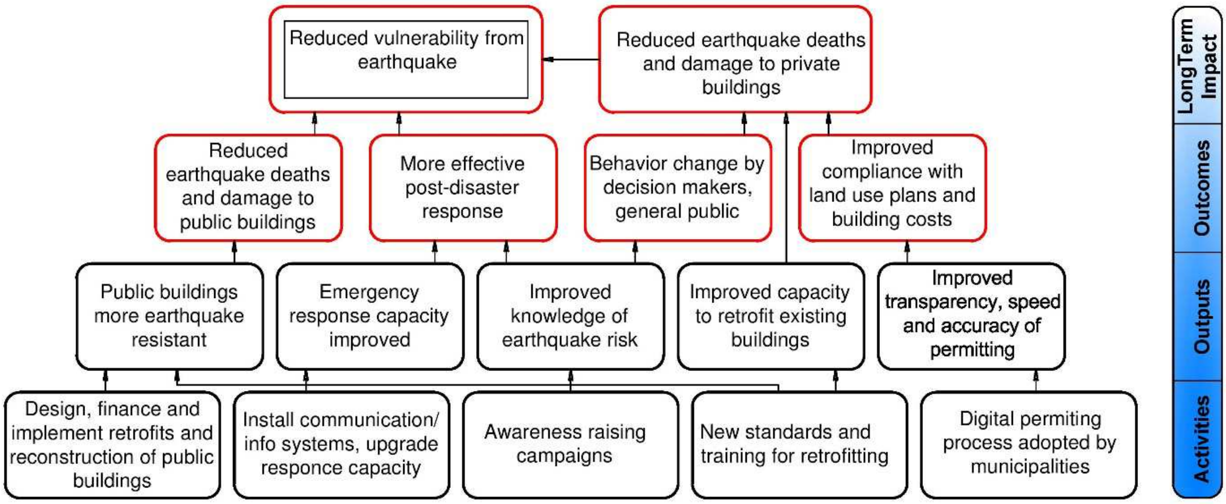

Fig. 4. Seismic risk mitigation program (Heider *et al*., 2018)

3.2. Greece

Greece seismic activity is underlined by the archipelagic nature, consisting of about 3000 islands. Although the frequency of earthquakes is high (about 20 of magnitude greater than 6 were recorded between 1900 and 2018), most of them are of low intensity and do not cause serious damage, having epicenters beneath the sea and often affecting only the surrounding islands.

The most destructive earthquake that hit Greece during the last decades occurred in 1953, with a 7.2 magnitude on the Richter scale; the seism affected the islands Kefalonia, Zakinthos and Ithaki. The consequences were catastrophic: 456 dead, 2412 injured, 27659 collapsed buildings of a total about 33000 (Gountromichou *et al*., 2014).

All the above figures point up the need to implement a seismic risk mitigation program, in order to ensure a sustainable development of the Greek society. This program focuses on two major directions (Nikos, 2016):

- Actions that need to be undertaken before the quake – measures for preparedness, planning and awareness, in order to minimize the earthquake risk.

- Actions that should be taken after the quake – measures for the efficient treatment and management of emergency situations, targeting particularly in the relief and housing of earthquake victims and in the rehabilitation of affected areas. An example of policy in risk management planning and preparedness for seismic disaster is shown in Fig. 5.

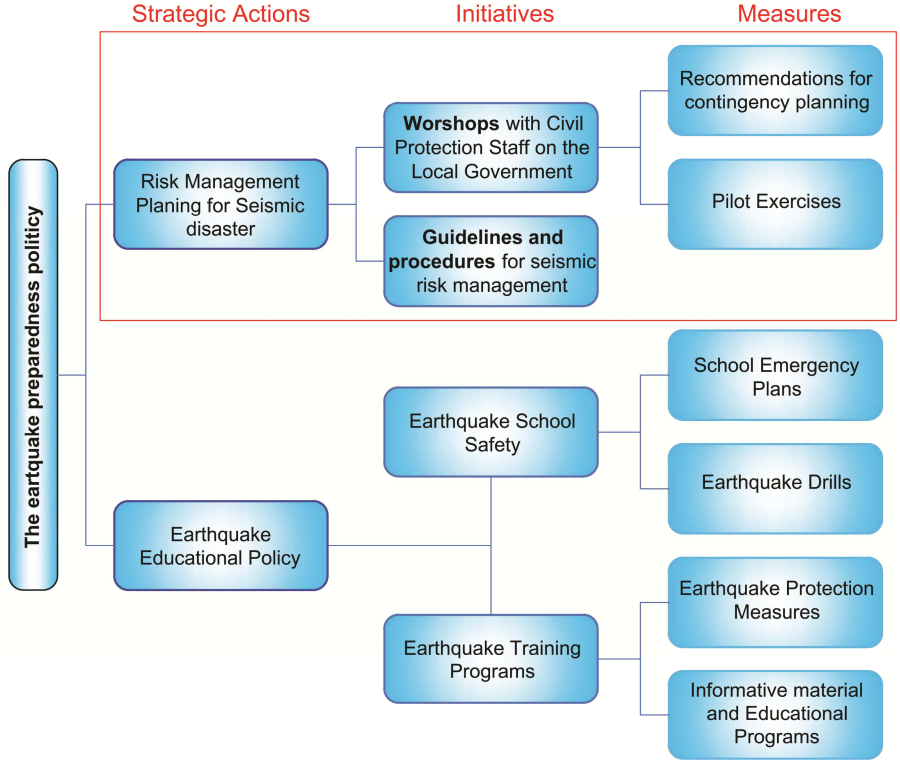

Fig. 5. Seismic disaster preparedness policy in risk management planning – Greece (Gountromichou *et al.*, 2014)

Two specific services were created to apply the antiseismic policy in the country:

- The Earthquake Planning and Protection Organization, with the aim to develop the plan of preventive activities and first measures after the earthquake.

- The Earthquake Rehabilitation Service, with the purpose to arrange the temporary or permanent housing for victims and the rehabilitation of affected areas. A model of temporary housing is given in Fig. 6.

Fig. 6. Modular prefabricated houses for affected regions, (Nikos, 2016)

Greece's seismic monitoring service started since 1893, the first seismic network being operated with 5 stations. At the beginning of 2006, a national project was launched to unify the seismological networks of the Greek institutions - "Hellenic Unified Seismological Network - HUSN". HUSN, together with the National Athens Observatory (NOA) and the Institute of Geodynamics (IG) as coordinators and the three University Seismic Networks (Athens, Thessaloniki and Patras) follow in real time the data from more than 150 stations (Fig. 7). In this way, appropriate conditions have been created for (Papanikolaou *et al.*, 2019):

– continuously receiving detailed and reliable information;
– the possibility of making common observations on seismicity and the exchange of all elements available between institutions;

– collecting data for research and the possibility of direct transmission to the scientific community for a thoroughly study of the country's seismicity;
- increasing the data recording performance of seismic activity in the extended area of Greece;
- unified calculation of seismic parameters.

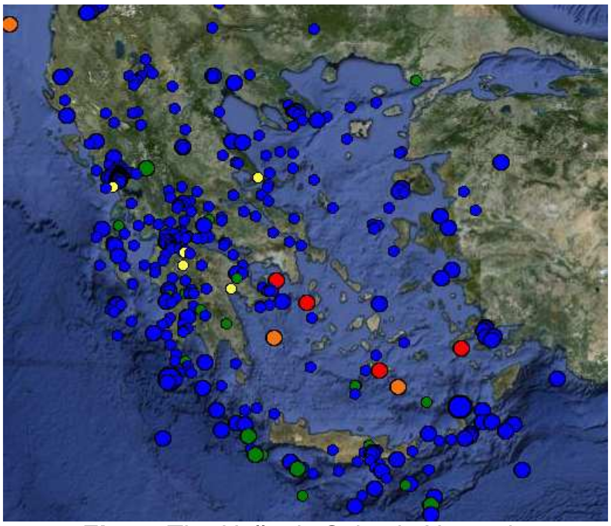

Fig. 7. The Hellenic Seismic Network, (Papanikolaou *et al.*, 2019)

3.3. Romania

Romania's seismogenic zone, with the highest destructive potential, is located in Vrancea, at the curvature of the Oriental Carpathians, in the subcrustal lithosphere. On the territory of the country there are also superficial seismic sources: Câmpulung, Maramureş, Bârlad depression, Predobrogean depression and other regions of local significance for seismic hazard.

Bucharest is one of the most exposed European cities to seismic hazard due to its geographical location, about 140 km far from the Vrancea region. The earthquake on March 4, 1977, with a magnitude of 7.2 on the Richter scale, has caused enormous damage to the country, the capital city being the most affected: over 1300 deaths recorded, 36 multi-storey buildings collapsed, more than 150 severely damaged old buildings (Balan *et al.*, 2014). At the same time, it should be noted that only in 1977 the first accelerogram of a strong Romanian earthquake was achieved. The recording was done by INCERC Bucharest, with a SMAC-B-type Japanese accelerometer. This represented the first real ground motion record used to analyze the frequency content of the Vrancea earthquakes. The obtained results contributed to the fundamental revision of the Romanian seismic design code.

At the moment, the seismic monitoring of Romania is carried out by two institutions:

- The seismic monitoring network of the National Institute for Earth Physics (NIEP), with 86 seismic registration points, from which the recorded data is transmitted in real-time to the headquarters, where they are automatically processed.
- The seismic monitoring network of the National Institute of Research and Development in Construction, Urban Planning and Sustainable Territorial Development (NIRD URBAN-INCERC), that owns 55 accelerometers and seismic stations distributed throughout the country - Fig. 8 (Dragomir *et al.*, 2015).

In 2003, as a result of the collaboration between NIEP, NIRD URBAN-INCERC and the public authorities, it was possible to create a single database of the strongest registered earthquakes: March 1977, August 1986 and May 1990.

Fig. 8. The distribution of seismic stations in RNS of NIRD URBAN INCERC on the territory of Romania (Dragomir *et al.*, 2015)

The seismic risk mitigation program is developed annually by the national public authorities, based on the analysis of the priorities established by county councils and county committees for emergency situations (Bălan *et al.*, 2014).

The implementation of advanced technologies, make possible a rapid earthquake magnitude estimation, which allows earthquake warnings to be emitted within 5 seconds of detection of epicenter location, generating a useful 20-27 seconds time interval to initiate preventive actions.

At the current time, three programs of building retrofitting are in progress (Bortea, 2019):

- A multi-storey residential building retrofitting program - which aims to retrofit residential buildings, classified as class I of seismic risk;
- The first emergency response program for vulnerable buildings - which involves the elimination of the risk of collapse of building elements and the minimization of the effects of landslides;
- The Risk Mitigation Project for Natural Calamities and Emergency Preparedness" - Component B - Seismic Risk Reduction – which develops a strategic approach to actions meant to prevent and mitigate the effects of natural disasters.

4. CONCLUSIONS

A proper perception of the earthquake destructive potential contributes to ensure the sustainable development of the society located in affected areas. The appropriate assessment of possible damage is an essential step to develop an applicable protection strategy. The seismic risk mitigation becomes a national priority, which involves a considerable effort and a close collaboration of all stakeholders.

The earthquake lessons have been hardly learned by modern society, due to the limited capacity to predict the place, the time and the intensity of such event. The caused damage is enormous for the civilization: loss of human lives, economic environment, and cultural heritage. An earthquake lasting for several tenths of seconds can generate losses which should be recovered in decades after its occurrence.

Each country develops in its own way; the required measures to reduce the seismic risk are specific for each region, based on the data collected during the monitored period.

It is already well-known that "nature has its own rules", regardless of the society development level, implemented reforms or highest technology. Natural calamities occur under an unresolved law. And the efforts made by the anthropic factor can aim only to prevent or to reduce their effects and in no way to cancel their occurrence.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge that an adjusted part of this paper was accepted for publishing on the 15th edition of the research conference on constructions, economy of buildings, architecture, urban and territorial development of NIRD URBAN-INCERC.

REFERENCES

1. Akkar S., Azak T., Çan T., Çeken U., *Updated probabilistic seismic hazard maps for Turkey*, report PSHA Workshop, Lenzburg Switzerland, 2017.
2. Bălan Ș.-F., Alcaz V., Trifonova P., Uker N., *Rețeaua de siguranță în caz de cutremur de la Marea Neagră*, Editura Press, București, România, 2014.
3. Borțea N., *Prezentarea programelor privind reducerea riscului seismic - actiune de interes national*, http://www.mdrap.ro/ro/constructii/siguranta-post-seism-a-cladirilor/programe-de-prevenire-a-riscului-seismic, 2019.
4. Choudhury P., Chopra S., Kumar M-R., *A review of seismic hazard assessment of Gujarat: A highly active intra-plate region*, Earth-Science Reviews 187:205-218, 2018.
5. Dragomir C.-S., Georgescu E.-S., Craifaleanu I.-G., Dobre D., Alecu C.-P., Cișmelaru A., *Infrastructura INCD URBAN-INCERC dedicată monitorizării seismice a amplasamentelor situate în zone urbane*, în Lucrările conferinței de cercetare în construcții, economia construcțiilor, urbanism și amenajarea teritoriului, ediția a X, 16 octombrie, București, România, 2015.
6. Farzan N, The seismic design handbook, Springer Science + Business Media, New York, USA, 2001.

7. Follesa M., Fragiacomo M., Casagrande D., Tomasi R., Rossie S., *The new provisions for the seismic design of timber buildings in Europe*, Engineering Structures 168:736-747, 2018.
8. Georgescu E.-S., *Urbanism, Arhitectură şi Construcţii în zonele seismice din România - de la blocul Carlton la faţadele cortină*, Urbanism, Arhitectură şi Construcţii 1(1):37-50, 2010
9. Gountromichou C., Manousaki M., Doga A., Lekkas E., *Seismic disaster preparedness policy in risk management planning – Greece*, in Second European Conference on Earthquake engineering and Seismology, 25-25 August, Istanbul, Turkey, 2014.
10. Heider C., Martinez J., Makino M., Hutton S., *Istanbul seismic risk mitigation and emergency preparedness project*, report World Bank Group, Washington, USA, 2018.
11. Jaramillo N., Carreño M.-L., Lantada N., *Evaluation of social context integrated into the study of seismic risk for urban areas*, International Journal of Disaster Risk Reduction 17:185-198, 2016.
12. Jia J, *Modern Earthquake Engineering*, Springer-Verlag GmbH, Berlin, Germany, 2017.
13. Kayabali K., Akin M. (2003), Seismic hazard map of Turkey using the deterministic approach, Engineering Geology 69(1):127-137.
14. Nikos B., *Good practice. Mitigation planning for earthquakes in Greece*, report MiSRaR, Epirus, Greece, 2016.
15. Oskin B., *New European Earthquake Catalog Offers Clues to Future Risks*, https://www.livescience.com/22559-earthquakes-europe-history.html, 2012
16. Papanikolaou D., Nomikou P., Papanikolaou I., Lampridou D., Rousakis G., Alexandri C., *Active tectonics and seismic hazard in Skyros Basin*, North Aegean Sea, Greece, Marine Geology 407:94-110, 2019
17. Raganelliab L., *From the risk integral to seismic PSA models. Practice and limitation of seismic risk assessment*, Energy Procedia 127:154-162, 2017.
18. Šipoš T.-K., Hadzima M., *Rapid seismic risk assessment*, International Journal of Disaster Risk Reduction 24:348-360, 2017.