Hazard Risk Mitigation for a Sustainable Built Environment

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Abstract. The aim of this study is to collect and review resources that map the hazard risk mitigation strategy for transferring research knowledge in the field on sustainable rehabilitation of the built environment.

Natural disasters occur all over the world and impact on large or small land areas. This study makes a brief review on the nature of disasters, but also the impact and consequences of such hazards on the built environment. It also investigates the need to manage and mitigate the hazard risk for a sustainable rehabilitation and reconstruction of the built environment.

This paper presents the concept of hazard risk mitigation for a sustainable built environment, analysing the most dangerous types of environmental hazards causing important social and economic damage in Romania: earthquakes, landslides and subsidence, storms and tornadoes, highlighting imperative risk mitigation actions. It also screens temporary measures solving immediate issues, restoration of services, rehabilitation of structures, several case studies and scenario-based mitigation measures.

Keywords: Hazard risk · Mitigation strategy · Sustainable rehabilitation · Built environment

1 Introduction

1.1 Overview of the Term Disaster

The term 'disaster' refers to the impact of different complex hazards on vulnerable communities [14, 74]. It includes disasters associated with extreme natural events such as earthquakes, hurricanes or volcanic eruptions [36]. Hazards can be classified in a wide diversity of typologies, with the objective of optimization of preventive measures (Fig. 1).

A significant part of development assistance spent on the construction of infrastructure gets lost in seconds in the event of a hazard event [86]. The majority of human and economic losses from a hazard event occur either as a result of damage to the built environment or ineffective early warning and evacuation systems [65]. The negative

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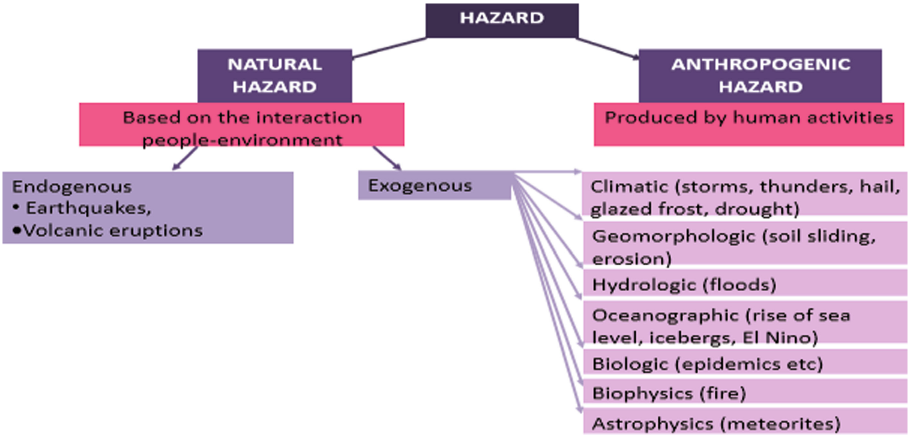

Fig. 1. Hazard typology

impact of hazards on communities can be mitigated by taking hazards into account when selecting sites, or designing/strengthening the infrastructure [76].

Hazard mitigation describes actions taken to reduce long-term risks caused by hazards or disasters, such as flooding, earthquakes, volcanic eruptions, tsunamis, cyclonic storms, wildfires, landslides, droughts dam failure, etc. [28, 66]. Each year, 130,000 people are killed, 90,000 are injured and 140 million are affected by natural disasters [2, 79]. Even though the costs of mitigating disasters continue to rise, governments as well as common citizens must find ways to reduce hazard risks. Hazard risk mitigation is an important component of the planning effort once communities plan for a sustainable built environment [75, 77, 81].

Hazard mitigation is essential after a disaster when repairs and reconstruction simply restore damaged property to pre-disaster conditions to get the community back to normal [15, 23]. However, the replication of pre-disaster conditions may result in a repetitive cycle of damage – reconstruction – repeated damage, the recurrent reconstruction becoming more expensive as the years go by. Hazard mitigation takes a long-term view of rebuilding for a sustainable built environment breaking this repetitive cycle. The implementation of such hazard mitigation actions leads to building stronger, safer and smarter to reduce future injuries and damage [16]. To design a disaster-resistant built environment is a successful way to mitigate losses of life and property [17].

A whole lot of techniques are applicable to mitigate the effects of hazards on the built environment [70]. The structure can be designed to resist hazard consequences depending on the hazard nature, location, construction type, and the specific requirements for the building. Later in the life cycle of the building, when incorporating disaster reduction measures into building design, additional opportunities to mitigate the risk from natural hazards may apply to protect lives and properties from damage [39, 41].

Hazard can be described by statements of ‘what’, ‘where’, ‘when’, ‘how strong’ and ‘how often’, demanding knowledge of fluctuation in both spatial conditions and temporal behaviour. The level of risk is the combination of the likelihood of something adverse occurring and the consequences if it does. The level of risk results from the intersection of hazard with the value of the elements at risk by way of their vulnerability (Fig. 2).

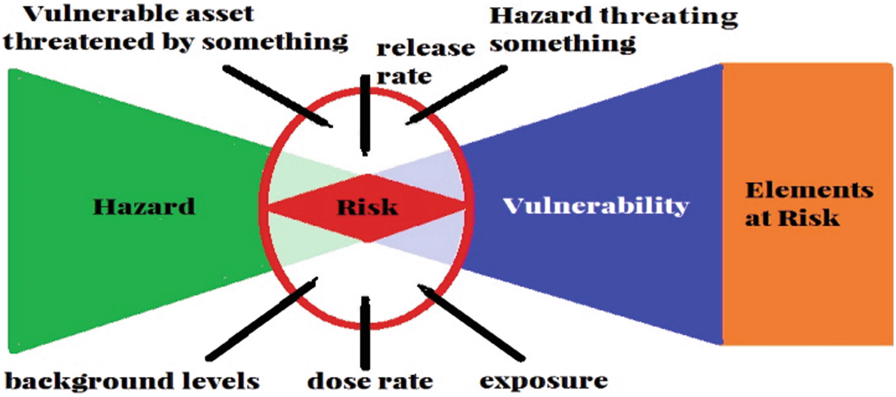

Fig. 2. Relationship between hazard, elements at risk, vulnerability and risk (after Alexander, 2002)

The wide discrepancy in losses has focused attention on the role and causes of vulnerability. The dominant view, referred to by scientists as the ‘behaviourist’ paradigm [2], attributes vulnerability to a lack of knowledge, insufficient preparedness and inappropriate adjustment to specific hazards. On the other hand, the ‘structuralist’ paradigm attributes vulnerability to disempowerment of the victims through political-economic structures that favour the elite at the expense of the mass of population. The denial of resources means that the affected populations can do little to improve their level of vulnerability. This view sees ‘underdevelopment’ in some countries as a product of ‘development’ in others [1].

2 Study on Several Types of Environmental Hazards

Natural hazards can be classified into: endogenous and exogenous hazards.

Endogenous hazards are generated by the energy coming from inside the planet such as volcanic eruptions and earthquakes.

Exogenous hazards are generated by climatic, hydrological, biological, etc., from where the following hazard categories result: geomorphological, climatic, hydrological, natural biological, oceanographic, biophysical and astrophysical.

Geomorphological hazards encompass a wide range of processes, such as collapses, landslides, avalanches. The most numerous landslides are recorded on the slopes with moderate inclinations, consisting of clays and alternations of clays, marls, tiles and sands. Anthropogenic causes, related especially to deforestation, play an important role.

Climatic hazards encompass phenomena and atmospheric processes that result in loss of human lives and environmental damage. The most common are the storms: 16

million storms occur annually on the earth resulting an average of 44,000 per day and 2,000 per hour. On the other hand, severe drought can lead to a reduction in water reserves from rivers, lakes and wells, which capture groundwater reserves, and causes a decrease of the harvests. Between 1876 and 1879, China was affected by drought killing 9 million people. Africa was hit by a severe drought between 1981 and 1984, which resulted in starvation of over 1 million people. Since 2011, East Africa has been hit by a new drought wave that threatens the lives of over 9.5 million people.

2.1 Earthquakes

The most frequent and violent seismic disasters occur in the 2 major belts of the world: the European and South Asian Alpine Belt and the Circumpacific Belt, where the degree of seismicity is the highest.

Building design will often be influenced by the level of seismic resistance desired. Even though the primary focus of earthquake design is initial life safety and getting people out of the building safely, this level can range from prevention of non-structural damage in occasional moderate ground shaking to prevention of structural damage and minimization of non-structural damage in occasional moderate ground shaking, and even avoidance of collapse or serious damage in rare major ground shaking. These performance objectives can be accomplished through a variety of structural engineering measures or structural components like shear walls, braced frames, moment resisting frames, and diaphragms, base isolation, energy dissipating devices such as visco-elastic dampers, elastomeric dampers, and hysteretic-loop dampers, and bracing of non-structural components [3, 13].

According to the geology of the earth there are areas on the globe with high seismicity where earthquakes are very frequent. The vulnerable countries developed sustainable measures in order to minimize losses by building adequate structures and preparing the population to react in case of a natural disaster. Considering the seismic hazard map, Romania is considered among the three most seismic countries from Europe due to Vrancea sesmic zone, one of the most active seismic areas in Europe.

In the list of most severe earthquakes occurred on the globe are the followings: China (1976), Indian Ocean (2004), Pakistan (2005), Haiti (2010), New Zealand (2011) and Japan (2011).

The great earthquake in Tangshan, China occurred on July 28, 1976 and was considered the most devastating earthquake of the 20th century, producing over 240,000 dead and 164,000 injured. On December 26, 2004, an earthquake with a magnitude of 9.15 on the Richter scale strike in the Sumatra-Andaman area. The earthquake, which lasted about 10 s, produced a tsunami wave that killed about 310,000 people on the coasts of Indonesia, Sri Lanka, South India and Thailand. The earthquake from Pakistan on October 8, 2005, with a magnitude of 7.6 on the Richter scale, had the epicentre in Kashmir and produced 75,000 dead and approximately 106,000 injured. The large number of damages revealed an inaccurate building configuration to earthquake, the country needing aids in the amount of $ 5.4 billion for the post disaster measures. The Haiti earthquake of January 12, 2010, with a magnitude of 7.0 on the Richter scale, with the epicentre in Port-Au-Prince, had 59 replications with magnitudes between 4.2 and 5.9 on the Richter scale, Fig. 3.

Fig. 3. Earthquakes in Haiti (2010), New Zeeland (2011), Japan (2011) (from left to right)

The need of efficient anti-seismic restrictions in the design code is sustained by the losses occurred: over 200,000 dead and 3 million people affected by this event. A total amount of over $ 300 million was needed to restore order after the disaster.

Less than 6 months after, the Darfield earthquake of September 4, 2010 with an intensity of 7.1° on the Richter scale, which did not result in significant damage, occurred on February 22, 2011, in Christchurch, an earthquake with a magnitude of 6.3 on the Richter scale, which was ranked second in the number of victims in New Zealand (185 dead, 238 missing and 164 injured). Old masonry buildings were mainly affected, but also the collapse of new buildings such as the one of the Local Television, Fig. 3. Land liquefaction, produced as a side effect of this earthquake, was another factor that led to the increase of the recorded damages, which were estimated at a total of 16 billion dollars [49, 60].

The most powerful earthquake in Japan so far, with a magnitude of 9° on the Richter scale occurred on March 11, 2011, Fig. 3. Strong ground accelerations were recorded in the prefectures of Miyagi, Iwate, Fukushima and Ibaraki to the east, where a huge landslide occurred. Initial research on the dimensions of this slip revealed that the difference between two points on opposite sides of the ridge reached 30 m. The maximum displacement of the land exceeded 100 cm in the Sendai area and 50 cm in the area from Tohoku to Kanto. It produced about 15,000 dead and injured, over 250,000 buildings damaged and was close to producing a nuclear disaster, affecting reactors at the Fukushima power plant [71, 72].

More recent events occurred in Nepal on April 25th, 2015, respectively on February 5th, 2016 in Taiwan. The Taiwan earthquake revealed severe irregularities in the execution process.

Earthquakes destroy engineering constructions in different ways, such as: huge inertia forces induced in structures due to the seismic motion; physical changes of the foundation soil properties (consolidations, settlements, liquefiers); fires; landslides; changing the topography of the land; earthquake-induced waves (tsunamis or tides); direct displacement of the fault on the ground level [59].

Even though Romania's territory is subjected to different natural calamities such as floods, drought, earthquakes and landslides, the event that caused the largest number of dead and required the most financial support to recover from is the March, 4th, 1977 earthquake. Even though not all the earthquakes had serious effects, the seismic risk in

Romania is important [48], being considered the third country in Europe, after Italy and Turkey, according to the number of people lost due to earthquakes in the 20th century. Bucharest is ranked as the tenth capital in the world in terms of seismic risk, being the city with the largest seismic exposure in Europe.

The most active crustal seismic regions in Romania are the Făgăraș and Banat seismic zones, which were highlighted by: the last major earthquake in Făgăraș occurred in January 1916 (estimated magnitude 6.4), respectively in 1991 in the Banat seismic zone with magnitudes of 5.6-5.7. The most powerful crustal earthquake in Romania is considered to be that of October 26, 1550, in the Făgăraș area, having an epicentral intensity of 9 on the MSK scale and a magnitude of 7.2 on Richter scale Lungu et al. [42].

The strongest earthquakes in our country, which cause great material damage, are recorded in Vrancea seismic region, located in the region of the Carpathian curvature. Such earthquakes, which caused numerous human lives losses, were recorded on November 26th, 1802, November 10th, 1940 and March 4th, 1977. Figure 4 shows the epicentres in Romania from 1984 - January 2013 according to the National Institute of Earth Physics, INFP.

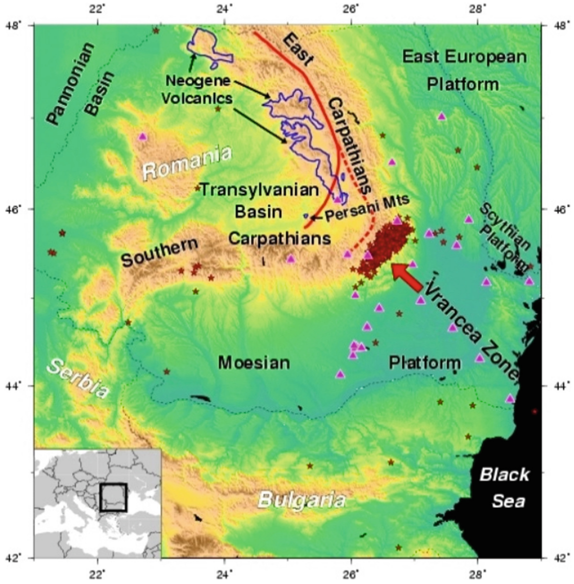

Fig. 4. Earthquakes epicentres recorded in Romania between 1984 and 2018 (Catalogue, INFP)

Earthquakes from Vrancea which occur at big depths can reach magnitudes of 7.6–7.7° on the Richter scale, while the crustal earthquakes are much smaller, rarely reaching 5.2–5.4° on the Richter scale [42]. In terms of effects, deep earthquakes are more important. Due to the great depth at which they occur, the remarkable properties of the focal mechanisms that determine a preferential directivity of the breaking process, as well as the nature of the soil, the effects of Vrancea earthquakes are felt at great distances from the epicentre [58, 73].

As a rule, the most serious consequences were reported not in the area near the epicentre, but on both sides, towards the North-East, in the direction of Focșani - Iași - Chisinau and to the South-West, in the direction of Bucharest - Zimnicea - Sofia. A characteristic of earthquakes from Vrancea region is that they feel weaker within the Carpathian Arch Bălat et al. [6].

The shallow crustal earthquakes have local effects, much limited in area, although in some cases they can be felt quite strongly in their epicentre areas, especially in the area of Focșani, Râmnicu Sărat [68]. Currently, in Romania, several national networks for seismic activity recording exist: - the national network for constructions RNSC, of the National Institute for Research and Development in Construction and Sustainable Territorial Development (URBAN-INCERC); CNRRS (National Centre for Seismic Risk Reduction) network, which works in partnership with the RNSC network; the INCDFP network (National Institute for Research and Development for Earth Physics) and GEOTEC network (Institute of Geological and Geophysical Studies).

Earthquake Risk Mitigation Actions. The fundamental problem or earthquake risk mitigation is not to find any solution, but to find a “best” solution. What is best usually depends on the circumstances, value and priorities of individuals, enterprise, authorities.

In an ideal world, all buildings have to be strong enough to withstand to any seismic action and damages must not occur. The main drawback of this idea is the higher cost of the structure, which is required in order to guarantee the safety and the stability of the building.

In the real world is not possible to provide maximum safety with no damages for all kind of buildings because the financial resources are limited. Thus, some compromises have to be made in order to keep the cost on a reasonable level.

The legislation from different countries adapt the earthquake risk mitigation according with the importance of the buildings. For vital buildings (like hospitals), no damage is accepted because victims have to be treated in them after a major earthquake.

A second category consist in buildings which are considered very important for the society. National museums, historical monuments and similar buildings have to be preserved and only minor damage is accepted in case of a big earthquake.

For regular buildings, in order to decrease the price of the structure, the best solution consists in the protection of human lives and goods. Damage is accepted in the structure but the stability of the building has to be guaranteed in order to avoid human losses and goods damage.

Last category of buildings involves low importance structure when the value of goods is small. In this case, a large financial investment in the structure is not rational because exceeds the value of the stored goods.

In case of an earthquake there are some general recommendation that people should consider so that the number of injures and human losses to be significantly reduced. Among these are: identifying the safest place to stay; create a correct mitigation plan with your colleagues and family in case of an earthquake; stop, if possible, gas and energy supply [25, 32]; do not use elevators or stairs; if you are in a public place, try not to run in order to avoid panic which can lead to accidents. The most common surviving technique in case of an earthquake is “duck, cover and hold”.

Unfortunately, these measures do not prevent structures to be damaged or even to collapse in case of a seismic action. For this, the government of each country has a specific department which is responsible for the seismic risk mitigation [48]. In many countries, due to the change of the code, the authorities started to evaluate the seismic vulnerability of buildings designed before the current restrictions. In Romania for example, there is a code that combines geometric figures with color, which shows the vulnerability state of a structure. The most dangerous constructions are marked with a red circle. This means that urgent rehabilitation works should be performed on the building. Unfortunately, not a lot is happening, because there is not a plan regarding on who should finance the works: the authorities or the owners.

The changes into the new codes represents an important action from the seismic risk mitigation. Adopting the new code provisions should reduce earthquake damage risk.

Another approach on the seismic risk mitigation refers to developing more accurate hazard maps. Research all around the world is focusing on probabilistic maps, instead on the old deterministic ones, emphasizing their benefits. A probabilistic seismic map considers more seismic action, with different characteristics, meaning that is based on more magnitudes, more epicentre depths, different frequencies, in contrast with the classical one which considered only one dangerous event. Also, researchers started to connect different hazards on the same map in order to offer a multi hazard perspective on the area. The main benefit of this is that secondary effects of an earthquake can be known ahead and complex measures can be considered. For example, if an earthquake occurs in an area vulnerable to landslides, when the seismic risk mitigation plan is done, the secondary hazard is also considered and terrain reinforcing works could be performed prior to the seismic action in order to diminish losses.

The potential damage of the critical facilities and infrastructure would be significantly reduced through actions such as: retrofitting public facilities [34], requiring bracing of generators, elevators or other vital equipment in hospitals, reviewing bridges state to determine their susceptibility to collapse and retrofitting the problematic ones, use of flexible piping and installing shutoff valves and emergency connector where necessary (FEMA, 2013).

Raising awareness through the population and educating people at a young age regarding seismic risk, would, on long term, reduce damage. This can be reached by the help of the insurance industry, by developing outreach programs on earthquake risk and mitigation activities in homes, schools and offices; and educating house owners. In the same direction, people responsible for a building, from the design stage to the demolishing should be made aware of proper design and building requirements.

Making a guide for the public with retrofitting measures for structural and non-structural elements can help owner to identify problems in homes or workplaces and take the necessary measures to repair the damage by calling an authorized worker or, if it is not very complicated, doing it by themselves.

Sometimes, earthquake insurance can also be an effective method to mitigate financial loss, even though it does not cover life loss or injury, and typically only partial offsets primary financial loss (SSC Report 99-04, 1999).

2.2 Landslides and Subsidence

Landslides and subsidence present a threat to life and livelihood throughout the world, ranging from minor disruption to social and economic catastrophe.

Landslides generate a small but important component of the spectrum of hazard and increasing risk that faces mankind. For landslides, the ‘adverse something’ might be a large rockslide and its ‘likelihood’ expressed as the probability of its occurrence [21]. Similarly, the consequences will depend on what is affected by the landslide, the degree of damage it causes and the costs incurred. It is the intersection of humanity with landslide activity that has recast a natural land-forming process into a potential hazard [20].

Ground subsidence can result from mining, sinkholes, underground fluid withdrawal, hydrocompaction, and organic soil drainage and oxidation [53]. Subsidence mitigation can best be achieved through careful site selection, including geotechnical study of the site. In subsidence-prone areas, foundations must be appropriately constructed, and utility lines and connections must be stress-resistant [54]. When retrofitting structures to be more subsidence-resistant, shear walls, geo-fabrics, and earth reinforcement techniques such as dynamic compaction can be used to increase resistance to subsidence damage and to stabilize collapsible soils [55].

Two hundred years or so of science and practice related to slope stability problems have transformed the landslide and subsidence issue from an ‘act of God’ into a comprehensible geophysical process [62].

Work on landslide ‘hazard’ assessment is site-based and driven by development projects and engineering concerns. Conventionally, this is approached by stability analysis of the site, determined from the balance of shear stress and strength and expressed as a factor of safety [26]. Recognition of the natural variability of factors controlling stress suggests that the factor of safety is realistically evaluated in probabilistic terms [61]. The major challenge for site-based stability analysis is the conversion of the factor of safety or equivalent stability assessment into a useful expression of hazard that can then be used as a component of risk assessment [18]. This involves employing the factor of safety along with temporal variability in triggering factors to determine the probability of failure per unit of time. Probability of occurrence, in turn, needs to be qualified by a statement of expected behaviour of the failure in terms of its impact characteristics [56].

Predicting the nature of the landslide, particularly for first-time failures, is another challenge for landslide hazard science [19].

Gravity-driven movement of earth material can result from water saturation, slope modifications, rainfall occurring after wildfire, and earthquakes [50, 78].

Techniques for reducing landslide risks to structures include selecting non-hillside or stable slope sites; constructing channels, drainage systems, retention structures, and deflection walls; planting groundcover; and soil reinforcement using geo-synthetic materials, avoiding the cut and fill sites [82]. Design for the direct effects of a landslide is not cost-effective.

Landslide and subsidence risk mitigation actions (Fig. 5). Ground subsidence can result from mining, sinkholes, underground fluid withdrawal, hydro-compaction, and organic soil drainage and oxidation. Subsidence mitigation can be achieved through careful site selection, including geotechnical study of the site [33].

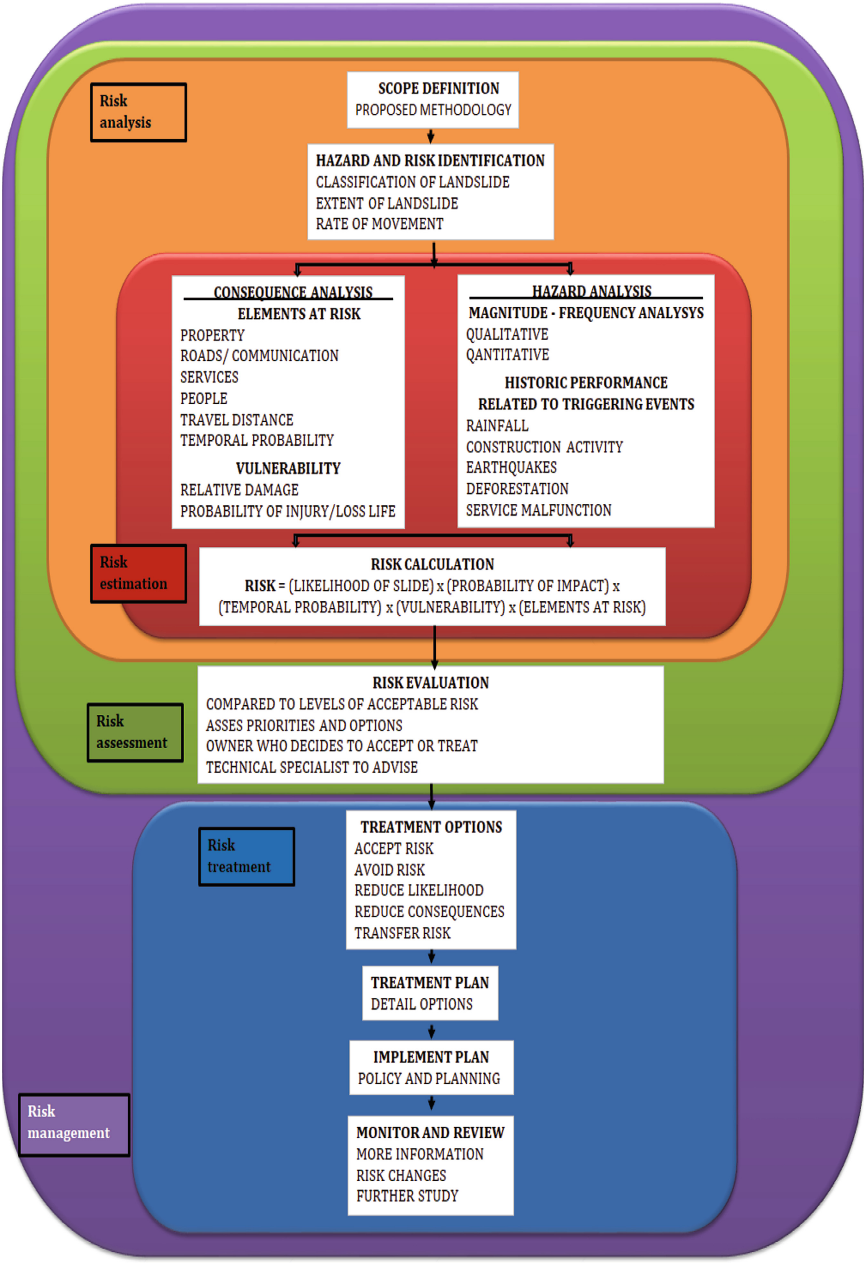

Fig. 5. Landslide risk mitigation actions

In subsidence-prone areas, foundations must be appropriately constructed, and utility lines and connections must be stress-resistant. When retrofitting structures to be more subsidence-resistant, shear walls, geo-fabrics, and earth reinforcement techniques such as dynamic compaction can be used to increase resistance to subsidence damage and to stabilize collapsible soils [5, 29].

2.3 Wind (Storms and Tornadoes)

Winds are generated by naturally convective movements of air masses in the nature and the moderate (speed) winds do not create hazard risk to the built environment. In the context of intense urbanization with an increasing number of high rise buildings or flexible, lightweight large buildings or constructions (like membrane structures, cable supported roofs) even the medium speed winds can produce important lateral forces and dynamic actions (as galloping, buffeting, vortex shedding, fluttering, look in effect etc.) that have to be taken into consideration in the design process.

In addition to the presented direct influence, the indirect risk is given by debris raised and carried by winds. First involves the structure, second involves the façade of the building and the pedestrian life.

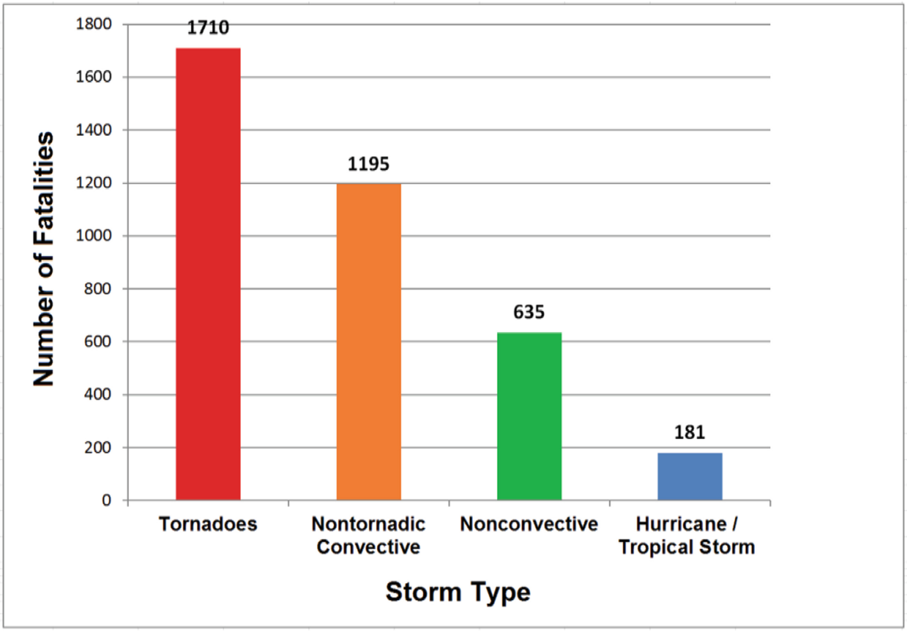

Fig. 6. Wind-related fatalities by storm type, between 1977–2007 in United States (after A. W. Black, 2009 [9])

On the other hand, high speed winds (with significant increase in maximum wind gusts) and severe windstorms (tropical storms, hurricanes, tornadoes (Fig. 7) or nontornadic convective winds) cause enormous loss to life and property worldwide (Fig. 6). Hurricane Andrew in 1992, with total economic losses estimated at $30 billion is labeled as one of the costliest natural disasters in the history of the United States of America.

Hurricane Georges in 1998 caused insured losses of about \$3.5 billion in the USA and the Caribbean and Hurricane Floyd in 1999 caused insured losses of \$1.96 billion in the USA. Thousands of people lost their lives in the “Super Cyclone” 05B that struck coastal India in October 1999.

The insured losses in the December 1999 European windstorms Lothar and Martin have been estimated at \$5.8 billion and \$2.4 billion, respectively, Hurricane Katrina in August of 2005 killed over 2,000 individuals, destroyed or damaged nearly 300,000 homes, and caused roughly \$96 billion in damages, Hurricane Sandy in October of 2012 wreaked havoc along the East Coast killing 147 individuals and damaging or destroying over 650,000 homes [69]. These figures show the serious implications of wind-related catastrophes to both life and property [38].

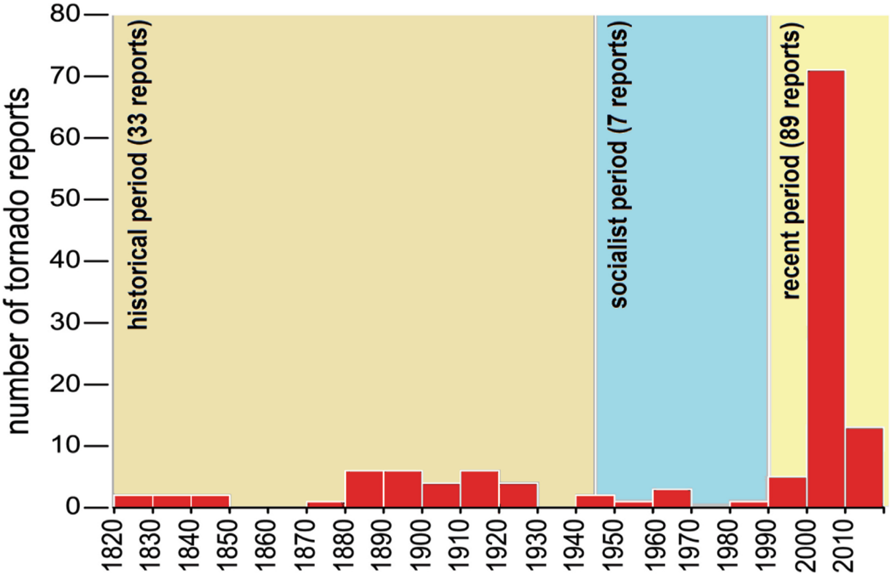

Fig. 7. The distribution of tornado reports per decade between 1822 and 2013. The first decade includes 1822–29 and the last decade includes 2010–13.

In Romania with a more temperate continental climate, the strong storms or tornadoes are less violent. There are studies summarizing the tornado climatology of Romania between 1822 and 2013 based on a dataset comprising 129 tornadoes reported on 112 days. The spatial distribution of tornado reports shows that tornadoes are more frequently reported over eastern Romania, with a maximum over south-eastern Romania [approximately 1.5–2.25 $(10^5\ \text{km}^2)^{-1}$ every 5 yr]. We speculate that a large number of tornadoes over south-eastern Romania can be attributed to the mesoscale environments over this region that are more favourable for tornadoes compared with other regions of the country, but further studies are necessary to confirm this hypothesis [4].

Storms and Tornadoes Risk Mitigation Actions. The reduction of the hazard risk due to the dynamic action of the common winds involve, as in the case of earthquakes, dynamic structural analysis in order to provide adequate strengthening, stiffness and dynamic behaviour to the construction by design methods. In many cases of high rise or aeroelastic structures, a more precise analysis can be carried out using studies on physical models of the building and surrounding aria tested in boundary layer wind tunnels. The hazard risk derived from the indirect wind effect (wind born debris) is more damaging with relation to humans, because the level of action is around ground where pedestrians can be always present.

"Objects raised and detached by wind can be carried out and, depending on the intensity of the wind, can cause significant impact on humans and on the building skin. Topics that should be taken into consideration in design are: impact resistant materials and elastic binds of façade and roof elements, but in the same time a more secure and homogenous site planning with green barriers and irregular relief and green roofs.

Benefits of this are, beside a friendly urban landscape, a wind filter that can attenuate winds and the amount of flying objects that can harm" [47].

Regarding the vulnerability of structures to extreme wind events, the studies are focused on three directions (a) damage assessment, (b) field examinations of wind-structure interaction and (c) hurricane risk assessment from the insurance perspective.

a) Damage assessment - Research mostly deals with observed damage from extreme wind events in order to correlate building damage intensity to measured wind speeds and to examine building performance when wind speeds were close to building code values. Buildings were grouped in various categories:

   - Fully engineered buildings, which performed well, even for wind speeds above the code specified values. The damage was limited on roofing material and façade.
   - Pre-engineered buildings suffered from structural framing damage for wind speeds close to, or over, the code-suggested values. Weak links (e.g. overhead door) were identified in such structures and held responsible for progressive damage.
   - Marginally engineered buildings, which were affected significantly at all wind speed regimes.
   - Non-engineered buildings, which were severely damaged when wind speed reached the code specified values.

Also, wind-induced damage can be classified to structural (lack of uplift load path, roof sheathing loss at corners and gable end wall loss) and non-structural (loss of roof shingles and vinyl siding, vulnerability of soffits, breach through attic vents and better performance of hip roofs over gable roofs).

b) Field studies of wind-structure interaction - This set deals with the effect of wind-structure interaction, which can be very important for groups of buildings, where the wind force acting on each building is heavily influenced by the nearby structures that may be shielding it or channelling the wind.
c) Hurricane risk assessment – Especially for the insurance and risk modelling, it has become important to estimate the risk faced by structures, especially in the catastrophic event of a hurricane. Risk information related to hurricane events in the

context of defining risk assessment models to be used for insurance purposes. The effort was mainly focused on refining the "general" vulnerability models by specific and detailed models related to factors such as different building types, occupancy, construction material, height etc.

3 Sustainable Rehabilitation of the Damaged Built Environment - Risk Mitigation Actions

3.1 Temporary Measures

In a world characterized by rapid change, disaster management must adapt rapidly and effectively to global and local tendencies in order to make the process as reliable as possible. Every day, people all around the world are exposed to devastating natural disasters, so that global statistics talk about a dramatic increase, by 93% in the last 40 years, of hazard risk.

The elements at risk in case of a hazard manifestation are: • Buildings and facilities; • Population; • Environment; • Production; • Economic activities [40].

It is highly important for certain facilities to be maintained functional after a hazard in order to provide the necessary services to the community. These facilities are: • Police stations; • Hospitals; • Fire stations; • Shelters (ex. Schools, churches).

The probability of an event to take place can be estimated based on a risk matrix, which takes into consideration in the evaluation process the degree of severity and the frequency of that potential event. The Risk Matrix provides three levels of risk: low risk (considered acceptable), moderate (may or may not be acceptable) and high (unacceptable). Manifestation of a risk comes associated with two types of losses, primary and secondary (Table 1).

In the context of six major natural hazards (earthquakes, volcanoes, tsunamis, tropical cyclone storm surge, tropical cyclone wind and floods), USA, Japan and European Union, restructured their policies and strategies in hazard management, investing time, effort and money to reduce the consequences. Characteristic for EU are joint strategies and action plans like Hyogo Framework for Action, "Managing risks to achieve resilience" [7, 8, 45] or a ten years plan on "Building the resilience of nations and communities to disasters" [24, 30, 44]. International Federation of Red Cross/Red Crescent Societies (IFRC) has developed a complete set of International Disaster Response Laws (IDRL). In November 2007, IFRC presented "Guidelines for the domestic facilitation and regulation of international disaster relief and initial recovery assistance" ("IDRL Guidelines"), unanimously adopted by all High Contracting Parties to Geneva Conventions.

Following the same trend as EU, Romania implemented several hazard management decisions and laws, resilience strategies [11, 37, 43], like Decision no. 762/2008 for National Strategy for Emergency Situations Prevention, and became a contributory member of International Strategy for Disaster Reduction (ISDR) in order to put into practice Hyogo Framework for Action. Even more challenging is to create a joint strategy and policy at NE Romanian border with Republic of Moldavia, since the legislation and intervention process is different.

Since 2004, Romania has a National Management System associated with Emergency Situations, IGSU – General Inspectorate for Emergency Situations [31], a medical

Table 1. Primary an secondary loses

	Human - social	Physical	Economical
Primary effect	• Fatalities • Injuries • Loss of income or employment opportunities • Homelessness	• Ground deformation or loss of ground quality • Structural damage or collapse to buildings and infrastructure • Non-structural damage and damage to contents	• Interruption of business due to damage to buildings and infrastructure • Loss of productive workforce through fatalities, injuries and relief efforts • Capital costs of response and relief
Secondary effect	Disease Permanent disability Psychological impact Loss of social cohesion due to disruption of community Political unrest (govt. response is perceived as inadequate)	Progressive deterioration of damaged buildings and infrastructure which are not repaired	• Losses borne by the insurance industry weakening the insurance market and increasing premiums • Loss of markets and trade opportunities through short term business interruption • Loss of confidence by investors, withdrawal of investment • Capital costs of repair

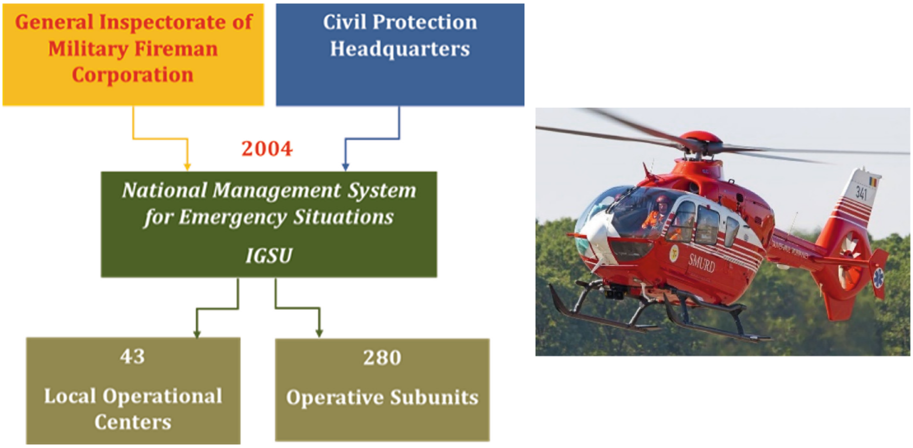

Fig. 8. Romanian National Management System for Emergency Situations

emergency unit SMURD – Mobile Emergency Service for Resuscitation and Extrication and an emergency phone number 112 (Fig. 8).

3.2 Restoration of Services

An integrated design approach shall provide opportunities for energy efficiency [35, 80]. The issues to be reviewed shall include site, plan form, orientation, passive ventilation and passive solar strategies and daylighting (Fig.9).

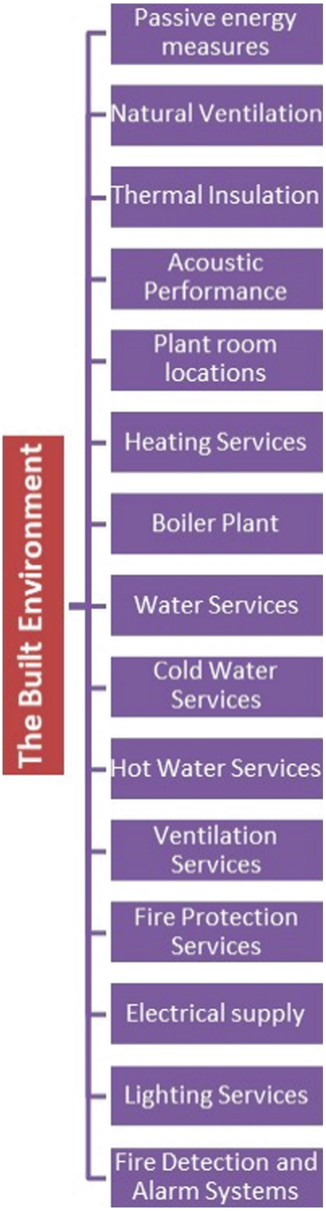

Fig. 9. Restoration of building services for energy efficiency

The use of passive energy measures to achieve a comfortable internal environment shall be employed where possible [67]. The form of the building shall be developed to take account of the need to minimise energy consumption with particular emphasis on maximising the use of natural ventilation, daylighting, useful solar gain and minimising heat losses and unwanted heat gains [64]. Ventilation where possible shall be natural ventilation by means of permanent wall vents and windows with opening sections.

Thermal insulation standards shall meet or exceed the prevailing standards but shall also be considered in the context of the balance of heat loss and gain to minimise the running costs and maintain comfort conditions.

The heating services shall comprise fuel installation, the heating centre plant room installation, the space heating and distribution services and controls.

Adequate protection services to enable the building occupants to evacuate safely against the risk of fire shall be provided in the form of handheld type fire extinguishers and fire blankets.

Energy system

The energy provided to the built environment need to adopt new strategies based on the impact category, on energy supply, and energy demand.

Energy Supply Strategies:

- Construct additional or redundant transmission or distribution line capacity to offset anticipated efficiency losses.
- Establish new coastal power plant siting rules to minimize flood risk.
- Install solar PV technology to reduce the effects of peak demand.
- Upgrade local transmission and distribution network to handle increased load associated with higher temperatures.
- Expand hazard preparedness programs.
- Require utilities to develop storm hardening plans regularly.
- Retrofit power plants so they use less cooling water.
- Automate restoration procedures to bring the energy system back online faster after weather-related service interruption.
- Provide additional support for distributed generation systems to spread climate risk over a larger area.

Energy Demand Strategies:

- Install steam-powered chillers to reduce the burden on local power system on hot days
- Establish or expand demand-response programs which encourage consumers to voluntarily reduce power consumption during peak demand events
- Establish public education programs to promote lifestyles that are less energy-dependent
- Employ passive building design strategies to maintain minimum comfort or lighting levels even in situations where energy system losses occur.

3.3 Scenario-Based Mitigation Measures

Each hazard manifestation has a certain level, impact and recovery level. A disaster arises when an extreme natural event (ex. storm, earthquake, flooding) strikes a vulnerable society. Whether a natural event becomes a disaster depends on the social, economic, ecological and political characteristics of the society in question.

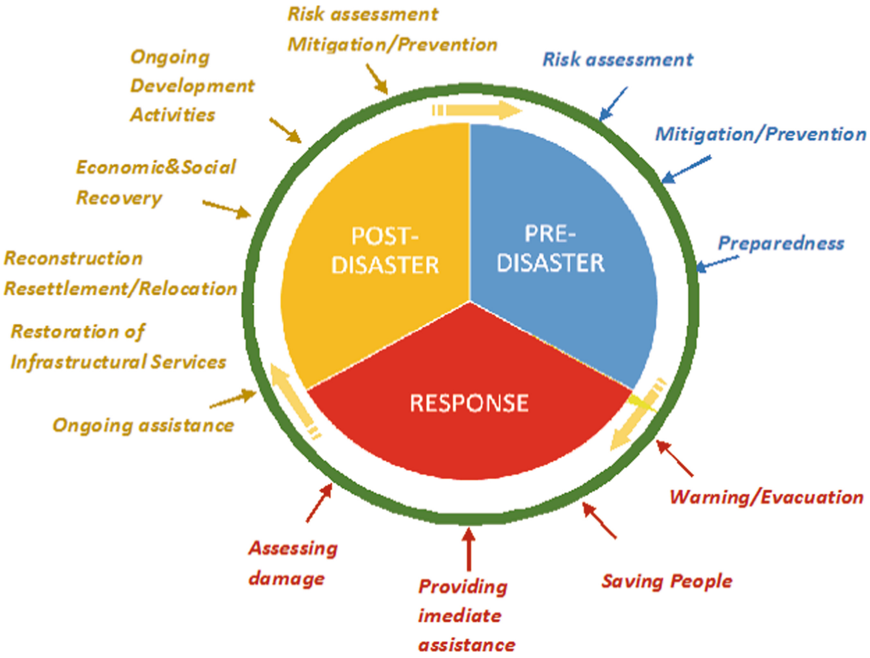

Fig. 10. Disaster risk management diagram [27]

The question is: are we, as individuals, and the authorities, as managers of the situation, prepared to face a worst-case scenario?

In a potential example of worst case scenario for the City of Iași was created an open list of main disruptions, like: • Building collapse; • Transport infrastructure destruction; • Human casualties: deceased or wounded; • Destruction of connections with other cities and with main emergency units; • Lack of food and water; • Lack of salvage units and shelters; • Economic breakdown.

The process of planning, implementing, evaluating and adapting strategies, procedures and measures relates to the analysis, reduction and transfer of disaster risks, with the aim of reducing hazards and vulnerability and strengthening the adaptation capacities of individuals, households, communities and state structures. Disaster risk management is a continuous process that involves physical and non-physical measures and takes into account the underlying risk factors within a society (Fig. 10) [46]. Disaster risk management [85] aims to avoid the generation of new risks, improves resilience to the effects of natural events and contributes to sustainable development [10, 12, 22].

Worst Case Scenario for Natural Hazards associated with Road Network in Iaşi County is based on the information received from Regional Direction of Roads and Bridges. For the scenario, the main components that can represent “critical points” in case of a natural hazard have been considered, points that might be part of a worst-case scenario for traffic communication sector.

Worst case scenario is correlated with destruction of main communication systems, bridges and roads. These constructive systems have the role to connect different areas. In their absence, a certain area remains blocked, potentially without possibility to provide food and water. According to DRDP (Road and Bridges Administration) representatives, in case of a natural hazard, they are capable of intervening with different types of temporary components for bridges and roads, in order to give into usage the network as soon as possible.

Statistics mapping the hazard risk at national level situate Romania on the 82nd position, in a total of 173 countries, with high risk of natural disasters. Romania position in European ranking of exposure to hazards is confirmed by annual hazards manifestation, but mostly by several dark historic events of natural disasters, like May 1970 floods resulting in over 50 deaths and significant economic loses or March 1977 Vrancea Earthquake, with over 1,500 deaths and huge material losses [34].

In order to underline the importance of a strategic risk management, worst case scenario focuses on an specific area from Iaşi city centre, namely Podu Roş Intersection and Bahlui River Bay (Fig. 11).

The city of Iaşi still has a large number of buildings built previously to 1977 based on old standards, buildings that were affected by the earthquake, that are unstable, that have not been properly rehabilitated. A significant number of buildings of this type are situated close to the most important traffic node, Podu Roş Bridge. These buildings, marked with”a red bullet” represent public danger and a significant risk of crashing in case of an earthquake, producing, according to experts, a large number of victims.

Podu Roş Intersection has been considered for the case study since it is the most significant road intersection in the city, connecting the city centre with 5 large neighbourhoods leading to city exists. More than this, a fail in accessing this intersection would mean breaking the connection with the city health and safety institutions, since all the hospitals are in the city centre.

Another characteristic of the area, from strategic point of view, is that Bahlui River crosses a large area of Iaşi, breaking the City in half. All connections between the two parts are made by bridges. In the last years the City developed greatly outside the old City area. Still, main emergency services, hospitals and police are situated in the old part of the City, leaving the only few private hospitals with reduced capacity, low level of traffic facilities (Arcadia Hospital, Providenţa Center) and no emergency services to the newly developed part of the city.

The two parts of Iaşi City are connected by several bridges, along Bahlui River, some of them only with pedestrian traffic, others cover also vehicle traffic. Of these, most significant, from capacity and traffic point of view, are the ones in Podu Roş and Tudor Vladimirescu (Fig. 12, Fig. 13). It is vital to preserve the functionality of these bridges in case of a hazard, since they provide access to medical assistance and emergency units.

Fig. 11. Podu Roş Intersection and Bahlui River Bay in Iaşi city, Romania

In the worst case scenario, failure of these bridges would mean isolation for half of City population, limited access to emergency units and delay in salvage operations.

3.4 Case Studies

Earthquakes

Following the 1940 earthquake which has been considered a major one, the 4th March 1977 Vrancea earthquake proved that seismic load is not yet correctly assessed in Romania.

At 21:22, Bucharest was hit by an earthquake of 7.4 on Richter scale (Fig. 14). It lasted around one minute and killed more than 1,500 people and injured around 11,300 in Romania and also in the neighbouring countries. 90.2% of the casualties occurred in Bucharest due to the collapse of 19 high-rise buildings, which were constructed as reinforced concrete frame structures, considering only the gravitational loads, according to regulation from the time. Two buildings constructed in 1962 and 1974 of 10 and 11 floors partially collapsed [6]. The main failure mechanism was similar to those observed after the 1940 earthquake, pancake collapse pattern [83, 84, 87]. Three public buildings collapsed, but considering the late hour the number of casualties was significantly reduced.

Other casualties occurred across Romania in Prahova (Plopeni), Ploiesti, Iasi and Craiova where unreinforced masonry buildings collapsed killing and injuring several people [6]. Some data recovered from Rosiorii de Vede, Turnu Magurele and Alexandria showed that gable walls of old masonry house have been the major source of injuries. Zimnicea city, in the south of Romania, suffered an 80% buildings destruction.

The earthquake was felt across the entire Balkan Peninsula. The most affected city was Svistov from Bulgaria where three block of flats collapsed killing 100 people [83].

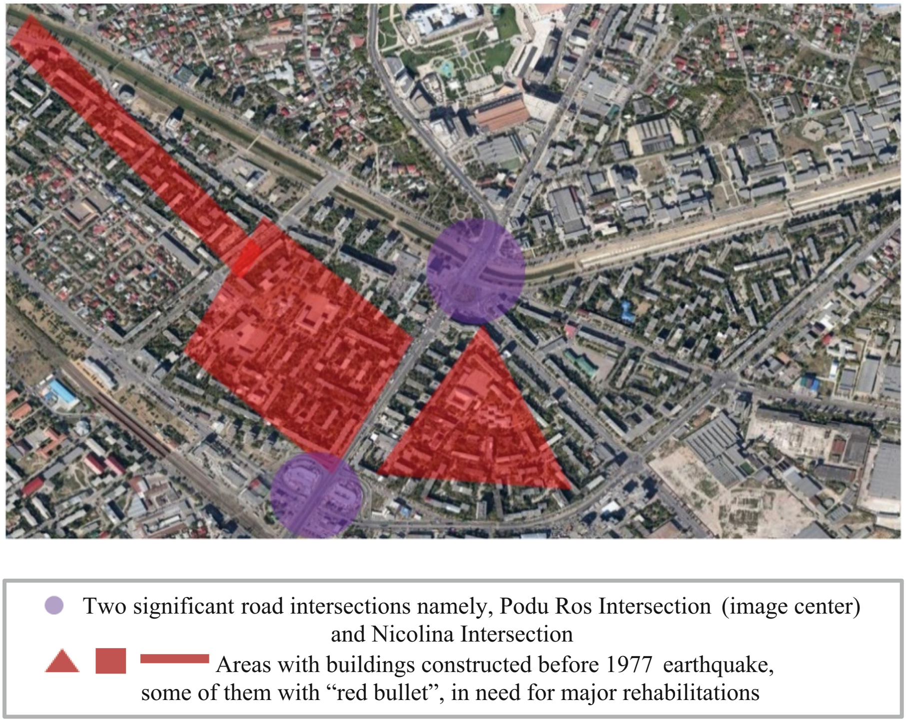

Fig. 12. The worst-case scenario – Podu Roş Intersection, Iaşi City, Romania

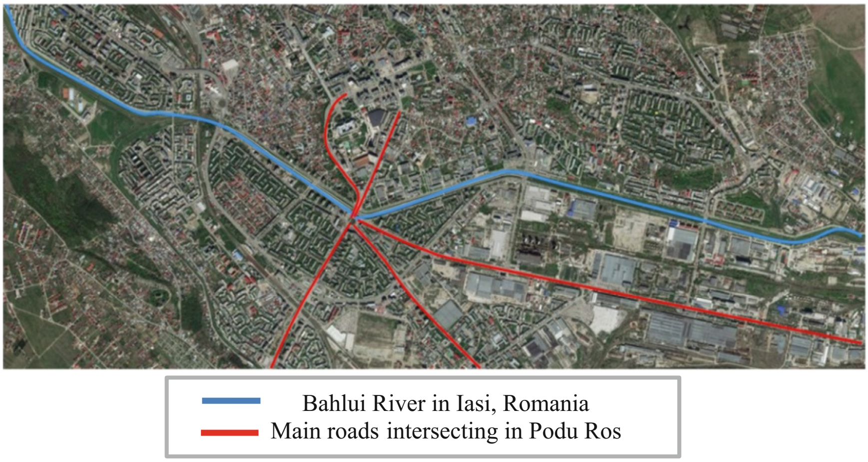

Fig. 13. The worst-case scenario –Podu Roş Intersection, Iaşi City, Romania

The problems arising from this earthquake highlighted the need for better conformity to earthquake of buildings, as well as the need for new seismic prescriptions, more accurate regulation on site, namely the urgent need for some draft laws regarding the responsibility of designers and executors. Following this event the 1978 seismic code appeared. Currently we design according to Eurocode, but the national norm has the spectrum defined based on the recordings of 1977 Vrancea earthquake.

Fig. 14. 4th March 1977 earthquake, Romania

Landslides

Pârcovaci locality, Iaşi county, Romania, is located west of the town of Hârlău. It spreads about 7 km along the Bahlui River [52]. The hills to the right of the Bahlui River are prone to landslides. The regularization of the flood rates occurs under the management of the Department of Water Resources of the Prut River, through the Storage Lake Pârcovaci, a hydropower work installed at approx. 10 km upstream of the town of Hârlău. The landslide occurred in Pârcovaci village in early December 1996 (Fig. 15). The landslide was profound, induced on a wide-spread area in continuous expansion, determining the damage of 97 peasant households out of the 186 located in the area.

a) Characteristics of the landslide: The affected area is located on the right side of the Bahlui River, downstream of the Pârcovaci accumulation dam (2–3 km). b) Characteristics of the slide: the length measured on the steepest slope gradient up to the axis of the Bahlui River is about 2.5 km with the width of 1 km, with extension tendency [51]. The area strongly affected is about 250 ha. Geomorphologically, the area presents a very pronounced relief energy, there being a level difference between the Bahlui River bed and the ridge slope over 250 m. The slip surface comes into the site in the upstream area as very rough, with vertical cracks in the order of tens of centimetres. Vertical displacements attributed to zonal collisions turned up, some with shallow overlaid compressed layers, others through stretching due to the layer bending. In the order of several meters, visible slides through horizontal movements go out between the slip surfaces and seemingly stable areas. The general deep slip surface rounded with a partial sliding mass directed to the valleys of the torrents facing the Bahlui River. The area had high humidity as a result of the existence of the groundwater at shallow depths highlighted by a series of springs and a very high level of water in the local wells (1–1.5 m from the ground elevation).

c) On the land affected by the landslide (250 ha), 186 peasant households (houses and annexes) settled down, and the rest availed for agricultural use and grazing. The peasant houses covered with tile, tin or asbestos cement held local materials (adobe, shallow foundations). The landslide affected 97 households (400 people) and destroyed a large number of houses (cracks in the walls and foundations of about 10–15 cm, Fig. 16).

Fig. 15. Lanslide – Pârcovaci village, 1996

Fig. 16. Cracks in the walls, Pârcovaci village, 1996

The landslide changed the hydrostatic regime of the area, completely changing the directions of water movement, also having effects on the well water [57]. By raising the slope of the Bahlui River about 40 cm, the drainage slope reduced, the riverbed narrowed, which resulted in an accumulation of water upstream with the continuous rise of the level, leading to the danger of flooding 300 peasant households (1,300 individuals). The decrease of the flow section of the Bahlui River by sliding mass obstruction could have affected the normal functioning of the Pârcovaci storage lake (2.75–4.02 million cubic meters of water) preventing the taking-over of the floods from the winter-spring period.

Measures: Deterioration of buildings made them unfit to habitation, endangering the lives of people, necessitating emergency evacuation, finding acceptable housing solutions in hygienic-sanitary conditions. The slip area being strongly fragmented and with sliding tendencies, it was necessary to allocate plots for new farms. To avoid the flooding of more or less than 300 households as well as the disturbance of the normal functioning of Pârcovaci storage lake by raising the Bahlui River thalweg and reducing its flow section, the riverbed of the water storage upstream of the slipped area necessitated urgent corrective measures. Technical improvements to limit the landslides and their effects in Pârcovaci village were: 1. Interception-collection-evacuation works of the groundwater from the plateau area carried out by the rapid capture and evacuation of the surface stagnant waters originated from heavy rains [63]. They employ interception drains, absorption drains, or spring water catchment chambers. 2. Interception-collection-evacuation works of the water within the slip surface originated from heavy rains through a network of open drainage collection channels, systematic drainage networks through absorbent drains, spring water catchment chambers, land modelling works, consolidation of slopes and the riverbed of the existing cloughs. 3. Anti-erosive roads and water-related works to consolidate the technological road platform through compaction and ballast addition. 4. 2.85 km of marginal channels along to protect the road platform; 5. Nine platforms at the junction of roads with canals of which a paved bridge; 6. Consolidation of the river bank with a pitching wall on a concrete foundation.

Storms and tornadoes. A building that shelters the archaeological vestiges of the ancient Goto-Dacical civilization discovered on Catalina hill, near Cotnari village, Iaşi County, Romania is a cable supported structure with curved hyperbolic paraboloid (or saddle shaped) roof. It is situated on the ridge of a steep hill (at 100 m over the rest of the site) near the crest. The structure is submitted to strong winds because the aerodynamic roughness parameters of the ground surface are specific to a category 3 open area - zo $\cong$ 0.1 m -on a distance of some km around. In addition, the particular position on the top of the hill emphasizes the wind action on the structure.

The thin covering made of fibber reinforced plastics was destroyed by the fluttering of the supporting cables and because the distance between the fixing points was too large comparing to the thickness of the covering.

The rigid model (Fig. 17) represents the saddle shaped structure at the length scale of 1/100. The boundary layer developed in the tunnel simulates open country exposure with a vertical velocity profile represented by a power-low with exponent $a = 0.185$. The similarity of Reynolds number is provided by artificially roughening of the external surface of the curved model. The model was equipped with 40 pressure taps. The first 39 placed on the envelope measure the local normal components of the dynamic pressure from the outer surface and the last one measures the internal pressure inside the model.

The mean dynamic velocity pressure used as reference is measured with a Pitot probe placed in the upstream and at the middle high of the model roof.

After measuring, the internal and local external pressures are composed to determine the local normal resultant of wind action on the envelope. The results are expressed as local pressure coefficients related to the reference pressure.

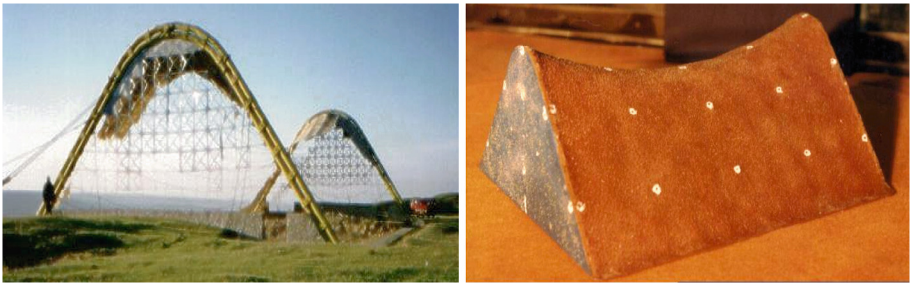

Fig. 17. Aspects of the damaged structure in 1994 and the building scaled model placed in the boundary layer wind tunnel

Using a software package based on the finite element method a numerical model of the same structure was created (Fig. 18). The software package that was tested in the Department of Structural Mechanics of our University develops a non-linear geometrical analysis, which takes into consideration the deformation of the structure.

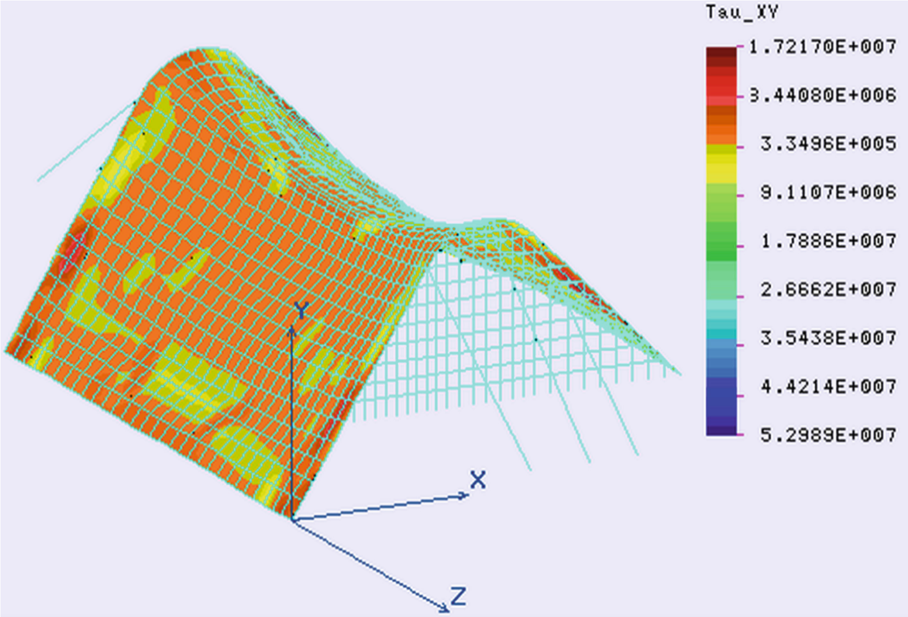

Fig. 18. Unitary shear stresses on envelope numerical model for the wind direction α = 0°.

The numerical model is made of 1072 finite elements and has 6120 degrees of freedom. As loading data, the values of the local normal pressure measured on the physical model in the boundary layer wind tunnel were used. We made the hypothesis that between the measuring points the pressure evolution is linear. The local pressure coefficients were multiplied by the basic dynamic pressure of the site and by a factor that reflects the influence of the hill where the structure is constructed. The basic dynamic pressure according EN 1991-1-4:2005 corresponds to a basic wind speed $\bar{U}10 = 30$ m/s (so $gv = 550$ N/m^2). This basic dynamic pressure of the site was multiplied with a factor that reflects the influence of the hill. This factor ($c = 1.75$ for the basic wind velocity) was determined in the wind tunnel on a 1:400 model where the hill and the structure has been reproduced.

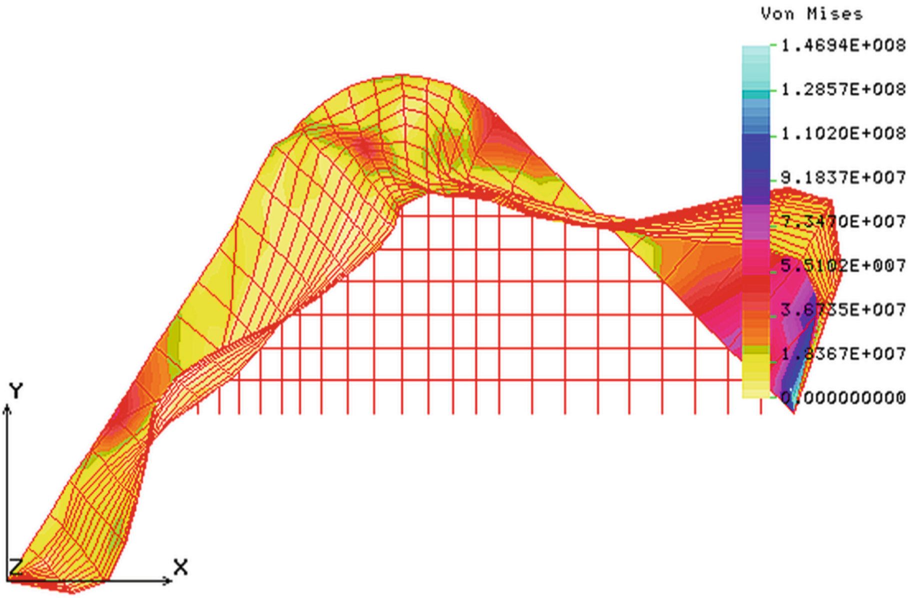

Fig. 19. Deformed cross section through the structure model for the wind direction $\alpha = 90^{o}$.

The results of the analysis on the numerical model are expressed as unitary (normal or tangential) stresses and deformations of the finite elements (Fig. 19). Forward are presented the values of different resultant unitary stresses, a map of colours according the intensity of the stress, and the displacements of the structure model Pescaru, R., Axinte, E. 2000.

- The results of the wind tunnel tests on the rigid model of the cable supported structure from the Catalina hill emphasises the following aspects:
- The maximum wind loads considered in the initial design of the structure were underestimated. An important aspect, which was neglected, is the particular position of the building which has a major influence especially on the negative pressure, more developed comparing with the usual conditions. Concerning these aspects, the revised

edition from 1990 of STAS-10101/20 regarding the wind loads on buildings, stipulate the necessity of wind tunnel tests for the design of lightweight structures with large size and unusual shape.
- The results of this program of measurements is a more accurate assessment of the wind loads on a hyperbolic paraboloid suspension structure, that has no analytical solution in STAS 10101/20-1990, and provide the appropriate data for the proposal of new solutions of reconstruction.

The membrane with an open area of 1.25%, showed that the magnitude of the surface pressure coefficients was generally considerably reduced and that the loading across the membrane material were alleviated in almost all conditions.

4 Conclusions: Hazard Risk Mitigation Opportunities

Mitigation opportunities are available to reduce losses from natural hazard events [86].

- Zoning as a form of land-use management and control can help regulate population and industrial development in hazard-prone areas. It can be used to control building density, adjust the timing of development plans, and better define “allowable” development. Maps that identify high-hazard areas should be adopted and used to guide, restrict or limit development. Models to identify hazard areas need to be developed or tested to verify accuracy.
- Control or protective structures may be useful in protecting life and property. Examples include dams to control floods and structures to mitigate de risk or control landslides.
- Building codes designed to improve construction, reinforcement, and anchoring of buildings. A nationwide hazard-based code may help to ensure implementation of standards appropriate for hazard- and damage-resistant structures. Examples of progress in this area are the seismic regulations for new and existing buildings that have been developed in Romania.
- Evacuation planning and preparedness programs are helpful in protecting residents in areas subject to imminent danger. In general, evacuation saves lives but does not result in significant damage reduction.
- Warnings and forecasts are useful for alerting communities and citizens to an impending hazard event. Both real-time, and longer range forecasts should be provided. Warnings and forecasts are issued in preparation of possible evacuations and to prompt property protection measures.
- Education and awareness efforts provide hazard information to the public to make them aware of the impacts of possible hazards. Information can include, but is not limited to, graphic depictions of hazard areas and evacuation routes, and simple, effective mitigation actions.
- Monitoring and data collection are necessary to support research, to provide affected communities and citizens with better warnings and forecasts, to understand hazards, and to develop loss reduction methodologies.
- Relocation of utilities and transportation routes out of extremely high risk areas can be beneficial.

- Research on hazard processes and model development are needed to understand hazards and their consequences. Dedicated hazard-specific research facilities could coordinate research efforts with academic institutions and international organizations.

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