Earthquakes
EVANDE project,
Technical report

European Civil Protection

Project co-funded under the Union Civil Protection Mechanism
Grant Agreement No.ECHO/SUB/2014/693261

EVANDE

www.evande.eu

Contributors

Charalampos Fassoulas (Proj. coordinator, NHMC-UoC, GR)
Kleopatra Georgila (NHMC-UoC, GR)
Alexandros Chatzipetros (AUTH, GR)
Aggeliki Avramidou (AUTH, GR)
Asimina Kourou (EPPO, GR)
Maria Panoutsopoulou (EPPO, GR)
Anastasia Ioakeimidou (EPPO, GR)
Tzvetan Tzvetanski (CEI, BG)
Yasen Tsvetkov (CEI, BG)
Moisés Benlloch (Head of IAE - Intervention, Help and Emergency, ES)
Miguel Ángel Belenguer (Head of Civil Protection Volunteers Group in Valencia City, ES)
Vicente Civera (Civil Protection Volunteers Group in Valencia City, ES)
Raúl Quesada (Civil Protection Volunteers Group in Valencia City, ES)
Maria Rita Bracchini (FCSVM, IT)
Marco Conti (FCSVM, IT)
Virginia Marconi (FCSVM, IT)

Graphic design

Federico Brozzetti (FCSVM, IT)

Project co-funded under the EU (or Union) Civil Protection Mechanism
Grant Agreement No. ECHO/SUB/2014/693261

Preface

The technical booklet on earthquakes was produced by the European civil protection project EVANDE (Enhancing Volunteer Awareness and education against Natural Disasters through E-learning).

The EVANDE project was implemented the period 2015-2016 and was co-funded by the Union Civil Protection Mechanism (Grant Agreement No. ECHO/SUB/2014/693261). It was coordinated by the Natural History Museum of Crete-University of Crete, in Greece and involved also the following partners:

- Technical University of Crete -Laboratory of Distributed Multimedia Information Systems and Applications, GREECE
- Consorci De La Ribera, SPAIN
- Beigua European & Global Geopark, ITALY
- Earthquake Planning & Protection Organisation, GREECE
- Fondazione Hallgarten - Franchetti Centro Studi Villa Montesca, ITALY
- Centre for Educational Initiatives, BULGARIA.

The present booklet is a synthesis of selected civil protection knowledge and experiences in Greece, Spain, Italy, Bulgaria and globally. It aims to present basic knowledge and information on civil protection against earthquakes and focuses in all aspects of civil protection including prevention, response, recovery and covers institutional, economical, social and educational issues.

The booklet is targeting local authorities' staff and civil protection volunteers and aims to offer insights on how civil protection policies and initiatives could be improved. The contributors were both staff member of the EVANDE partner organizations as well as experts and external collaborators. The synthesis of these experiences indicates the diversity of approaches per country as well as the importance of prevention and awareness-raising on natural disaster risks.

Further information about the EVANDE project:

EVANDE website: www.evande.eu

EVANDE e-learning platform: http://evande.coursevo.com

EVANDE Facebook Group: https://www.facebook.com/evandeproject

Table of Contents

1. Hazard description

1.1 What is an earthquake?

The rocks of the Earth's crust undergo intense stresses induced by various reasons, the most common being the lithospheric plate movements. These stresses accumulate huge energy within the rocks. Whenever rocks suddenly break due the deformation they received, the accumulated energy is released in the form of vibrations. An earthquake is thus the shaking or vibration of the ground due to the release of the accumulated energy (Fig. 1.1).

The energy concentrated in the area of the rock failure is then expressed as vibrations or shaking of the ground, called seismic waves that are radiated out within the rocks. Depending on the amount of energy that is released seismic waves may be strong enough to be felt as a shaking of the ground or even shake many of human constructions. The more energy released the stronger the earthquake is.

The earthquakes can thus be considered as the indicators of plate tectonic movements and Earth's surface uplift.

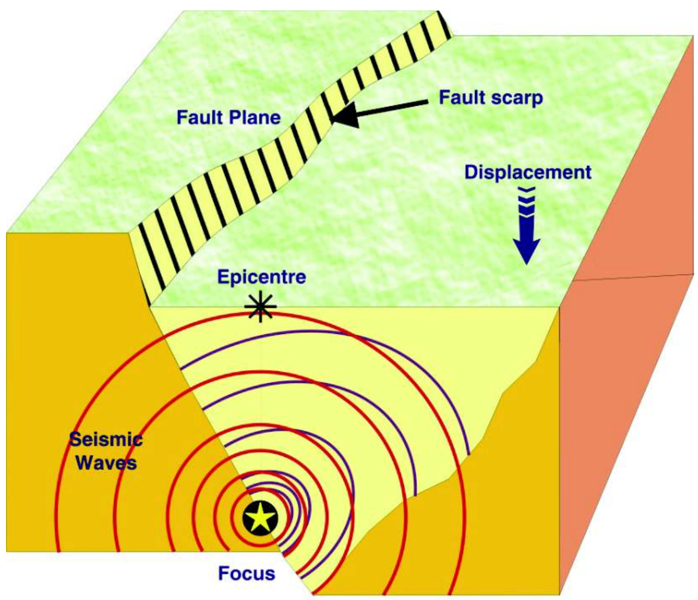


Figure 1.1 *Earthquake focus and epicenter (NHMC)*

1.2 What causes earthquakes?

Earthquake is a natural phenomenon originated in Earth's interior. The natural processes which may result in rock break down, producing thus an earthquake are related with dynamic processes that take place in the Mantle and Crust of the Earth, but also with rock erosion.

Three types of earthquakes can be distinguished. When an earthquake happens as a result of the sudden displacement of massive bodies of rocks along a fault surface deep in the Earth, then we have a tectonic earthquake. If an earthquake happens due to upraise and emplacement of magma in the Earth crust during a volcanic eruption then we speak for a volcanic earthquake. In case that rocks break due to the collapse of a cave or to a large rock displacement during a landslide, the earthquake is called collapse earthquake.

Apart from natural earthquakes humans can cause ground shaking by modifying the local natural stress patterns of the crust, actually reactivating pre-existing faults. These are called man-made earthquakes and include shakings caused by mining explosions, water reservoir/dam filling, underground nuclear tests and underground fluid injections for shale oil extraction.

The vast majority of earthquakes (about 90% globally) and of released energy is due to tectonic origin, and thus very often when speaking for earthquakes we refer to the tectonic type.

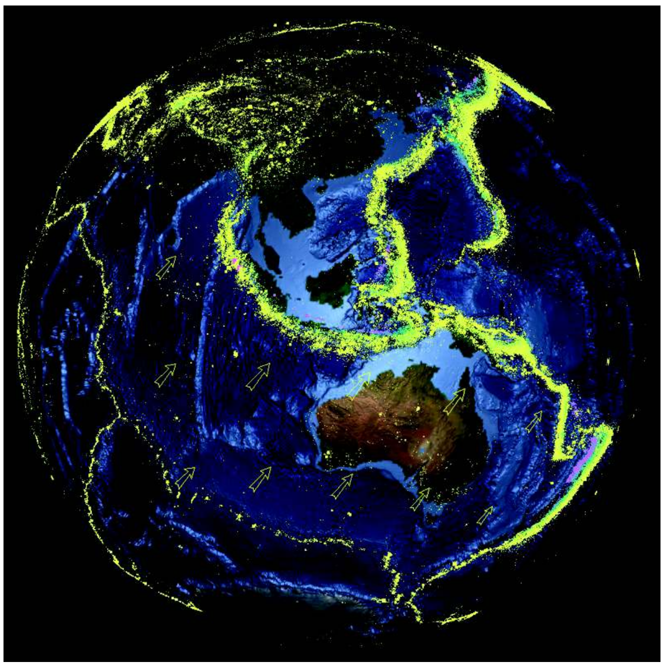


Figure 1.2 *Earthquake epicentres in the Pacific area (from jaeger.earthsci.unimelb.edu.au)*

Tectonic earthquakes are generally caused by the tectonic plate motions that induce stresses not only along their boundaries but also within their bodies. This is the reason that earthquakes are concentrated in plate boundaries (Fig. 1.2). As stresses are concentrated within rocks the lithospheric material can react elastically for a certain period but very soon it will break. Whenever such a break occurs in rocks a fault develops, pieces of rocks move apart each other and the energy concentrated is released as an earthquake. Progressive and continuous concentration of stresses on a fault tends to move rock pieces against friction. As long as friction prevails a seismic quietness occurs, but when this ends an earthquake is produced releasing the seismic energy. The longer the seismic quietness is, the stronger the resulted earthquake.

The area of the fault where a rupture is initiated and the seismic waves originate is called earthquake focus and is depicted by the weight point. Its projection on earth's surface is called epicenter.

Depending on the focus distribution the earthquakes can be divided in:

1. Shallow: the focal depth measures less than 60km,
2. Intermediate: the focal depth measures between 60 and 300km, or
3. Deep: the focal depth measures more than 300km.

Faults and Earthquakes

Planet Earth's structure consists of three main parts: the **crust,** the **mantle** (upper and lower) and the **core** (outer and inner, being fluid and solid respectively). Life on planet Earth is possible only on its uppermost part, the crust. If you want to grasp how thin the crust is, think of a peach: the peel is the crust, the fleshy part is the mantle and the seed is the core. In reality however, the crust is even thinner than the peach's peel: its thickness is just about 40 km of the total radius of Earth (6,370km).

The crust and the top of the mantle make up a thin skin on the surface of Earth, the lithosphere. The lithosphere is not all in one piece – it is made up of many pieces, the tectonic lithospheric plates. These plates keep slowly moving around, sliding past one another and bumping into each other. There are seven large and eight smaller lithospheric plates. They are in constant movement and they converge, diverge or crush into each other. As a result, mountain chains are being built and destroyed, volcanoes are formed, etc. One such area is Greece, where the African plate is subducting below the Eurasian one.

When two lithospheric plates meet, immense forces can break up the crust and form discontinuities called **faults.** Generally, faults are fractures of the rocks along which a displacement of the fragmented parts take place. A fault can be just a single crack or a much wider zone (reaching several meters) within rocks which may cut all the Earth's crust. The dimensions of the fault surface, i.e. length and depth, define the maximum magnitude of an earthquake that can happen due to its activation.

Faults are categorized in three groups (Fig. 1.3) in respect to the displacement that can happen:
1. **Strike slip fault**: the fault plane is almost vertical and the two blocks slide parallel to each other, in opposite direction, without significant vertical displacement component.
2. **Normal fault**: the rock section above the fault plane moves downward relative to the section below the plane following gravity. It is created in areas where the crust is extended.
3. **Reverse fault**: the rock section above the fault plane moves upward, against gravity, relative to the section below the plane. They are indicative of shortening of the crust. Reverse are further classified in overthrust (high angle) and thrust (more horizontal) faults.

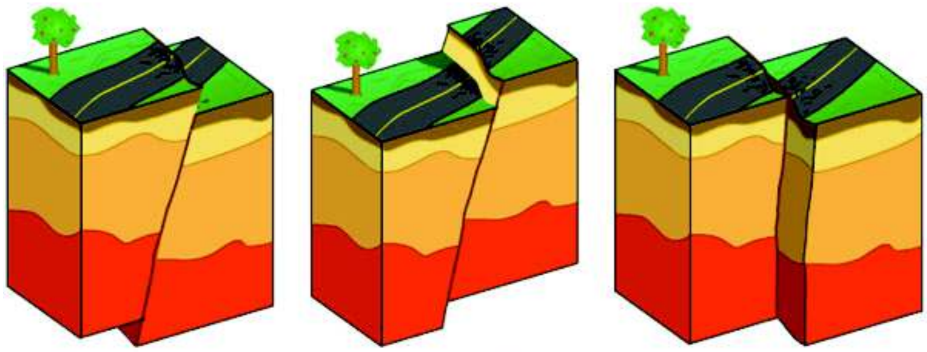


Figure 1.3 *Fault types (USGS)*

Lithospheric plate movement causes all sorts of deformation to the rocks, the most important being **faults** and **folds.** Furthermore, Earth's crust may move towards all directions. When it subsides, oceans cover former landmasses (transgression), while when it uplifts new landmasses emerge from the water (regression).

Generally speaking, the mountain ranges on Earth are formed as a result of continental uplift. This is called **tectonic uplift,** as it is caused by tectonic forces. These forces stem to the gigantic stress imposed on the rocks as the lithospheric plates converge. This uplift is not abrupt; it can last for several millions of years. For example, the latest stage of tectonic deformation in Greece has started since tens of millions of years and is still active today. The Hellenides, as the youngest mountain ranges in Greece are called, are part of the Alpine orogenic chain, which begins at Atlas mountains (Morocco) and through Alps, the Balkans, Turkey and Zagros (Iran) terminates at the Himalayas. This enormous mountain chain has been formed under the same conditions and its mountains share a common geological history.

When the deformed rocks are located deep in Earth's crust, where high pressure and high temperature prevail, they tend to fold. As a result, folds are being observed at almost every mountain's rocks, as they once have been situated in deeper parts of the crust. At the uppermost crustal parts however, where pressure and temperature are lower, rocks tend to break, forming **faults** and **joints.** Joints are discontinuities in the crust, breaking up the rocks into discrete blocks. When the stress applied to the rocks exceeds a certain limit, blocks on both sides of the joint start to move and the joints are then transformed to faults. This deformational process is continuous and unstoppable. Today's Earth is just a snapshot of an instant in the immense geological time.

The plate boundaries are made up of many faults, and most of the earthquakes around the world occur on these faults. Every time the fault blocks move, an **earthquake** occurs. Most faults are old and can no longer produce earthquakes. Those that can, however, are called **active faults.** A fault can be still active for millions of years after it was formed. Earthquakes are one of the most important indications showing that the Earth is a live planet. Especially in areas close to lithospheric boundaries, such as Greece, earthquakes are happening daily and have often catastrophic effects. Unfortunately, earthquake occurrence cannot be predicted, so the only way of mitigating its effects is to build resistant buildings and be properly informed.

However, not all faults are capable to product earthquakes; only those on which stress is continuously accumulated. Many faults are considered thus as inactive to produce an earthquake in respect to others that can be considered as potentially active or active.

Study of active faults

Since active faults are the ones that generate earthquakes, it is of crucial importance to identify and study them in detail, in order to mitigate their hazard, which, in our modern societies, tends to be high. There are several stages and many ways to study active faults:

- Firstly, a fault has to be identified as active. This is not always an easy task, as most of them are not directly associated with a known earthquake. The majority of active faults either has not generated an earthquake in historical times, or its association with one is unknown or dubious. Therefore, a careful geological investigation should be conducted, mainly addressed to the age of the rocks that this fault is deforming: if they are young enough, it means that this fault has been reactivated in the recent geological past, hence it is likely to be reactivated again in the future. Depending on the definition, a fault that has been activated during the Holocene (i.e. in the past *ca.* 12,000 years) is characterized as active.
- If a fault is found out to be an active one, the next step is to find out its quantitative characteristics. This means knowing its spatial (length, dip angle, strike, etc.) and temporal (recurrence interval, slip rate, etc.) characteristics. These are important parameters that are required in seismic hazard evaluation and provide valuable information for a dependable result. Spatial characteristics can be derived by geological mapping and measurements in the field. Temporal characteristics however require a more sophisticated set of methodologies. During the past few decades, two main research directions have been developed to address this problem: palaeoseismology and archaeoseismology.
  - ✓ Palaeoseismology studies the effects of a past earthquake to the environment. They are numerous and varied in nature: surface ruptures, landslides, rockfalls, tilted blocks, liquefaction, subsidence, uplift, etc. Palaeoseismology requires also precise dating of samples taken from key layers, so that an activity timeline of the fault can be established.
  - ✓ Archaeoseismology studies the effects of an earthquake to man-made structures. They are also very diverse and disperse, so they should be interpreted with caution. Their dating is easier however, as archaeologists usually have established a precise timeline of events based on their findings.

1.3 Defining an earthquake

The seismic waves

To measure the earthquakes we are mainly concentrated in the study of the seismic waves using various instruments and recordings. The energy released during an earthquake causes deformation of the rocks in the area of the focus and produces seismic waves, which transfer the energy through the interior and the surface of the Earth. The instruments that record the seismic waves are called seismographs.

The seismic waves spread out to all directions around the focus; they gradually weaken as the distance from the focus increases (Fig. 1.4). There are many different types of seismic waves; some can be transmitted through all material, some only through solid material.

The seismic waves are divided in two groups; those transmitted through Earth's crust that are called **surface** waves and those transmitted within Earths internal that are called **body** waves. **Surface** waves are travelling only through Earth's surface and are of a lower frequency than body waves which make them to be easily distinguished on a seismogram. Though they arrive after body waves, it is surface waves that are almost entirely responsible for the damage and destruction associated with earthquakes.

Surface waves are the **Rayleigh** and **Love**. Love is the fastest surface wave and moves the ground from side-to-side. Confined to the surface of the crust, **Love** waves produce entirely horizontal motion. **Rayleigh** wave rolls along the ground just like a wave rolls across a lake or an ocean. Because it rolls, it moves the ground up and down and side-to-side in the same direction that the wave is moving. Most of the shaking felt from an earthquake is due to the Rayleigh wave, which can be much larger than the other waves.

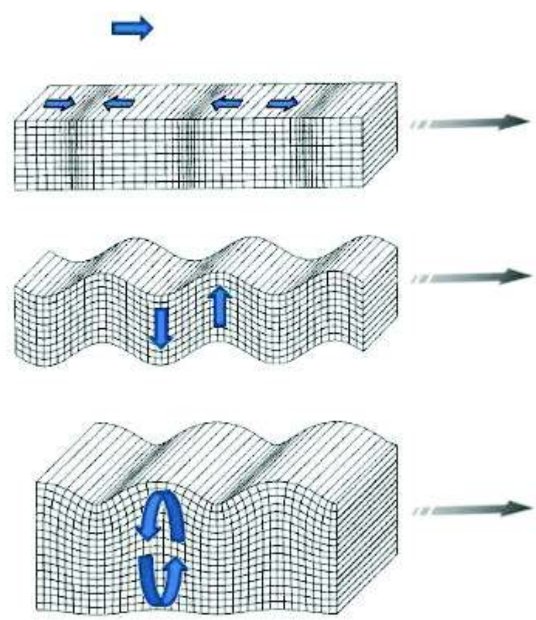


Figure 1.4 *Seismic waves: Upper image P waves, middle image S waves and lower image surface waves (USGS)*

Travelling through the interior of the earth, **body waves** arrive before the surface waves emitted by an earthquake. These waves are of a higher frequency than surface waves. Body waves are distinguish in primary (P) and secondary (S).

Primary waves (P) can travel through all types of matter (solid, liquid, gas) and are faster than all other seismic waves, meaning that they arrive first at a seismic station (primary). They are longitudinal or compressional, which means that the molecules alternately compresses and dilates in the direction of the wave propagation and transformation.

Secondary waves (S) can travel only through solids. They are transverse or shear waves, which mean that the molecules are displaced perpendicularly to the direction of the wave propagation. The difference in the arrival times of the P and S waves to a seismological station can be used by the seismologists to determine the distance between the station and the epicentre of an earthquake and in Early Warning Systems.

As body waves travel through the interior of the Earth, they create ray paths refracted by the varying density and modulus (stiffness) of the Earth's interior. The density and modulus, in turn, vary according to temperature, composition, and phase. Based on these facts body waves help scientists (geophysicists) to study Earth's interior.

Measuring earthquakes

The vibrations produced by earthquakes are detected, recorded, and measured by instruments, called seismographs (Fig. 1.5). The zig-zag line made by a seismograph, called a "seismogram," reflects the changing intensity of the vibrations by responding to the motion of the ground surface beneath the instrument. From the data expressed in seismograms, scientists can determine the time, the epicenter, the focal depth, and the type of faulting of an earthquake and can estimate how much energy was released.

As primary waves travel faster than the secondary waves, the time difference in arrival represents the distance of the seismograph station from the earthquake focus. Recordings of an earthquake by two different seismographs help to locate the epicentre on a map (Fig. 1.6).

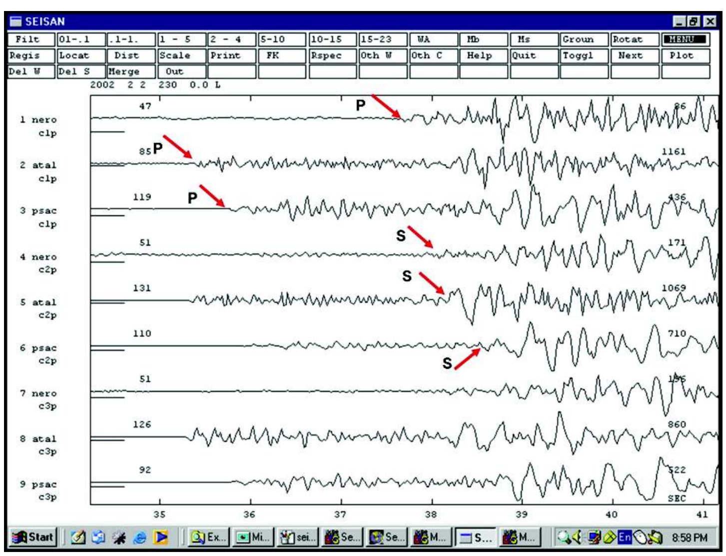


Figure 1.5 *Identification of P & S waves on a seismogram of a Greek earthquake (National Observation of Athens)*

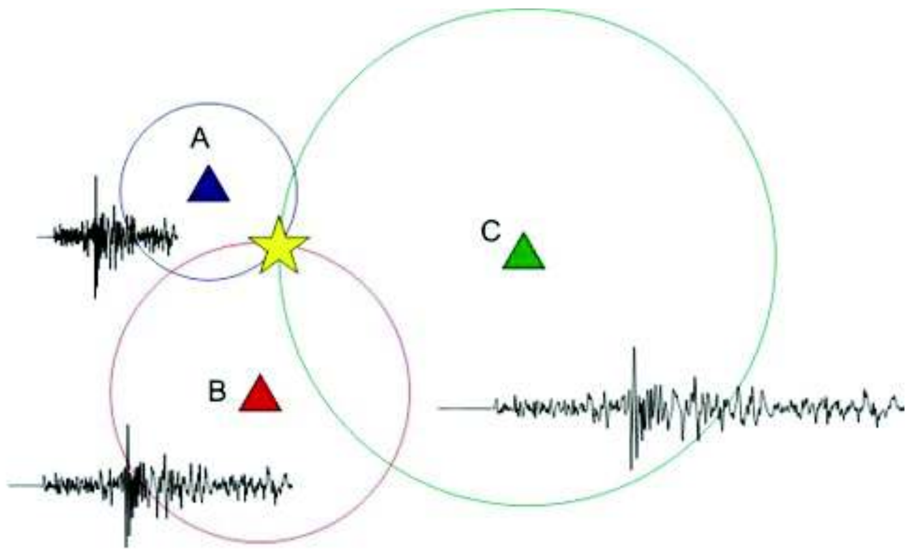


Figure 1.6 *Locating an earthquake epicentre (star) by three seismograph stations (A, B, C) by the British Geological Survey (http://www.bgs.ac.uk/discoveringGeology/hazards/earthquakes/locatingQuakes.html)*

The energy released during an earthquake is expressed by the magnitude of the quake. The ***magnitude*** of an earthquake, usually expressed by the *Richter Scale*, is a measure of the amplitude of the seismic waves in respect to the distance from focus (Fig. 1.7). The scale is logarithmic so that a recording of 7, for example, indicates a disturbance with ground motion 10 times as large as a recording of 6. A quake of magnitude 2 is the smallest quake normally felt by people. Earthquakes with a Richter value of 6 or more are commonly considered major; great earthquakes have magnitude of 8 or more on the Richter scale. This is normally what we call *Local Magnitude* (M_L).

However, in order to estimate the actual conditions of focal area instead of using the shaking of the ground far away from event, scientists developed another scale the *Moment magnitude* (M_m). This scale depends on the product of the slip of the fault when it is breaking, as well as on fault surface features, helping scientists to compare earthquakes on a global scale. The existence of other magnitude scales creates sometimes a misunderstanding and confusion regarding the magnitude of a specific earthquake.

The magnitude of an earthquake is not always related with the level of destructions caused. An earthquake far away from populated areas and human infrastructures, or very deep in focus, regardless its magnitude, may cause no destructions at all. The earthquake's destructiveness depends on many other factors and is commonly expressed as earthquake **intensity**. In addition to magnitude and the local geological conditions, these factors include also the focal depth, the distance from the epicenter, and the design of buildings and other structures. The extent of damage also depends on the density of population and construction types in the area shaken by the quake.

Intensity refer thus to the effects of an earthquake and is commonly measured by Mercalli scale or even the modified Mercalli scale. Scale is mainly a qualitative method to study the effects of an earthquake on humans and modern constructions. It ranges between I (a very weak event not felt by humans) to XII (a total damage to all constructions). Intensity is also used to study historical earthquakes because the effects are those that can be found in records.

Earthquake prediction

Earthquakes are natural phenomena yet not predicted. This means that scientists are not in the position to predict the exact location, magnitude and time of occurrence of a forthcoming event. However many efforts are undertaken in this topic to predict an earthquake.

These efforts can be specific, short term or long term. **Specific** - **Short term predictions** aim to inform State and public about a forthcoming earthquake, providing time and expected magnitude in a certain area. Only five or six times such predictions in the former USSR and China were actually successful, where combined ground, instrumental and also animal behaviours were used. These predictions are based on mainly instrumental observations on micro displacements in the ground, elastic behaviour of rocks, changes in physical and chemical properties of rocks and underground water, or ground gas emissions (like radon) or even smaller foreshock earthquakes.

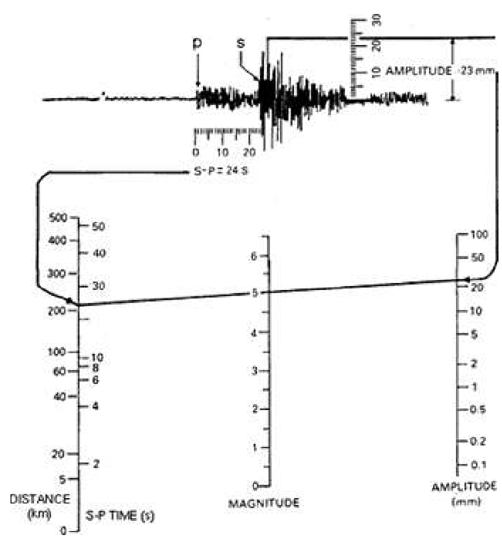


Figure 1.7 *Emprirical estimation of Earthquake magnitude using distance from focus and seismograph amplitude (British Geological Survey)*

Long term predictions methodologies are based on theoretical and statistical data, that estimate the probability of earthquakes of given magnitude in a given time period and region.

Nowadays important is the role of **early warning indicators.** These are signs of the forthcoming earthquake some hours or even seconds before it happens. Scientists have developed **early warning systems** for earthquakes or tsunamis, using modern technology and infrastructure. It is known that primary waves travel much faster than the secondary and surface waves which transfer the vast amount of seismic energy. Automatic systems can identify strong primary wave signals in a seismograph station and thus alert authorities in real-time, several seconds or even minutes before the main shaking arrive. Core systems and procedures can thus be automatically activated (or deactivated like the gas supply) to minimize effects and damage and offer the greater support.

1.4 Earthquake effects

The effects of an earthquake can be summarized in two main groups the direct effects that are induced by the earthquake phenomenon itself and the secondary effects that follow or accompany the direct effects. Buildings, roads or ground lines may be destroyed or disrupted in case of a strong earthquake.

After an earthquake secondary effects may appear. The most serious and common secondary effects are the following:

- **Fires** may occur after a strong earthquake. The ground motion can displace stoves, break gas lines or result in short-circuits that can start fire. Due to damages in water supply systems, their confrontation is also very difficult, thus their impact may be severe. Typical case studies of such effects come from the 1906 San Francisco and the 1923 Tokyo earthquakes where the 90% of damages was caused by the fires.
- **Ground displacements** like landslides, rock movements or debris flows can be triggered by seismic waves in places where surface slopes are very high and rock instabilities already exist. In many cases landslides can cover whole towns, disrupting communication and transportation assets, thus magnifying the effects of the quake.
- **Mass liquefaction** is another typical phenomenon that appears in soft and loose sediments. Due to the earthquake shaking the strength and stiffness of saturated soils or loose sediments is reduced in such a way that mass behaves actually as a liquid. Thus soil or loose sediments can no longer support foundations for buildings or bridges and that may overturn or even collapse due to differential shift of foundations. Normally after liquefactions a rearrangement of materials like sand and clay can be observed that may create fissures and sediment settlement on the earth surface. Typical examples of liquefaction have been observed during the 1964 Alaska and 1995 Kobe (Japan) earthquakes.
- Finally, another very important effect of earthquakes is the seismic sea waves, called **tsunamis**. 2004 Sumatra and 2011 Japan very strong earthquakes revealed that tsunamis might be even more hazardous than the earthquakes themselves. A tsunami is a series of sea waves with very long wavelengths (typically hundreds of kilometres) caused by large-scale disturbances of the ocean floor, such as: earthquakes, landslide, volcanic eruptions etc. For the cases of offshore and swallow earthquakes the ocean floor can be shifted suddenly due to fault slip, displacing also a large amount of seawater that forms the tsunami**.** When reaching ashore, it develops a destructive force that can cause enormous damage and many casualties. On one hand, tsunami causes disaster by sheer impact force, which depends more on the length and speed of the waves than on their height. On the other hand, retreating water masses can cause great damage by dragging along everything on their way. A tsunami develops a speed between 50 and 800km/h. Even at minimal speed, the impact of one cubic meter of water equals the force of a car crashing at 50km/h.

2. Risk Assessment

2.1 General aspect of the risk assessment

The risk assessment is a process to identify potential hazards and analyze what could happen if a hazard occurs. There are numerous hazards to consider. For each hazard there are many possible scenarios that could unfold depending on timing, magnitude and location of the hazard.

Disaster risk reduction activities generally treat different natural hazards and their associated risks separately. However, this approach ignores the spatial and temporal interactions that may arise along the disaster risk chain. For instance, an extreme event may trigger others, e.g. earthquakes causing tsunamis, or several different types may occur concurrently, e.g. severe weather and earthquakes.

There are many "assets" at risk from hazards. First and foremost, injuries to people should be the first consideration of the risk assessment. Hazard scenarios that could cause significant injuries should be highlighted to ensure that appropriate emergency plans are in place. Many other physical assets may be at risk. These include buildings, information technology, utility systems, machinery, raw materials and finished goods. The potential environmental impact should also be considered.

At EU-level there are not fixed rules about how risk assessments should be undertaken. The risk assessment includes the following issues:

- Identifying hazards and those at risk
- Evaluating and prioritising risks
- Deciding on preventive actions
- Taking actions
- Monitoring and reviewing.

However, there are two principles which should always be born in mind when approaching a risk assessment:

- to structure the assessment to ensure that all relevant hazards and risks are addressed;
- when a risk is identified, to begin assessment from first principles by asking whether the risk can be eliminated.

A holistic risk assessment framework drives development of tools and resources:

- Models of seismic hazard are built on a complex combination of geophysical and geological data. Historical and instrumental catalogues of events, together with databases of active faults and models of geodetic strain form a critical basis for the development of global models of earthquake hazard. At regional scales, data and models of earthquake hazard are developed together with local experts to form a reliable basis for seismic hazard assessment.
- Potential losses from earthquakes in terms of damage to structures and people can be estimated for the first time on a global scale and in a consistent manner.
- Composite indices of social vulnerability, resilience and indirect economic loss can be coupled to physical risk (loss and damage estimates) in order to assess risk in an integrated manner.

The impact of earthquakes on public safety and the national economy can be reduced through improvement of the built-environment to resist earthquake effects such as ground shaking.

Improving the ability of the built environment to resist earthquakes requires research in at least three areas: 1) quantification of earthquake effects, such as ground shaking, into a form suitable for use by design engineers (e.g. structural and geotechnical engineers), 2) improvement of design practices, and 3) knowledge of the types of damage that occur as a consequence of earthquakes.

The objective of an earthquake risk assessment is to quantify the potential damages and losses due to future earthquakes (the consequences) and their probabilities of occurrence in a given period (the likelihood).

Earthquake risk is a measure that combines, over a given time, the likelihood and the consequences of a set of earthquake scenarios. The risk can be estimated as the probability of harmful consequences or expected losses of lives and property and damages (e.g. people injured, economic activity disrupted, environment damaged) due to an earthquake resulting from interactions between seismic hazards (H), vulnerability (V), and exposed values (E).

Each of those factors is disaggregated into the more specific parameters that comprise it. Seismic hazard is typically interrelated with the past seismicity, geological and geophysical parameters (e.g. peak ground acceleration, seismic intensity, seismic wave propagation and attenuation, site effect). Vulnerability depends on the quality of building structures, ground condition, and population features. Infrastructure, critical facilities, and important communication system represent the values exposed to damage due to an earthquake and should be taken into account in risk estimation.

It is generally accepted that the proper approach to the problem of earthquake risk estimation and risk management should include consideration of all the contributing components. More specifically, the basic steps in an earthquake risk assessment are:

Hazard Analysis:

- Identification of earthquake sources.
- Modelling of the occurrence of earthquakes from these sources.
- Estimation of the attenuation of earthquake motions between these sources and the study area.
- Evaluation of the site effects of soil amplification, liquefaction, landslide and surface fault rupture.

Inventory Collection:

- Identification of infrastructure (buildings and lifelines) that are exposed to damage.
- Classification of the buildings and lifelines according to their vulnerability to damage.
- Classification of the occupancy of the buildings and facilities.

Damage Modelling:

- Modelling of the performance of the inventory classes under earthquake shaking and consequent effects such as ground damage.
- Development of damage functions (relationship between levels of damage and corresponding levels of shaking).

- Estimation of the damage to the inventory from the earthquake motion at the inventory locations.
- Estimation of the damage caused by post earthquake fires and other secondary events.

Loss Estimation:

- Estimation of direct losses due to damage repair costs.
- Estimation of indirect losses due to loss of function of the inventory.
- Estimation of casualties caused by the damage.

2.2 National Maps of Hazard in Greece, Italy, Bulgaria and Spain

2.2.1 Greek Seismic Hazard Map

To mitigate earthquake losses, it is necessary to evaluate the earthquake hazards across the country. The seismic hazard map addresses this need by integrating what scientists have learned about earthquake sources, crustal deformation, active faulting, and ground shaking. This information is translated into a form that can be used to reduce the risk from earthquakes and to improve public safety. The Greek Seismic Hazard Map is the basis for seismic provisions in building codes and for risk models.

The Greek Seismic Hazard Map is improved and updated on a periodic basis by incorporating new information. The Seismic Hazard Map was replaced in 2003 with a New Seismic Hazard Map (Fig. 2.2.1.1). Greece is divided into three seismic hazard zones I (a=0,16), II (a=0,24), III (a=0,36). The values of the ground accelerations are estimated to have a 10% probability of exceedance in 50 years according to the seismological data.

The EPPO Permanent Scientific Committee studies and updates the Greek Design Code and the Greek Seismic Hazard Map.

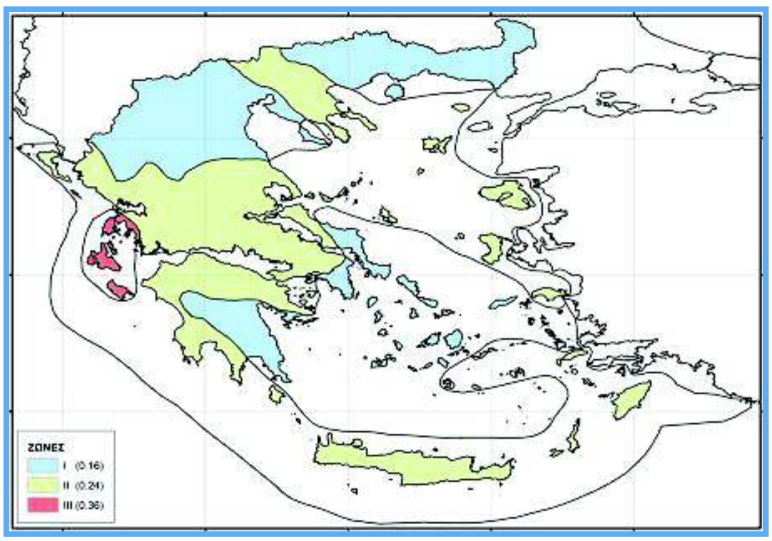


Figure 2.2.1.1 *Greek Seismic Hazard Map (EPPO 2003)*

2.2.2 Italian Seismic Hazard Map

The Italian Seismic Hazard Map shows the probably peak ground acceleration for different parts of Italy. Italy is one of the countries in the Mediterranean with the highest seismic risk, due to its particular geographic position at the convergence of the African and Eurasian plates. The highest seismicity is concentrated in the central-southern part of the peninsula, along the Apennine ridge (Val di Magra, Mugello, Val Tiberina, Val Nerina, Aquilano, Fucino, Valle del Liri, Beneventano, Irpinia) in Calabria and Sicily and in some northern areas, like Friuli, part of Veneto and western Liguria. Only Sardinia is not particularly affected by seismic events. The pink and purple areas need to undertake more preventative measures in order to evaluate the earthquake hazards across the country and to mitigate earthquake losses.

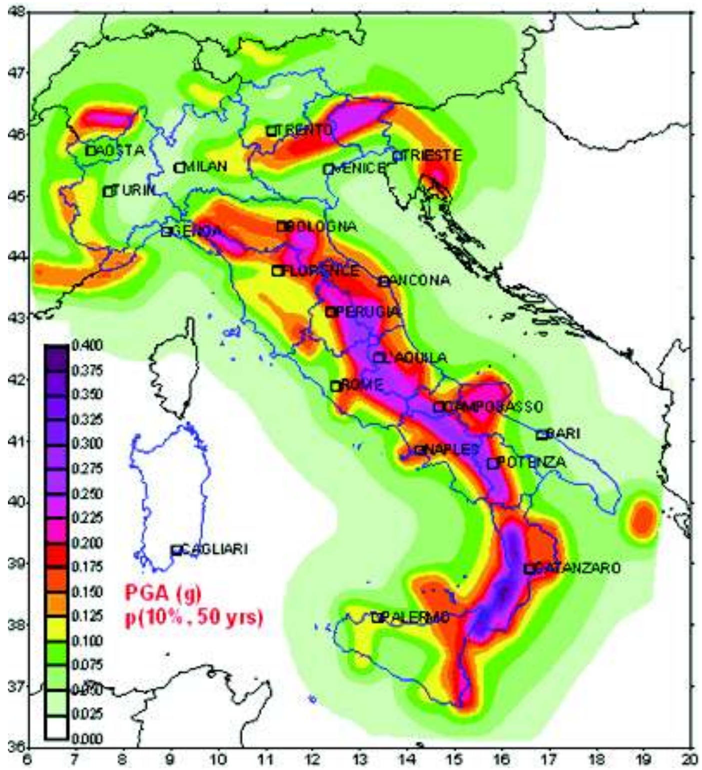


Figure 2.2.2.1 *Italian Seismic Hazard Map (source University of Urbino Italy - Seismic Hazard)*

The seismicity has remained closely localize along the orographic divide and the main hazards are associated with the Apennines. Seismicity has remained localized along the central divide, with very little seismic action along the western shore, where extension is also taking place, or along the eastern shore, where mountain-building is taking place.

The metamorphosed, folded rock comprising the Apennines might give the impression that the seismic activity there is primarily due to compressional forces. However, the seismic map of Italy illustrates otherwise: compressional stresses off the coast are associated with continued thrusting, while the central divide of the Apennines is a hotbed of extensional motion.

This wedge is centred on the drainage divide of the Apennines, between the highly permeable, extended crust of the Tyrrhenian basin and the impermeable thrust front. Over pressuring from upwelling fluids has no effect on the impermeable thrust front, while the highly permeable Tyrrhenian basin allows for the ascent of magmatic fluids. However, the upwelling of fluids in the mid-region is capable of causing seismic events of magnitudes $5 < M < 7$. Increases of stress from the fluids on the young normal faults still rooted into reactivated thrust faults is capable of causing episodic earthquakes

There is a UNESCO project underway to microzone Italy according to soil type. The properties of soils are important in deciding what preventative measures to take before the earthquake hits. Cities on soils that amplify ground motion will undergo more extensive renovation to decrease risk and possible earthquake damage.

2.2.3 Bulgarian Seismic Hazard Map

Bulgaria's territory belongs to the Earth's dangerous earthquake zones. The world's most violent and frequent earthquakes happen in the Pacific seismic belt – around 75-80%. Bulgaria is among the most active nodes in Europe, which belong to next global seismic zone – the Alpine-Himalayan. This is where the remaining 15-20% of the shocks over the world takes place. In the Balkans, however, they are 2-3 times weaker and less frequent than the most active places in the Pacific zone. Therefore the region, including our country, belongs to the second rank of the dangerous places on the planet.

97% of the territory of the country is threatened by seismic events and is classified as second rank in regard to the potential risk of earthquake occurrence. Therefore we consider it very important to map out seismic risk zones and epicenters of earthquakes, rated M ≥ 5 on the Richter scale. In Bulgaria, highest seismic risk zones are located around Blagoevgrad, Sofia, Shabla, Maritsa river, Veliko Tarnovo and Gorna Oryahovitza. (Fig. 2.2.3.1)

Figure 2.2.3.1 *Seismic risk map, showing maximum values of acceleration of the Earth surface (measured in g) with a repetition time of 475 years (Bulgarian Standards Institute)*

Only one area in Bulgaria ranks highest on this scale and this is the area around the Kresna Gorge along the Struma river (Fig. 2.2.3.2) On April 4th, 1904 there occurred the most violent shallow-focus earthquake on the Balkan peninsula and one of the strongest in Europe during the last 120 years. This earthquake was rated 7.8 on the Richter scale.

Figure 2.2.3.2 *The Kresna Gorge, Bulgaria's most dangerous seismic region* [*http://www.rezhodka.com/*](http://www.rezhodka.com/)

Seismic regions/areas in Bulgaria could be delineated as follows:

1-The Krupnik-Kresna earthquake focus – last significant earthquake in 1904 (Fig. 2.2.3.3)

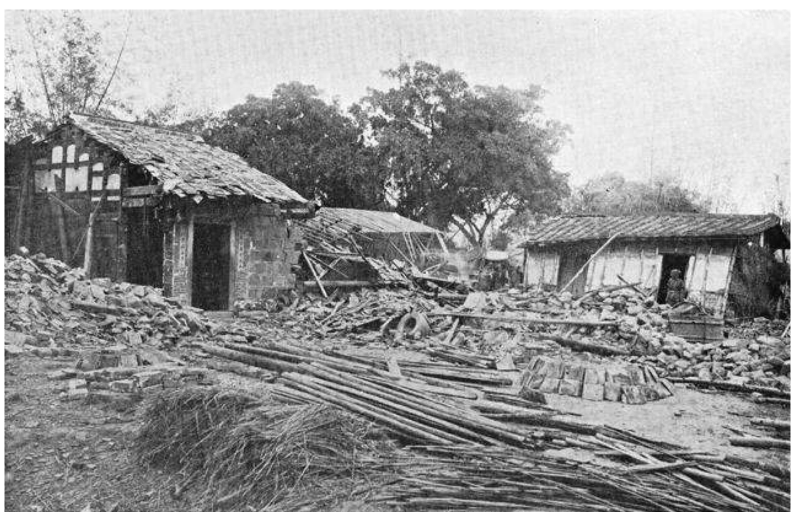


Figure 2.2.3.3 *Earthquake in Kresna, 04.04.1904 (http://novinar.bg/)*

Predicted magnitude – 7-8 on the Richter scale (X-XI on the Medvedev–Sponheuer–*Karnik scale*).

Repetition cycle – unknown.

This is Bulgaria's most "loaded" seismic zones and one of the most dangerous in Europe. **Most endangered** are populated areas around Blagoevgrad. Together, the Kresna, Blagoevgrad, Sadanski and Petrich municipalities count close to 400 000 inhabitants.

2 - Shabla earthquake focus – last significant earthquake in 1901

Predicted magnitude – 7-7,5 on the Richter scale (IX-X on the Medvedev–Sponheuer–*Karnik scale*).

Repetition cycle – unknown.

Most endangered are populated areas in two relatively crowded areas in northeastern Bulgaria – Shabla, Dobrich, Silistra, Balchik, Kavarna, Varna, counting approx. 700 000 inhabitants.

3 - Gorna Oryahovitza earthquake focus – last significant earthquake in 1913 (Fig.2.2.2.4)

Figure 2.2.3.4 *Earthquake damage in Gorna Oryahovitza after the 1913 earthquake (Archives of Regional History Museum) http://www.capital.bg/*

Predicted magnitude – 7 on the Richter scale

Repetition cycle - unknown

most endangered populated areas – Gorna Oryahovitza, Veliko Tarnovo counting close to 200 000 inhabitants.

4 - The Plovdiv-Chirpan (Maritsa river) earthquake focus – last significant earthquake in 1928 (Fig. 2.2.3.5)

Figure 2.2.3.5 *The demolished officers club in Plovdiv after the 1928 earthquake (http://dariknews.bg/)*

Predicted magnitude – 7 on the Richter scale.

Repetition cycle - unknown

Most endangered populated locations – Chirpan, Plovdiv, Stara Zagora, counting approx. 700 000 inhabitants

Besides already mentioned high-risk areas, there are many less dangerous foci, with a maximum magnitude of **6,5 to 7** on the Richter scale. **Such are the Sofia, Provadia and Yambol earthquake epicenters.** More that 1.5 mio inhabitants are potentially at risk.

Buildings and critical infrastructure are designed to withstand earthquakes with a magnitude up to 9 on the Richter scale. However, unregulated reconstructions on buildings and apartments, made over time by their owners, can lead to a weakening of the buildings' earthquake resistance. Unfortunately, this is common practice in our country.

Figure 2.2.3.6 *Damages after earthquake (http://elearn.uni-sofia.bg/)*

Housing in rural areas poses another problem, not any less significant. Qualified architectural design was extremely rare in the past. There are no guarantees whatsoever for the earthquake resistance of such buildings. Many insurance companies even decline to pay compensations when the architectural plans or a professional assessment of the building's stability are missing. This is the situation in almost all villages in the country.

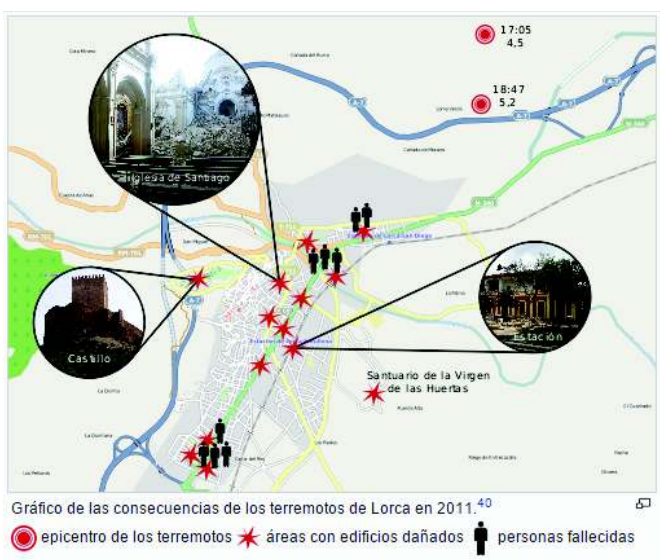
Figure 2.2.3.7 *Damages after earthquake, 1986 (www.lostbulgaria.com)*

2.2.4 Spanish Seismic Hazard Map

Spain is located in an area with moderate seismic activity. Throughout history, this phenomenon has taken lives and caused costly property damage. Compared to other natural disasters, earthquakes have the lowest impact in terms of the number of deaths caused (0.9% since 1995, including the deaths from the 2011 Lorca earthquake).

Deaths 1,056 (100%)	Natural Disasters
304 (28.8%)	Floods
222 (21.0%)	Deaths on land resulting from rough seas
183 (17.3%)	Storms, lightning and strong winds
124 (11.7%)	Forest fires
107 (10.1%)	Heat waves
48 (4.5%)	Snow avalanches
36 (3.4%)	Landslides
23 (2.2%)	Snow and cold weather
9 (0.9%)	Earthquakes

Figure 2.2.4.1 *Deaths caused by natural disasters, 1995-2012 (www.magrama.gob.es)*



Earthquake epicentre ✶ buildings damaged areas dead people

Figure 2.2.4.2 *Graphic of the consequences of the 2011 Lorca earthquakes (Zafra M., 2011, "Consequences of the Lorca earthquakes." El País)*

Within the geological risk classification categories, the types according to the derived risks must be pointed out (Fig. 2.2.4.3).

Geological Risk Classification			
Risks resulting from:	**Types of Risks**		
The planet's internal dynamics	Seismic	Volcanic	Halokinetic
The planet's external dynamics	Associated with river and torrential dynamics	Associated with mountain range movements	Associated with land subsidence
Mining and industrial activities	Caused by certain minerals and rocks that could contaminate or be harmful to health		

Figure 2.2.4.3 *Geological risk classification (García,A.)*

As shown below (Fig. 2.2.4.4), the main high seismicity areas in Spain are: the Pyrenean region, the Baetic System mountain range (Vera, Almeria, Torrevieja), the Baetic Depression, the south-west region of the peninsula and the Canary Islands.

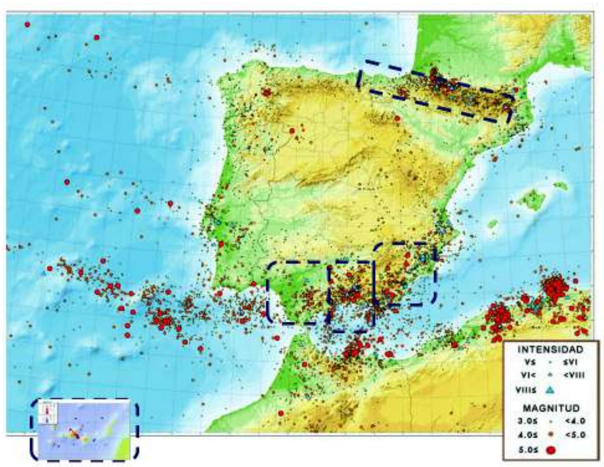


Figure 2.2.4.4 *Seismicity map for Spain (IGN)*

The methodology followed in Spain consists of gathering historical information on the events that have taken place and their consequences, ordering the information and then classifying it by creating a database. The information gathered is then analysed and the losses in recent years are assessed along with the expected losses for future decades.

Risk Analysis

Despite the extremely low probability, the risk exists and therefore the consequences must be studied and analysed as a preventive measure. The damage caused by an earthquake depends on aspects such as:

- Magnitude and intensity.
- Distance from the epicentre.

- Depth of the focus or hypocentre.
- Nature of the land affected by the waves.
- Population density.
- Type of construction.

Figure 2.2.4.5 *Seismic hazard (500-year return period) (IGN)*

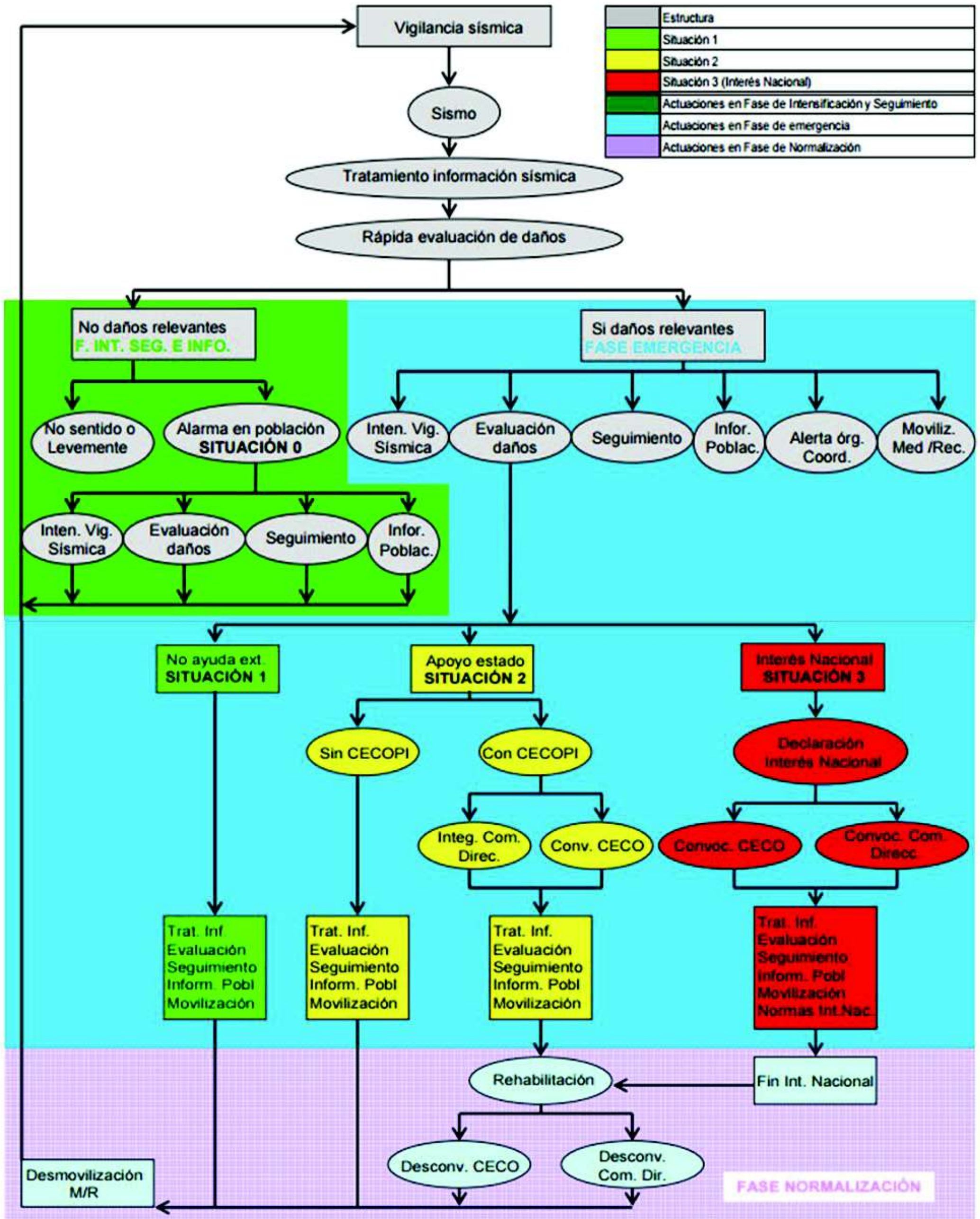


Figure 2.2.4.6 *Diagram of the National Civil Protection Plan Operations for seismic risk (ENPC: Escuela Nacional de Protección Civil de España)*

3. Prevention and Mitigation

3.1 Emergency planning

General aspects

Mitigation expresses the lessening or limitation of the adverse impacts of hazards and related disasters. The adverse impacts of earthquake hazards often cannot be prevented fully, but their scale or severity can be substantially lessened by various strategies and actions. Mitigation measures encompass engineering techniques and hazard-resistant construction as well as improved environmental policies and public awareness (UNISDR 2009).

Prevention is the outright avoidance of adverse impacts of hazards and related disasters. More specifically prevention expresses the concept and intention to completely avoid potential adverse impacts through action taken in advance. Examples include land-use regulations that do not permit any settlement in high risk zones and seismic engineering designs that ensure the survival and function of a critical building in any likely earthquake. Very often the complete avoidance of losses is not feasible and the task transforms to that of mitigation (UNISDR 2009).

Partly for this reason, the terms prevention and mitigation are sometimes used interchangeably in casual use. Disasters happen - the risks cannot be completely eliminated. But, emergency management helps all manage those disasters. A nation should prioritize the mitigation actions and should understand the importance of risk reduction to the security, resiliency, and sustainability of communities. Hazard assessment, mitigation planning, hazard-resilient building codes, seismic retrofitting, land-use management, and a host of other mitigation measures reduce the impact of disasters. *"Through mitigation, we support preparedness, make response easier and faster, speed recovery, and reduce the financial impact of disasters on individuals, businesses, communities, and governments" (FEMA 2011).*

Mitigation Core Capabilities

The Mitigation Framework (Fig. 3.1) describes each of eight core capabilities listed below:

- **Earthquake Hazard Identification.** Build cooperation between private and public sectors by protecting internal interests and sharing threats and hazard identification resources and benefits.
- **Earthquake Risk Assessment.** Perform credible risk assessments using scientifically valid and widely used risk assessment techniques.
- **Planning.** Incorporate the findings from assessment of earthquake risk and disaster resilience into the planning process.
- **Community Resilience.** Recognize the interdependent nature of the economy, health and social services, housing infrastructure and natural and cultural resources within a community.
- **Public Information.** In the framework of population awareness, National Authorities:
    - provide guidelines for safety issues, emergency plans and earthquake drills
    - implement training seminars for teachers and civil protection personnel, lectures for students, volunteers, business staff, people with disabilities, employees in hotels e.tc.

- publish informative material (booklets, posters, books, CD-ROM, advertising TV messages, website)
- hold earthquake emergency drills in schools and working places.

- **Long-Term Vulnerability Reduction.** Adopt and enforce a suitable building code to ensure resilient construction. One of the most effective ways to mitigate the damage of earthquakes from an engineering standpoint is to design and construct structures capable of withstanding strong ground motions. Seismic upgrade of the building stock and the subsequent mitigation of seismic risk may be performed either through a gradual replacement of the under-designed (old) buildings with seismic resistant ones, or through seismic strengthening of existing buildings. The first, quite natural but also slow approach does not lead to remarkable results but is of low cost. The second can upgrade the building stock faster but is inevitably associated with enormous cost, which is unbearable even in the most developed countries.
- **Operational Coordination.** Capitalize on opportunities for mitigation actions following disasters and incidents.

Figure 3.1 *National Mitigation Framework (Homeland Security, May 2013)*

- **Monitoring and Early Warning Systems.** The expression "early warning" is used in many fields to mean the provision of information on an emerging dangerous circumstance where that information can enable action in advance to reduce the risks involved. Early warning systems exist for natural geophysical and biological hazards, complex socio-political emergencies, industrial hazards, personal health risks and many other related risks. In the current UN-ISDR terminology, early warning is defined as "*the provision of timely and effective information, through identified institutions, that allows individuals exposed to a hazard to take action to avoid or reduce their risk and prepare for effective response*" (ISDR 2004).

To be effective and complete, an early warning system needs to comprise four interacting elements (ISDR-PPEW 2005a), namely: (i) risk knowledge, (ii) monitoring and warning service, (iii) dissemination and communication and (iv) response capability. While this set of four elements appears to have a logical sequence, in fact each element has direct two-way linkages and interactions with each of the other elements.

Earthquake early warning systems use earthquake science and the technology of monitoring systems to alert devices and people when shaking waves generated by an earthquake are expected to arrive at their location. The seconds to minutes of advance warning can allow people and systems to take actions to protect life and property from destructive shaking. Even a few seconds of warning can enable protective actions such as:

- Public: Citizens, including schoolchildren drop, cover, and hold on, turn off stoves, safely stop vehicles.
- Businesses: Personnel move to safe locations, automated systems ensure elevators doors open, production lines shut down and sensitive equipment is placed in a safe mode. Personnel take protective actions.
- Medical services: Surgeons, dentists, and others stop delicate procedures and take protective actions.
- Emergency responders: Open firehouse doors, personnel prepare and prioritize response decisions and take protective actions.

Improving the seismic capacity of structures

Of the many earthquake hazard mitigation measures in existence, this one still remains the most elusive even today and requires constant attention as it is well known that any updated changes and adjustments to current building code performance requirements are not retroactive. In fact the majority of older structures constructed over the years are still recognized as not meeting the seismic standards promulgated by current code levels of performance, which makes them quite vulnerable to earthquake risk.

Over the years, it has become clear that most of the casualties resulting from seismic activity around the world are, in fact, a result of the failure of older classes of buildings with unreinforced masonry, pre-1970 non-ductile concrete frame, and late 1960's pre-cast, pre-stressed structures being among the most vulnerable. It has only been during the last two decades that the problem associated with the seismic safety of older, existing buildings has been seriously addressed and codified. It is only recently in the U.S.A. that NEHRP provisions for the earthquake performance of existing buildings have been published on a national basis.

Currently, the rehabilitation and seismic upgrading of older, existing buildings is clearly recognized as one of the most critical areas of study in which the architect and design engineer have an important responsibility of joint interest. The economic feasibility of these retrofit programs is based on the assumption that it is possible to produce dramatic improvements in a structure's seismic performance on several levels.

In typical urban environments today, a basic rehabilitation problem confronted by design professionals is that many older, existing buildings are represented by structures of high architectural value. Many cities have a highly prized architectural heritage which cannot be duplicated. The rehabilitation and renewal process also means dealing with the complexities of structural systems and the modelling of the mechanical behaviour of materials of construction. An acute problem occurs when the historical and architectural value of these buildings is incompatible with strengthening interventions which cannot be appropriately masked.

Open Urban Space Utilization

This is a critical area in the disaster mitigation process that still requires intensive study by urban planners and architects. Immediately following a major damaging earthquake, confusion reigns as the forces of the immediate post-earthquake recovery process are called into action.

3.2 Raising awareness

The key to reducing loss of life, personal injuries, and damage from natural disasters is widespread public awareness and education. People must be aware of what they are likely to face in their own communities because of natural hazards. They should know in advance what specific preparations to make before an event, what to do during an earthquake, flood, fire, or other likely event, and what actions to take in its aftermath.
Competent authorities worldwide:

- Organize training seminars for teachers, volunteers or engineers on earthquake protection issues.
- Implement lectures for civil protection personnel, volunteers, students, business staff, people with disabilities, employees in hotels e.tc.
- Compose informative material (booklets, posters, books, CD-ROM, website, advertising TV messages, interactive games, internet games) for different target groups (students, teachers, general public, tourists).
- Participate in preparedness drills in schools and working places (Fig. 3.2).
- Provide guidelines for seismic disaster management at local and regional level, emergency plans and earthquake drills.

Figure 3.2 *Earthquake drill at school (EPPO)*

4. Preparedness

4.1 Protective guidelines before, during and after the phenomenon

Because earthquakes strike suddenly and without warning, being prepared in advance is critical to minimize damages and loss. Surviving an earthquake and reducing its health impact requires preparation, planning, and practice. Actually, almost all earthquake damages and losses can be reduced by measures everybody should take before, during, and after the earthquake event.

"Disasters can be substantially reduced if people are well informed and motivated towards a culture of disaster prevention and resilience, which in turn requires the collection, compilation and dissemination of relevant knowledge and information on hazards, vulnerabilities and capacities" (UN/ISDR, 2005).

Typical preparedness measures include developing mutual aid agreements and memorandums of understanding, training for both response personnel and concerned citizens, conducting disaster exercises to reinforce training and test capabilities, and presenting all-hazards education campaigns (Fig. 4.1.). Unlike mitigation activities, which are aimed at preventing a disaster from occurring, personal preparedness focuses on preparing equipment and procedures for use when a disaster occurs i.e. planning. Also earthquake protective measures involve Drop-Cover-Hold on.

Figure 4.1 *Poster with preparedness measures (EPPO)*

4.2 Guidelines for emergency planning

Preparedness Cycle

"A secure and resilient nation with the capabilities required across the whole community to prevent, protect against, mitigate, respond to, and recover from the threats and hazards that pose the greatest risk." (U.S. Department of Homeland Security, 2011). Preparedness encompasses those pre-disaster activities that develop and maintain an ability to respond rapidly and effectively to emergencies and disasters (FEMA, 2015).

Preparedness could be defined as "*a continuous cycle of planning, organizing, training, equipping, exercising, evaluating, and taking corrective action in an effort to ensure effective coordination during incident response*" (Fig. 4.2). This "preparedness cycle" is one element of a broader Preparedness System to prevent, respond to, recover from, and mitigate against natural disasters, acts of terrorism, and other man-made disasters (U.S. Department of Homeland Security, 2011).

Figure 4.2 *Components of the Preparedness Cycle*
(U.S. Department of Homeland Security, 2011)

More specifically:

a. Planning makes it possible to manage the entire life cycle of a potential crisis. Strategic and operational planning establishes priorities, identifies expected levels of performance and capability requirements, provides the standard for assessing capabilities and helps stakeholders learn their roles.

b. Organizing and equipping provide the human and technical capital stock necessary to build capabilities and address modernization and sustainability requirements. Organizing and equipping include identifying what competencies and skill sets people delivering a capability should possess and ensuring an organization possesses the correct personnel. Additionally, it includes identifying and acquiring standard and/or surge equipment an organization may need to use when delivering a specific capability.

c. Exercises enable entities to identify strengths and incorporate them within best practices to sustain and enhance existing capabilities. They also provide an objective assessment of gaps and shortfalls within plans, policies and procedures to address areas for improvement prior to a real-world incident. Exercises help clarify roles and responsibilities among different entities, improve interagency coordination and communications and identify needed resources and opportunities for improvement.

The overall objective of emergency plan

An emergency plan specifies procedures for handling sudden or unexpected situations. The objective is to be prepared to:

- Prevent fatalities and injuries.
- Reduce damage to buildings, stock, and equipment.
- Protect the environment and the community.
- Accelerate the resumption of normal operations.

Development of the plan begins with a vulnerability assessment. The results of the study will show:

- How likely a situation is to occur and its effects?
- What means are available to stop or prevent the situation?
- What is necessary for a given situation?

From this analysis, appropriate emergency procedures can be established.

At the planning stage, it is important that several groups be asked to participate. Among these groups, the health and safety groups can provide valuable input and a means of wider worker involvement. Appropriate municipal officials should also be consulted since control may be exercised by the local government in major emergencies and additional resources may be available. Communication, training and periodic drills will ensure adequate performance if the plan must be carried out.

The emergency plan includes:

- All possible emergencies, consequences, required actions, written procedures, and the resources available.
- Detailed lists of personnel including their home and other telephone numbers, their skills, their duties and responsibilities.
- Floor plans.
- Large scale maps showing evacuation routes and service conduits (such as gas and water lines).

4.3 Family Emergency Planning

If someone lives in an area at risk for earthquakes, there are actions that he can do to reduce the chance that he or other members of his family will be injured, that his property will be damaged, or that his home life will be unduly disrupted by an earthquake. These actions all fit under the term "preparedness", because to be effective, they must be done before earthquakes occur.

Preparing for earthquakes involves: a. learning what people should do before, during, and after earthquakes; and b. doing or preparing to do those actions now, before the next quake.

Before an earthquake

The members of each family can take several measures to protect themselves and their property in case of an earthquake, such as to:

- Be informed about the earthquake phenomenon and the municipality plan.
- Develop family emergency procedures and make plans for reuniting the family in a safe, open place in the neighbourhood (Fig. 4.3).
- Organize a Personal Support Network, in case there is a family member with disabilities.
- Locate safe spots in each room.
- Build an emergency kit with the basic items that may needed in an earthquake event and keep a list of emergency phone numbers (www.oasp.gr, www.fema.gov).
- Identify and reduce non-structural hazards. The contents of the buildings must be secured to reduce the risk for life and property. Anything heavy enough that can cause injury or fragile and/or expensive enough to be a significant loss if it falls, should be secured (fasten shelves and mirrors securely to walls, put large or heavy objects on lower shelves etc).
- Be aware of how to turn off gas, water and electricity in case the lines are damaged.
- Hold earthquake drills at home with family members according to the guideline “Drop, cover and hold on”.

Figure 4.3 *Develop family emergency procedures and make plans for reuniting the family in a safe, open place in the neighbourhood (EPPO 2013)*

During an earthquake

If indoors, all members of the family should:

- **Stay inside and calm until the shaking stops**. Do not exit of a building during the shaking. The most injuries occur when people inside buildings attempt to move to a different location inside the building or try to leave it.
- **Drop** to the ground, take **cover** by getting under a study table and **hold on** until the shaking stops (Fig. 4.4). If there isn't a suitable furniture, drop to the ground and cover the head and the neck with the arms (Fig 4.5).
- Stay away from glass, windows, and anything that could fall, such as lighting fixtures or furniture.
- **Do not stand in a doorway.** In reinforced concrete buildings, doorways are no stronger than any other part of the house. Stand in a doorway only in case of masonry building.

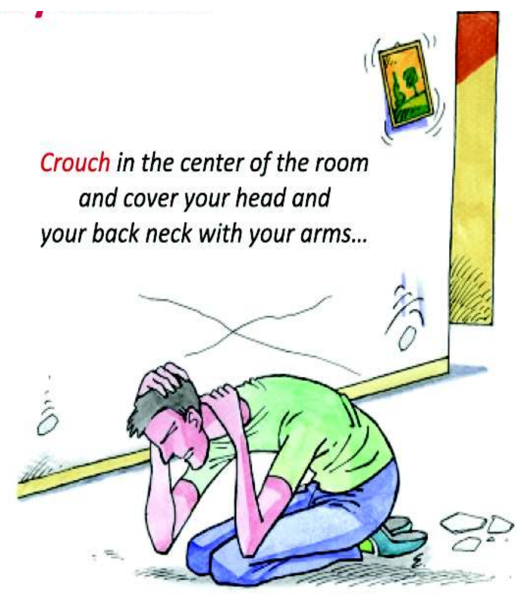


Figure 4.4 *Drop to the ground, take cover by getting under a study table and hold on until the shaking stops (EPPO 2013)*

Figure 4.5 *If there isn't a suitable furniture, drop to the ground and cover the head and the neck with the arms (EPPO 2013)*

If someone uses a wheelchair, he should lock the break on the wheels and cover the head and neck with his hands, crouching towards his knees as much as possible.

If outdoors, everyone should remember to stay outside, away from buildings facades, utility wires, exterior walls etc.

If in a vehicle, everyone should stop as quickly as safety permits in a safe area and avoid stopping near or under buildings, trees, utility wires etc.

After an earthquake

After the shaking stops all members of the family should:

- Provide first aid as needed and call for emergency medical assistance.
- Turn off water and electric services to avoid further damage.
- Extinguish small fires or report larger blazes.
- Wear shoes and proper clothes.
- Evacuate the building without using elevator.
- Go to a predefined safe, open space and stay away from damage areas (Fig. 4.6). Avoid waterfront areas because of the threat of tsunamis.
- Keep in mind that aftershocks may strike at any time, exacerbating hazards and requiring you to immediately drop, cover, and hold on.
- Follow the guidelines of the competent authority. Use telephone for emergencies, only.

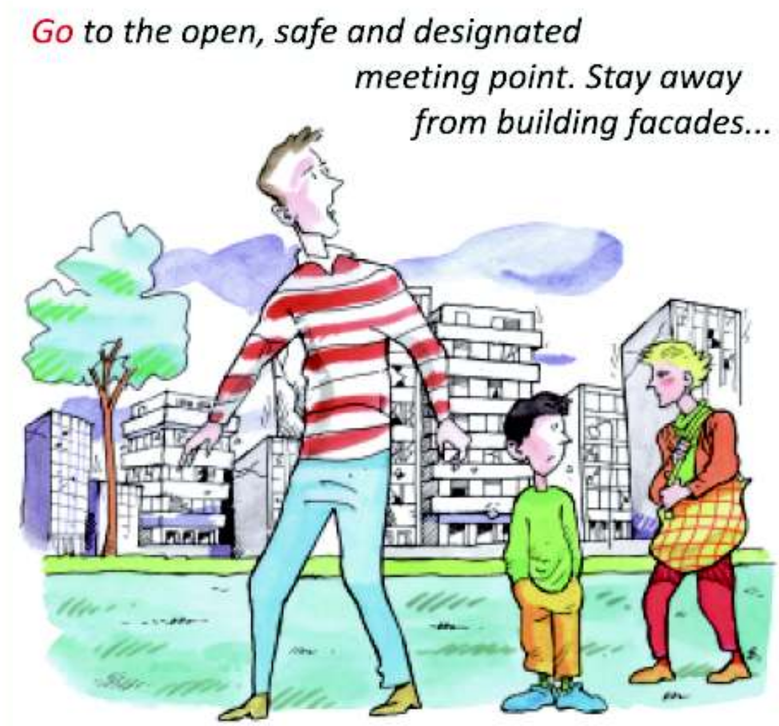


Figure 4.6 *Go to a predefined safe, open space and stay away from damage areas (EPPO 2013)*

4.4 Emergency Planning at schools, work places etc.

Earthquake Safety at School

School preparedness requires the participation of Directors, teachers, students, and parents, as well as those who design, build, regulate, and maintain school buildings in order to deal with a strong earthquake event (Fig. 4.7).

Figure 4.7 *Preparation of students on earthquake protection issues (EPPO)*

<u>*Before an earthquake*</u>

Each school is responsible to:

- Prepare students and school staff to react safely. Everyone who attends or works in a school needs to learn "What to do during an Earthquake", how to prepare for earthquake shaking, how to stay safe during and after an earthquake at school and how to deal with psychological impacts of an earthquake.
- Develop and update of School Earthquake Emergency Plan. To be operational, this Plan should be clear and straightforward and should contain description of procedures and actions to be taken before, during and after an earthquake.
- Hold earthquake drills in order to give students and staff opportunities to practice what they have learned and condition themselves to react spontaneously and safely when the first shaking is felt.

<u>*During the earthquake*</u>

When earthquake shaking begins, it is time for school staff and students to immediately apply what they have learned about "What to do during an Earthquake". Reacting promptly and safely reduces the chances of being injured. More specifically:

- If indoors, the students and teachers should:

- remain calm, do not run and stay inside.

- Drop, Cover and Hold on. If the students are in the classroom they should **drop** to the floor, take **cover** under the desk, and **hold on** firmly. If the students are in the corridors or other areas of the school building, they should drop to the floor, cover and protect head and neck with their arms, until the shaking stops.
- know that the children with impaired mobility should cover their head and neck with their arms. If they are using a wheelchair they have to lock the brake of the wheels first and then to cover their head and neck with their hands.

- If outdoors, the students should stay outside away from the buildings, avoid power lines, signs and other hazards, and follow the orders given by the School Director or the teachers.

After an earthquake

Once the shaking stops, schools should be prepared to implement prearranged, earthquake-specific emergency response following the emergency plans. Students and staff must keep in mind that aftershocks may strike at any time, exacerbating hazards created by earlier shaking and requiring that everyone again drop, cover, and hold on. After the shaking stops, students should be gathered in the courtyard or other safe outdoor area following the school emergency plan, stay calm away from buildings and wait for further information through the competent authorities.

Earthquake Safety at Community

Disaster response and contingency planning leads to organizational readiness in anticipation of an emergency. This includes management of human and financial resources, availability of emergency supplies, and communications procedures.

Communities which have made disaster preparedness plans well in advance of the time of the actual event can achieve quicker and better organized responses when an emergency arises. Essential components of an effective community-based emergency management planning process include the following:

- Determine the risks and hazards the community faces.
- Determine current capacities and capabilities.
- Identify and establish the emergency management preparedness and response teams.
- Develop a preparedness and response planning taking into account vulnerable populations, communication planning, health planning, mental health planning etc.
- Inform the population and specific target groups.
- Train, exercise, and drill collaboratively.
- Evaluate and improve the integrated community plan.

5. Response

5.1 First Response actions

General aspects

Response expresses the provision of emergency services and public assistance during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected (UNISDR 2009).

Response versus Recovery: A Critical Distinction

Disaster response is predominantly focused on immediate and short-term needs and is sometimes called "disaster relief". The division between this response stage and the subsequent recovery stage is not clear-cut. Some response actions, such as the supply of temporary housing and water supplies, may extend well into the recovery stage (UNISDR 2009).

The kind of relief needed in an emergency depends very much on the immediate goal of the affected people. Their most immediate needs during or soon after the event are food, rescue, communications, etc. After the direct dangers of the disaster have passed, rebuilding is one of the first priorities. Therefore, relief agencies distinguish between Response and Recovery.

Response begins as soon as a disaster is detected or begins to threaten an area. Response involves mobilizing and positioning emergency equipment; getting people out of danger; providing needed food, water, shelter and medical services; and bringing damaged services and systems back on line. Local responders, government agencies and private organizations also take action.

Earthquake response activities

Disaster response activities are designed to protect life and property and control secondary earthquake hazards (e.g. earthquake-induced fires and hazardous materials spills). These actions begin with the warning of an oncoming threatening event or with the event itself if it occurs without warning (e.g. earthquakes provide no warning).

Disaster response activities typically include:

Initial Information

Perhaps the most significant challenge facing affected communities in the immediate post-impact period is accurate assessment of the situation and prioritization of response needs (MCEER, 2000).

The estimation of the situation concerning damages and side effects is difficult because earthquakes tend to affect a widespread area even if the event is moderate. Also, earthquakes affect above- and below-ground lifelines, buried utilities and communication systems.

Fast, reliable estimation of the situation after earthquakes is vital for the effective mobilization of civil protection forces and for the control and repression of side effects.

Search and Rescue Operations

Search and Rescue (SAR), is the process of identifying the location of disaster victims who may be trapped or isolated and bringing them to safety and medical attention. The search and rescue operations started once there is information concerning trapped persons in partial or total collapse buildings.

International Search and Rescue Advisory Group (INSARAG) is a global network of more than 80 countries and organizations under the United Nations umbrella. INSARAG deals with urban search and rescue (USAR) related issues, aiming to establish minimum international standards for USAR teams and methodology for international coordination in earthquake response based on the INSARAG Guidelines endorsed by the United Nations General Assembly Resolution 57/150 of 2002, on "Strengthening the Effectiveness and Coordination of International Urban Search and Rescue Assistance".

Emergency relief

Emergency relief is the provision, on a humanitarian basis, of material aid and emergency medical care necessary to save and preserve human lives. It also enables families to meet their basic needs for medical and health care, shelter, clothing, water, and food (including the means to prepare food). Relief supplies or services are provided, in the days and weeks immediately following a sudden disaster.

A well-organized supply service is crucial for handling the procurement or donation, storage, and dispatch of relief supplies for distribution to disaster victims.

Evacuation/migration

Evacuation includes the movement of population to a safer location if structures are susceptible to damage.

Emergency restoration of essential services - Other technical emergency operations

The continued operation of critical facilities (i.e., hospitals, emergency centers, water treatment facilities, air traffic control towers, etc.) and restoration of lifelines are essential.

Additionally other technical interventions after an earthquake are: removal or demolition of dangerous parts and elements of the building, emergency demolition of buildings damaged beyond repair, emergency support of some damaged buildings, disconnection of electricity, water, gas utilities if necessary, application of all necessary security measures e.g. barricades, warning messages (Fig. 5.1).

Figure 5.1 *1999 Athens Earthquake (EPPO, 2000)*

Communication and information management

All of the above activities are dependent on communication. There are two key aspects to communications in disasters:

- The equipment essential for information flow, such as: radios, telephones, and their supporting systems.

- The information management, that is, the protocol of knowing who communicates, what information to whom, what priority is given to it, and how it is disseminated and interpreted.

Psychological support of the affected population

Victims of devastating earthquakes experience intense physical and mental distress. They have to adapt to a considerably modified natural environment and to face the psychological distress caused by the loss of property, the possible injuries and the potential loss of life in their environment. At the same time, they have to live for quite a long period in a situation of continuous vigilance and fear of strong aftershocks (Fig. 5.2).

During the early post earthquake period efforts are focused on dealing with the needs as well as on the full recovery and convalescence of the individual, the family and the society in general. The professionals who provide mental health care aim at restoring the victims' and first responders' mental balance to what was before the event.

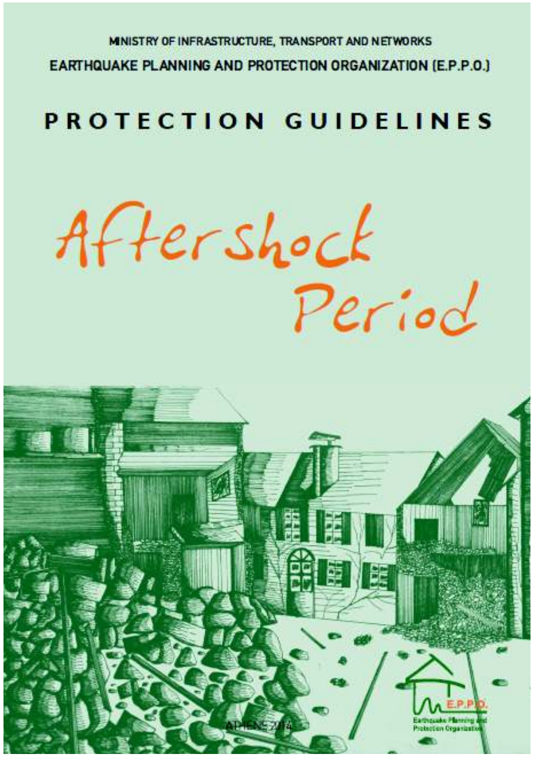


Figure 5.2 *Booklet with protection guidelines at aftershock period (EPPO)*

5.2 Post assessment of buildings and infrastructure

After an earthquake, an operation of emergency inspection of buildings and infrastructures is carried out. The buildings are inspected in order to be classified in categories in regard to their usability. The aims of the inspections are:

- To identify as soon as possible all buildings which are safe to occupy and use (Fig. 5.3).
- To examine if there is an immediate danger due to building collapse.
- To propose safety measures for the protection of the occupants or the public.
- To assess as soon as possible after the earthquake the number of building those are not usable and provide the number of homeless households.
- To present a reliable overview of the damage of building stock in the area that will allow authorities to take relief measures.
- To support future scientific studies on building response and vulnerability. These studies may lead to revaluation of existing codes and construction practices.
- To identify frequent causes of damage, so that potential rehabilitation plans may take into account such assessments.

To be successful an operation, must be: well organized, yield uniformly reliable damage data and completed in a short period of time. Depending upon the aftershock sequence, the operation could start immediately or after it is assessed by seismologists that the major threat has passed.

Figure 5.3 *Damaged building at 2014 Cephalonia Earthquake in Greece (EPPO)*

5.3 Temporary shelters

A series of measures are taken for the support of the population affected by the earthquake, the most important of which are: accommodation in tents, ships and hotels (Fig. 5.4). For the immediate accommodation of the earthquake victims the responsible Ministries (e.g. Ministry of Health and Welfare, Ministry of a National Defence) may offer tents and those made homeless may accommodated in hotels.

Also Electricity Power Companies and Telecommunication Companies are paying for the necessary works (network, sub-stations and supply) for the supply of electricity to the organized tent camps and to the organized settlements of prefabricated houses.

Figure 5.4 *Temporary shelter (EPPO)*

5.4 Financial aid and other benefits

After an earthquake the government may announce financial assistance measures to those affected, such as:

- special financial aid, as a temporary assistance during the first few weeks after the disaster, to those categorized as homeless by the first rapid safety inspection of buildings.
- special financial aid to pensioners and unemployed in areas hit by the earthquake.
- special financial aid for all households that had a life loss or injury that caused incapacity or lived in a collapsed building.
- special regulations for dues to the State and to Health Funds. The State may postpone dues for a time period (e.g. from six months to two years) for earthquake victims.

6. Recovery

6.1 Temporary Housing Settlements

Recovery is the phase of earthquake management that aims to restore communities affected by disasters to a normal regime of social and economic activity. It involves not only repairing or replacing physical infrastructure damaged during an earthquake, but also rebuilding the economic strength and social stability of a community through appropriate financial and regulatory programs. Recovery activities consist of actions taken to return to (or, ideally, exceed) pre-earthquake levels of activity and productivity (Quarantelli, 1999).

These actions include restoring, repairing, and reconstructing lifelines and buildings, undertaking measures to overcome earthquake-induced economic downturns, and providing financial assistance to compensate for losses. The recovery period typically is the time in which decisions are made about adopting new mitigation measures with the long-term objective of increasing the earthquake resistance of the built environment. If undertaken properly, recovery strategies can contain indirect and induced earthquake losses, shorten the recovery period for affected social units, and avoid future losses through improvements in mitigation.

Recovery once was viewed as a linear phenomenon, with discrete stages and end products. Today it is seen as a process that entails decision-making and interaction among all stakeholders such as households, businesses, and the community at large.

Following an earthquake, support to transitional settlement and reconstruction may be the greatest priority of those affected. Shelter is critical to survival. From the emergency phase until durable solutions, it is necessary to provide security and personal safety, while protection from the climate also protects from ill health and disease. Shelter and settlement support human dignity and family and community life, when populations are displaced from their homes, maximizing communal coping strategies (UNDRO, 1982).

Temporary housing is a crucial but controversial part of disaster recovery. Disaster-affected families who have lost their homes need a private and secure place to restart their daily activities as soon as possible after the disaster, yet temporary housing programmes tend to be overly expensive, and responsible for undesirable impacts on the urban environment.

However, judging by the frequency of use after large-scale earthquakes, the supply of temporary housing units can be essential for quick recovery of the population and to allow time for safe rebuilding. Ideally, after a disaster, temporary housing would be immediately available, offering a level of comfort consistent with the prevailing standard of living, at a cost proportional to intended length of use and easily eradicated or transformed once it is no longer needed. But in reality temporary housing campuses can become an environmental issue and a hotbed of social dysfunctions (Johnson, 2007).

After serious earthquakes, families may be temporarily housed in existing but vacant housing or they may be able to shelter themselves. But, many disasters situations create a housing crisis that forces the authorities to supply temporary housing units. To be successful in terms of recovery, cost effectiveness and environmental concerns, temporary housing programmes must address factors existing in the larger environment, such as local living standards, local industries, local politics and permanent reconstruction programmes. Temporary housing allows for -in a temporary location- a return to normal daily activities, i.e. work, school, cooking at home, shopping, etc.

Temporary housing can take different physical forms and the simplest type of temporary housing is rented apartments. In the situation where there is a supply of vacant apartments available in the disaster area, families often receive rental subsidies from the government. Also, if possible, many people go and stay with relatives close-by or at summer houses. If these options are not sufficient, some type of temporary housing must be constructed or supplied by the State (Fig. 6.1).

After the Athens 1999 earthquake in Greece, all the three above mentioned solutions were available to the homeless. The vast majority of affected citizens preferred the temporary container-dwellings solution (Fig. 6.2). Most of these families did not own their homes and have found themselves pushed out of the rental market, due to the significant increases in rents that have occurred following the earthquake. Also the poorest families did not have sufficient funds to finance the necessary repairs despite the financial assistance (Pomonis, 2002). In Attica region, 5.736 prefabricated houses were established for the temporary accommodation of earthquake homeless families, in 112 organized settlements at 32 Municipalities. About 30.000 families used the measure of rent subsidy (EPPO, 2014).

Figure 6.1 Temporary housing in Japan after the 1995 Kobe Earthquake (Comerio, 1998)

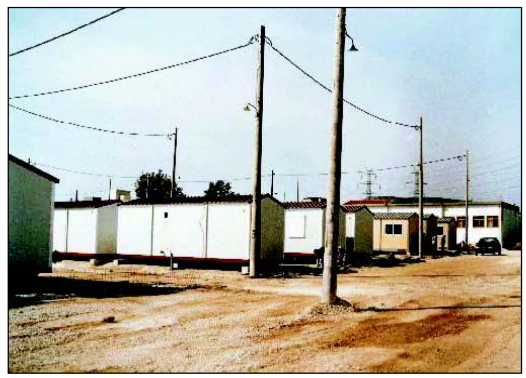


Figure 6.2 *Temporary housing settlement in Attica region (ECPFE, 2000)*

An extremely important aspect of temporary housing is the designing of the time length that temporary housing will be needed or an efficient long-term plan for the units: The length of time temporary housing is needed will depend upon the timing of the permanent reconstruction programme and must reflect who will be included in this programme.

Temporary accommodation tends to be used longer than originally anticipated and this can affect the form of the city and the region. As time passes, temporary accommodation takes on a more permanent status. For these reasons, decision-makers need to consider the long-term when planning for supposedly short to mid-term temporary accommodation.

6.2 Spatial regeneration of the affected area

Historically, and even in recent events, when a community is struck by a disaster, a rapid return to the status quo is often hoped for. But one of the most significant lessons of the last few decades has been that simply rebuilding communities to pre-disaster status will definitely recreate the vulnerabilities that existed before and again expose them to devastation from future disasters. Over the years there has been a consideration that reconstruction after a disaster is an opportunity to "build back better" (UNDRR, 2015).

This "build back better" approach advocates for the restoration of communities and assets in a manner that makes them less vulnerable to disasters and strengthens their resilience. The Hyogo Framework for Action called for the "incorporation of disaster risk reduction' measures into post-disaster recovery and rehabilitation processes and use opportunities during the recovery phase to develop capacities that reduce disaster risk in the long term".

Worldwide, the urban development and disaster management arena stand at a critical crossroad, as a growing volume of damage caused by natural disasters is increasingly affecting urban and rural inhabitants. The role that a spatial planning plays is becoming increasingly important. Experiences in rebounding from disasters have led to advances in the field of spatial planning.

Resilient recovery and reconstruction can be realized through a variety of strategies: a) enhancing preparedness b) relocating critical facilities to safer areas c) integrating disaster risk reduction measures into infrastructure improvements d) strengthening governance structures, including the development of institutional mandates for disaster risk management e) using the reconstruction process to address urban planning challenges and f) establishing predictable contingent financing mechanisms, including disaster risk financing (UNDRR, 2015).

Resilient recovery and reconstruction are now recognized as imperative for sustainable development. To maintain sustainability, recovery and reconstruction programs require predictable technical and financial resource commitments for planning, implementation, and performance management. Additionally, at national levels, governments must have the capacity to develop policies and mechanisms that ensure integration of disaster risk reduction in recovery and reconstruction efforts. According to the 2007-2013 Hyogo Framework of Action, while many countries have successfully introduced policies to integrate disaster risk reduction in recovery planning, they often encounter difficulties during implementation.

To be successful, recovery and reconstruction programs require high levels of political commitment and strong institutional frameworks, which provide greater opportunity for promoting risk reduction and building resilience.

Earthquake protection occupies a marginal position in spatial planning. A range of factors are contributing to this situation, among them divisions between the disciplines and differences in their perceptions and convictions, experiences and traditions, means of communication, aggregate understanding and knowledge on earthquake protection. Post-earthquake "*window of opportunity"* in the affected areas needs upmost a multi-sectoral and multi-thematic approach to reconstruction.

6.3 Financial Support for reconstruction

General aspects

Many factors contribute to a community's capacity to make rapid progress in housing recovery; economic conditions, disaster management system and especially the availability of financing (Jie-Ying and Lindell, 2003).

In developing countries most of the funds for housing reconstruction come from international aid while in developed ones financing for recovery comes from a diverse set of domestic sources including insurance, savings, and other sources (Comerio, 1998). Unfortunately, housing reconstruction is not possible to rely only to market forces because some aspects of the victim population, lack savings or insurance (Peacock and Girard, 1997). Consequently, national treasuries are tapped for grants and loans.

Greece: Financial assistance for reconstruction and repairs

In Greece due to the lack of an earthquake mandatory insurance policy, after each earthquake the government is obliged to support the families and businesses affected. A law was first established in 1979 that described the government obligations towards those affected by earthquakes. Due to the repeated earthquake losses in the 1978–1998 period, valuable experience has been gained resulting in a more organized and less reactive system of protection and recovery from earthquakes. Risk awareness has also increased resulting in greatly improved construction standards (Pomonis, 2002).

Over the last decades many regions of Greece were severely affected by catastrophic earthquakes. In all these cases, the State immediately conducted rehabilitation and reconstruction efforts which fulfil all important concerns that arose from the earthquake, starting from immediate relief, economic rehabilitation and livelihood restoration.

In Athens 1999 earthquake the government's assistance for the reconstruction and repair of properties was available to all uninsured residential properties that collapsed or be demolished, 33% in the form of a grant, and 67% in the form of a 15-year interest free loan. For residential properties the amount of assistance was capped to 382€/m^2 for up to 120 m^2. The average size of a dwelling in Greece is 90m^2. This assistance amounts to about 60% of the average cost of construction (645€/m^2). In case of bigger properties (applies especially to business premises) it was reported that for the surface area above 120m^2, only the interest free loan would be made available (Pomonis, 2002).

In Cephalonia 2014 earthquakes the government's financial aid for the reconstruction and repair of properties has been offered to temporarily unsafe (yellow) or dangerous for use (red). More specifically, eighty percent 80% of the aid was covered directly from the State, and the rest 20% was in the form of an interest-free loan to be paid back over a period of 15 years (GEER, 2014).

Specifically, for rebuilding structures up to 120m^2, the government provided: a) 1000€/m^2 for residential buildings, b) 500€/m^2 for business and public facilities, and c) 250€/m^2 for farm storage structures, warehouses, stables, etc. (GEER, 2014).

For structural damage repair, the government provided 450€/m^2 (up to 120m^2 area) for damage restoration of load-bearing and not load-bearing elements. For non-structural damage, the financial aid was set up to €250€/m^2. Funds were provided in successive instalments paid upon completion of specific stages of the work. For yellow or red building owners, the government subsidizes rents to owners for a period of two years.

6.4 Psychological support

Earthquake is a sudden, stressful and sometimes traumatic event, because it gives no time for psychological preparation, causes a sense of horror and helplessness, destroys what was once familiar, upset the normal sense of safety and stability and can significantly impact the normal balance of a person's overall health and wellness.

Earthquakes can affect a person, a family, a social cycle, or the whole community. The effective management in a case of a strong earthquake, including a strengthening of confidence and resilience of every one, is a necessary prevention measure. Major natural disasters are events that mark the beginning of a crucial period for both the direct and indirect victims and have particularly severe impacts on vulnerable population groups (e.g. children or elderly people). The way in which one can deal with the natural disaster and the impact of psychological stress depends on individual factors such as:

- Individual characteristics of victims and their relationships.- Social factors, such as the social structure of the affected region.
- Cultural framework.
- Environmental factors.

The guiding principles form the basis of disaster mental health intervention programs describe some departures and deviations from traditional mental health work; they also orient administrators and service providers to priority issues. Some of these principals are:

- No one who sees a disaster is untouched by it.
- There are two types of disaster trauma—individual and community.
- Most people pull together and function during and after a disaster, but their effectiveness is diminished.
- Disaster stress and grief reactions are normal responses to an abnormal situation.
- Many emotional reactions of disaster survivors stem from problems of living brought about by the disaster.
- Disaster relief assistance may be confusing to disaster survivors.
- They may experience frustration, anger, and feelings of helplessness related to Federal, State and non-profit agencies' disaster assistance programs.
- Most people do not see themselves as needing psychological services following a disaster and will not seek such services.
- Survivors may reject disaster assistance of all types.
- Disaster mental health services must be uniquely tailored to the communities they serve.
- Mental health workers need to set aside traditional methods, avoid the use of mental health labels, and use an active outreach approach to intervene successfully in disaster.
- Survivors respond to active, genuine interest, and concern.
- Interventions must be appropriate to the phase of disaster.
- Social support systems are crucial to recovery.

7. Case Studies related to Earthquakes

7.1 Greek Case Studies

CEPHALONIA EARTHQUAKE

Introduction

Cephalonia is an island located in the Ionian Sea of Greece, next to the island of Ithaca. It is the sixth largest island in the country; the largest of the Ionian islands with area of 786 m^2 and population of 35800 people according to the 2011 census. The capital of the prefecture of Cephalonia and Ithaca is Argostoli, of population of 8000. Lixouri is the second major town on the island, and combined with Argostoli they account for almost two thirds of the prefecture's population. Cephalonia has a long seismic history that can be traced back to antiquity. In 1953, the island was completely destroyed by a sequence of destructive shocks that caused more than 450 deaths.

On January 26 (15:55 local time) and February 3 2014 (05:08 local time) Cephalonia Island, was struck by two major earthquakes. No lives were lost during the 2014 earthquakes. The majority of the structures performed remarkably well considering they were subjected to ground motions that were often more than twice their elastic code design values probably due to significant site and topographic effects. However, damage to non structural elements was significant enough to affect life, business operations, and economy.

Earthquakes' details

On January 26 and February 3 2014 Cephalonia Island was struck by two strong earthquakes (NOA local magnitudes M_L5.8 and M_L5.7, respectively). The epicenter of the first event was located at the southwestern coasts of the Cephalonia island, while the second one was located in western coasts of the Cephalonia island, about 7km northwest of the Lixouri town. According to the Hellenic Unified Seismological Network (HUSN), it was a shallow crustal event with epicenter 38.25N, 20.39E and depth 10km (Fig. 7.1.1).

From the epicenter and focal mechanisms of the earthquakes it is deduced that they are related to the Cephalonia Transform Fault (CTF) (Scordilis et al. 1985). Due to the moderate magnitude of both earthquakes, the ground shaking was felt on the Cephalonia, on the islands of Ithaki, Lefkas and Zakynthos, as well as on areas of western Greece and Peloponnesos. According to the EMSC the ground motion was also felt in large part of continental Greece and in south Italy and Albania (Fig. 7.1.2).

During both earthquakes, ground-shaking phenomena such as, road failures liquefaction, rock falls, landslides and stonewall failures were widespread all over the western part of the island, in the Paliki peninsula and the area around Argostoli Bay. In the northern and eastern parts of the island only few isolated rock falls and landslides in loose materials were observed. Most of these effects were created after the first event in Jan. 26 and were reactivated one week later in the second (Feb. 3) event.

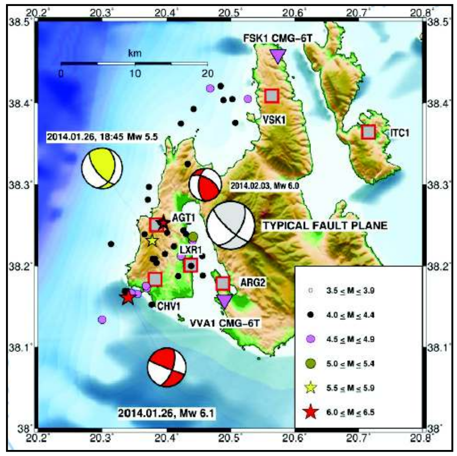


Figure 7.1.1 *Location map showing the epicenters (red stars) of the two main shocks. The yellow star shows the one aftershock of Jan. 26, 2014 at 18:45 UTC, M=5.6. The aftershock distribution (M>4.0) of the seismic sequence is also shown (EPPO-ITSAK, 2014).*

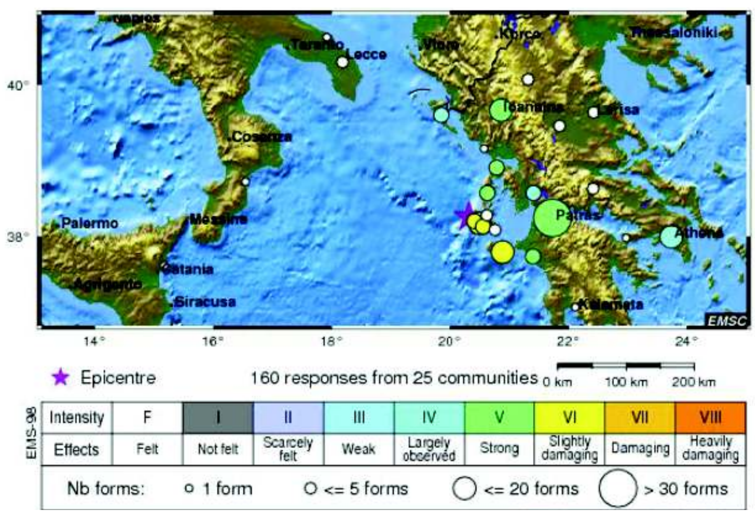


Figure 7.1.2 *Map of observed macro seismic intensities of 3/2/2014 main shock in Cephalonia (EMSC, 2014)*

<u>Geotechnical failures</u>

As a general comment, it may be stated that the two earthquake events of 26/01 and 3/02/2014 imposed extensive geotechnical failures. These had occurred mainly in the Western part of the Island (peninsula of Paliki) and may be grouped in the following categories:

- Landslides and rock falls
- Extensive cracks on the road network
- Failures of port marines.

A large number of local landslides were observed in several locations in an area with radius of ~10 km around the epicenter of Jan. 26, 2014. The failures were especially severe in the south/central part of Paliki peninsula and in the east coast of Argostoli Bay, and resulted in days-long closure of these roads for traffic.

On the south Paliki, we observed damages on road network, connecting villages. Rock falls and locally loose material flows were observed along parts of the coast of Myrtos beach where heavy rock falls rolled along the cliffs damaging the roads and even reaching the beach (Fig. 7.1.3). Blocks rolled down also to Atheras village causing damage in few houses. Rock falls were also widespread in the western and central part of the island.

Along the road Argostoli–Lixouri numerous landslides damaged sections of the road and disrupted the traffic. Construction and road service teams were working non-stop during the 2 weeks after the Jan. 26 and Feb. 2 events, in order to repair damages and re-open the road to civilians. Failures on stone retaining walls were recorded. Particularly extensive cracks were observed at the stone retaining wall supporting the foundation soil of a church located in the Havriata village (Fig. 7.1.4).

Extensive cracks in the major part of the road network mainly within the Paliki peninsula were observed as direct result of the geotechnical failures described above combined with the old construction age of the road network. Significant problems with severe cracks were recorded to a large part of the road network joining Lixouri with Ag. Thecla, Havdata, Havriata, Vouni and Manzavinata villages (Fig. 7.1.5).

Extensive failures and displacement were recorded at Lixouri port and at Argostoli port (to a lesser extent). Characteristically extended subsidences, movements of seawalls, soil liquefaction along coastline and cracking of ports' concrete were recorded. At the Lixouri port, the earthquake-induced horizontal displacement of the concrete quay walls (Fig. 7.1.6). At the Argostoli port, the observed failures were less extensive.

Figure 7.1.3 *Rock falls rolled along the cliffs in Myrtos beach (EPPO, 2014)*

Figure 7.1.4 *Failures at the stone retaining wall in Havriata village (EPPO, 2014)*

Figure 7.1.5 *Damages on road network Lixouri-Havriata (EPPO, 2014)*

Figure 7.1.6 *Damage at Lixouri port (EPPO, 2014)*

Buildings

In general, the buildings on the island behaved well, considering the intensity of the earthquake which had ground accelerations of up to 0.75g (g=acceleration of gravity). The majority of reinforced concrete buildings suffered negligible or minor damage at the brick infill walls, which, in some cases, were separated from the RC frame. The overall satisfactory structural performance can be attributed to good construction quality, especially of the infill walls which, in most cases, were able to withstand the largest portion of the seismic loads without cracking.

A Rapid Assessment Inspection was performed immediately after the first event (January 26th), followed by a Detailed Assessment Inspection. In the Rapid Assessment Inspection, 4865 buildings were inspected, mostly in the Paliki peninsula with 31% or 1505 buildings unsafe to immediately occupy (Fig. 7.1.7).

During the Detailed Assessment Inspection, 2770 buildings were inspected, including the yellow-tagged buildings from the Rapid Assessment Inspection and others that required further investigation. During this inspection, 1265 buildings (46%) were deemed safe (green), 1325 (48%) were considered temporarily unsafe (yellow), and 180 (6%) were unsafe (red). The statistics showed that the masonry suffered the most. The most affected buildings, 76% of the red and 60% of the yellow buildings were located on the Paliki peninsula. When considering the use, 52% of the red buildings were farm storage, warehouses, etc. or abandoned, 39% were residential buildings and 9% were commercial buildings such as offices.

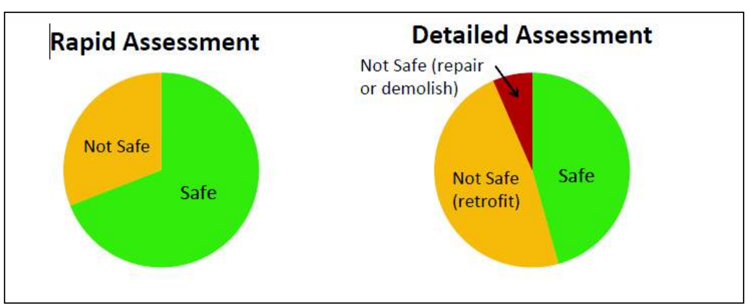


Figure 7.1.7 *Results of Rapid Assessment and Detailed Assessment phases. In the Rapid Assessment, 31% or 1505 buildings were found unsafe to occupy. The Detailed Assessment of the yellow-tagged buildings found 46% (1265) safe, 48% (1325) temporarily unsafe, and 6% (180) unsafe and pending detailed evaluation of whether to repair or demolish (GEER/EERI/ATC)*

The public low income housing complex in Lixouri was one of the most heavily damaged buildings. The complex is a series of two and three-story structures built during the 1960's under the first 1959 seismic code. The structures suffered extensive, non-repairable in most vertical RC structural members (Fig. 7.1.8). In contrast to the behaviour of the public housing complex, all of the newer buildings in the immediate vicinity remained essentially intact as they were built after 2000, in accordance with the recent seismic codes.


Figure 7.1.8 *Public housing complex heavily damaged buildings in Lixouri (EPPO, 2014)*

School facilities

Following assessment by the Organization of School Buildings (now known as Building Infrastructure Organization), 37 educational units in Cephalonia were classified as "A" (immediate occupancy), 19 as "B" (immediate occupancy with rehabilitation after school hours), and 9 will restore operation after the damage is repaired (Fig. 7.1.9).


Figure 7.1.9 *"Petritsio" high school, in Lixouri, suffered minor-moderate damage from 2014 earthquakes (EPPO, 2014)*

Churches and cultural buildings

Unlike the residential and public buildings which, in their majority, suffered minor to moderate damage under the two strong earthquake events, the Cephalonia churches suffered extensive structural damage (even partial collapse), and severe nonstructural damage (Fig. 7.1.10). This can be attributed to their construction type, retrofit history. Most of the churches are very old, tracing back to the 17th century, and have accumulated structural strain from the several historic earthquakes in the past, which must have played a significant role in their response to the 2014 events.

The Argostoli Archaeological Museum was constructed in 1957 to replace the original one which was destroyed during the 1953 earthquakes that resulted in loss of several findings Argostoli museum, was the only one building in Argostoli, for which significant damages were reported. Damages occurred on the walls and the structure of the building. Specifically cracks recorded in the columns of the ground floor (Fig. 7.1.11). Due to these damages the museum is closed until today and the possibility of enhancing the structural adequacy or reconstruction of the museum is still under investigation. A number of exhibits overturned or fell within their showcases.

Figure 7.1.10 *Church in Havriata (EPPO, 2014)*

Figure 7.1.11 *Argostoli Archaeological Museum after 2014 earthquakes (EPPO, 2014)*

Damage of nonstructural components

Damage of nonstructural components was extensive in the Lixouri area and significant in Argostoli exposing people to life threats and resulting in significant interruption of the function and impacts on the economy of the island. Nonstructural component failures, like roof tile collapse, lack of fence foundations, lack of seismic stoppers for rolling storage racks, absence of flexible joints in piping, lack of floor or wall bracement of heavy office furniture, bookcases and bank vaults, not properly braced or anchored equipment, and unsecured objects on shelves, were extensive in the densely populated towns of the island (Fig. 7.1.12). Their damage significantly affected the everyday function of the island and its economy, and could have resulted in serious injuries or loss of life if the residents were not intuitive about expecting the 2nd earthquake and for the good fortune of both major events happening when businesses were not operating.

The critical facilities of the Cephalonia international airport Terminal remained closed for 3 weeks following the events and the Hospital of Lixouri was evacuated, mainly due to nonstructural damage.

Figure 7.1.12 *Non structural damage: Lack of seismic protection for rolling restaurant shelves, lack of shelving restraints and lack of support for ceiling tiles and light fixtures (GEER/EERI/ATC).*

Response

The Greek government responded rapidly in the aftermath of the disaster. Damage assessment survey efforts were led by the Greek Seismic Rehabilitation Agency (SRA). A temporary field office was established in the facilities of the Technological Educational Institute (TEI) of the Ionian Islands, a public building in Argostoli, to organize the inspections and emergency interventions.

The inspections were mostly performed by teams of structural engineers who work for public agencies. Shortly after the main shocks it announced that aid would be offered to repair temporarily unsafe for use (yellow) or reconstruct dangerous for use (red) buildings. 80% of the aid will be in the form of free assistance and the rest will be in the form of an interest-free loan to be paid back over a period of 15 years. The government will pay up to 1000€/m^2 to rebuild residential buildings up to 120m^2 in area.

Following the two main shocks and numerous aftershocks some critical and essential facilities had to be evacuated temporarily and some were evacuated as a precaution due to the earthquake history of the island. Examples of evacuated facilities include the Lixouri hospital senior citizen housing and schools. Temporary housing included tents offered by the army (Fig. 7.1.13), two navy ships in Argostoli (550 beds) and the "Aegean Paradise" cruise boat in Lixouri with 600 beds (including free breakfast and dinner offered by the ship owner for two months) were offered to the homeless.

Tent settlements available by the army proved no useful because the rainy weather made living hard and several homeless people had to also be moved to ships or chose to sleep in their cars. Water supply was interrupted in Lixouri after the 2nd event and bottled water was distributed until the network became operable.

Government authorities, churches and volunteers also provided food and other aid to those whose homes were deemed unsafe. Water supply was interrupted in Lixouri after the 2nd event, and bottled water was distributed until the network was repaired. Government authorities, churches and volunteers also provided food and other aid to those whose homes were deemed unsafe (Fig. 7.1.14). Financial support has been provided by various sources, including fundraising by Greek communities, locally and abroad and private donations from various companies and organizations.

Psychological help was provided, especially to children, who experienced such a natural phenomenon for the first time. The people of Cephalonia handled the events stoically, as they have most likely experienced earthquakes in their lifetime, which helped to avoid panic and allow for emergency response to run smoothly.

The people complained about the impact of the earthquakes to their personal and professional lives, which were mostly affected by non structural damage. This appears to be the case in other earthquake-prone areas, and suggests that more effort is needed to educate the public on their risk exposure and expectations of operations after large earthquakes.

Figure 7.1.13 *Tent settlements (EPPO) in Lixuri stadium (EPPO)*

Figure 7.1.14 *Food supplies for distribution to residents*

Bibliography

Giotis, G., Sextos, A. (2014). “Seismic behavior study of Argostoli Museum's exhibits during Cephalonia earthquakes on 26 January & 3 February 2014” Bauhaus Summer School in Forecast Engineering: Global Climate change and the challenge for built environment 17-29 August 2014, Weimar, Germany

GEER/EERI/ATC (2014). Earthquake Reconnaissance Cephalonia, Greece Events, Version 1: June 6, 2014

EPPO (2014). “The earthquake of 26/1/2014 (m6.1) in Cephalonia (Greece): strong ground motion, soil behavior and response of structures” (1st Preliminary Report**),** Thessaloniki, February 2014

EPPO (2014). “The earthquake of 26/1/2014 (m6.1) in Cephalonia (Greece): strong ground motion, soil behavior and response of structures” (2st Preliminary Report), Thessaloniki, February 2014

Valkaniotis S., et al. (2014). “Field observations of geological effects triggered by the January–February 2014 Cephalonia (Ionian Sea, Greece) earthquakes”, Tectonophysics, 2014

CULTURAL HERITAGE AND EARTHQUAKES AT HERAKLION, CRETE

Introduction

The prefecture of Heraklion is very wealthy in archaeological findings, especially from the Minoan Era. Three of the most important palaces, Knossos, Malia and Galatas are located within its territory, as well as very famous towns and sites like Phaistos, Agia Triada, Tylissos etc. Most of the precious findings of these locations were stored since the 19^{th} century at the collections of the Heraklion Archaeological Museum (Fig. 7.1.15).

The first exhibition was set at the place of the Venetian St Francis Monastery, a big construction at the center of the town that was heavily damaged from several older earthquakes and totally collapsed during the 1856 earthquake. In 1904 a new building was made at the place of St Francis Monastery without any concern for the seismic risk, both for the construction itself and the exhibits.

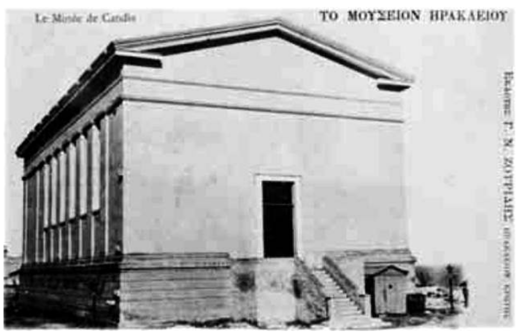


Figure 7.1.15 *The First Archaeological Museum of Heraklion in 1904 (Dimopoulou-Rethimiotaki N. 2005)*

The museum was strongly affected by the 1926 Rhodes earthquake (M=8). Part of its roof collapsed damaging many of the exhibits. Unsecured Minoan pottery, frescos and the Agia Triada larnax were fragmented in pieces. Many of the archaeologists who visited the museum that time, including the famous Sir Arthur Evans who excavated Knossos, were very pessimist for a future restoration and recovery. However, the Director of the museum S. Xanthoudidis very carefully collected and stored the exhibit's fragments. Soon after the earthquake the fragmented frescos and pottery were fixed together again and restored by the conservator of the museum M. Saloustros; a huge work concerning time, materials available and the economic situation. Furthermore, the damages of the building were also restored under the assistance and financial support of the Italian government after the proposal of Prof. Federicco Halbherr and other Italian archaeologists.

Although discussions were risen up for a new and safe museum, the next strong earthquake at 1930 damaged again the building and the exhibits. It was that time that serious decisions were taken in national level for a new building to host the valuable findings from all over Crete that were hosted in the museum. The strong earthquake of 1935 found the museum still unprotected. Again serious damages were made to important Minoan findings and the building faced very serious constructional problems.

It was in 1951, soon after the Second World War that delayed the constructions that the first exhibition in the new building was opened to public. The same year the new storage building of the museum was also finished.

The 1935 Earthquake

On February 25, 1935 and at 02:51 a very strong earthquake of 7 magnitude, depth 100km and intensity 8 of Mercalli Scale with epicentre in Anogia village (located east of Heraklion) took place.

The earthquake stroke mainly the northern and central Crete, but was felt all along Eastern Mediterranean. The earthquake resulted in collapse of buildings and infrastructure, damage to archaeological exhibits etc.

Heraklion and surroundings: The Electric Power station, the Gymnasium and St Minas church, many schools and housed suffered serious damages (Fig. 7.1.16). The villages of Skalani, Anopoli, Epano Vatheia, Kainourio and Gournes destroyed . The villages Episkopi, Tylissos, Sampas, Voni, Kamari, Arckalochori were heavily damaged and the majority of buildings collapsed.

Figure 7.1.16 *The town cathedral, Agios Minas after the 1935 earthquake (Andrikakis A. 2008)*

Serious deviations were observed in the walls of the old Archaeological Museum. Many exhibits were also damaged. The small Minoan statue of the “Goddess with Snakes”, was broken again as in the 1926 earthquake. More than 50 Minoan vessels of great importance were broken too (Andrikakis A 2008).

The staff of the museum collected all exhibits and broken parts, and stored them in safe place, till the construction of the new building which started in 1937. The first exhibition was opened to public after the Second World War, in 1951. The same year the new storage building of the museums was finished. (Dimopoulou-Rethimiotaki N. 2005).

Rest of Crete: The cities of Rethimnon and Chania suffered several damages.

Population: 8 killed 204 injured and 374 families homeless.

Impact on Cultural Heritage of Heraklion

The Archaeological Museum in Heraklion was built to host some of the most important and invaluable findings of the Minoan civilization. Unfortunately, at this period no considerable concern about the seismic protection of building and exhibits occurred. Thus the museum was repeatedly affected by earthquakes. After 1935 earthquake serious deviations were observed in the walls of the building and many exhibits were also damaged. The small Minoan statue of the “Goddess with Snakes” was broken again as in the 1926 (Fig. 7.1.17).

Figure 7.1.17 *The Goddess with the Snakes that was again destroyed by the 1935 earthquake (Dimopoulou-Rethimniotaki N. 2005)*

During the 1930 earthquake (M=6,7) the museum was also seriously damaged. Many ancient vessels and Minoan findings of minor importance were broken because part of the roof collapsed, or exhibits fell down from their stands.

Preparedness and prevention measures

Although discussions for a new and safe museum were risen up after the 1926 earthquake, the next strong event of 1930 damaged again the building and the exhibits. It was that time that serious decisions were taken in National level for a new building to host the valuable findings from all over Crete. The curator of the Museum Spyridon Marinatos informed the authorities immediately on the serious damages and the government decided to build a modern and seismic resistant museum to host the important exhibits. Preparations however delayed a lot and the foundation of the building was delayed till 1934 *(*Chatzidakis, 1931, Dimopoulou-Rethimiotaki N.2005).

The next strong earthquake of 1935 found the museum still unprotected. Again serious damages were made to important Minoan findings and the building faced very serious constructional problems. The staff of the museum collected all exhibits and broken parts, and stored them in safe place for conservation till the construction of the new building which started in 1937.

In 1951, soon after the Second World War the first exhibition in the new building was opened to public. Judging from the results, the construction of the Heraklion Archaeological Museum in 1904 and the presentation of its important Minoan exhibits can be considered as insufficient.

The construction of the museum took no precautions against future earthquakes although Heraklion was heavily damaged or destroyed during the previous decades. Exhibits were not secured on their stands and show-cases, so that many of them fell down or were smashed under the roof fragments that have collapsed.

Even though the problems were recognised and the solutions were found after the first earthquake of 1926, political decisions took a long time since a new, safer museum was established in 1951. In the meantime two more earthquakes affected museum again causing more damages to building and exhibits. It should also be stated that the museum staff worked very hard, even against the archaeologists' opinions and managed to collect and restore all fragmented exhibits.

Nowadays the Archaeological Museum is the second most important Archaeological Museum in Greece hosting the most profound findings of the Minoan civilization. Most of the fragmented exhibits are presented at its halls, whereas a new larger part has been recently constructed under the most strict and recent regulations for seismic protection, to host these exhibits.

Literature

Andrikakis A. (2008) The earthquakes of Crete, Patris, Heraklion

Chatzidakis I. (1931). The history of the Cretan Museum and the archaeological studies in Crete, Athens.

Dimopoulou-Rethimiotaki N (2005). The Archaeological Museum of Heraklion, J. Latsis Foundation, Athens.

Papazachos and Papazachou (1997). The Earthquake of Greece, Ziti eds, Thessaloniki.

Sieberg A. (1932). Untersuchungen uber erbeben und bruchschollenbau im ostlichen Mittelmeergebiet. Velag von Gustav Fisher, Jean, 163-173

7.2 Italian Case study

THE APPLICATION OF THE UMBRIAN REGIONAL LAW FOR SEISMIC PREVENTION

September 26, 1997: a strong earthquake shook the Umbria Region and the central Italy. The quake, with a magnitude of 5.8, severely damaged several villages. The quake and its attendant tremors also damaged a number of historical buildings, including the famous Basilica of Saint Francis in the hillside town of Assisi. In the figure on the right it is possible to see the epicenters of the main quake and of the tremors of the following days.

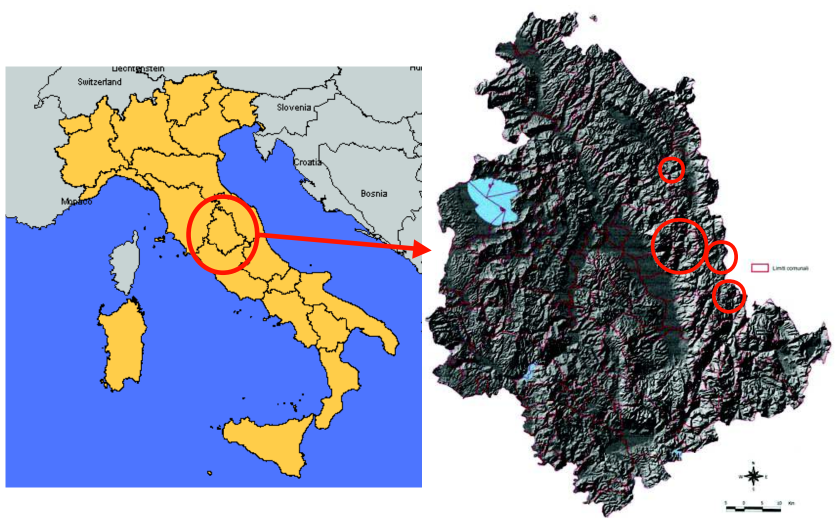


Figure 7.2.1 *In the figures above it is possible to see the damage caused by the Umbrian earthquake of 1997. Destroyed village (on the left), collapsed masonry buildings (on the center and right images).*

Damaged buildings

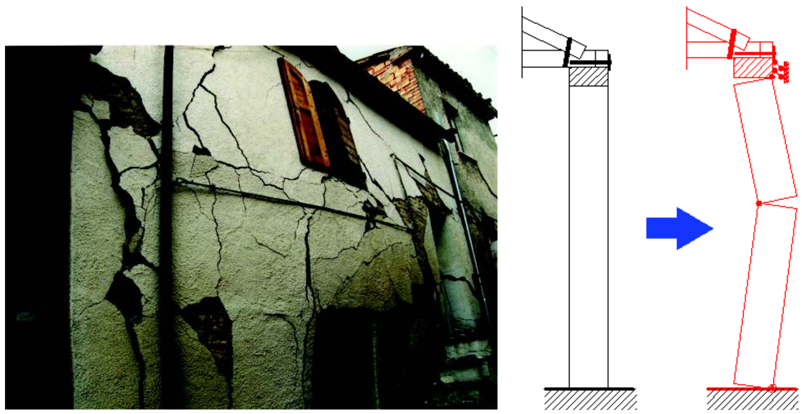


Figure 7.2.2 *In this masonry building it is possible to see a flexural wall failure. There is a good roof-to-wall connection but the middle floor is not connected to the wall.*

Figure 7.2.3 *This is a masonry building with reinforced concrete ring beams. In this case we can see how important is to achieve the connection between the new reinforced concrete ring beam and the existing masonry.*

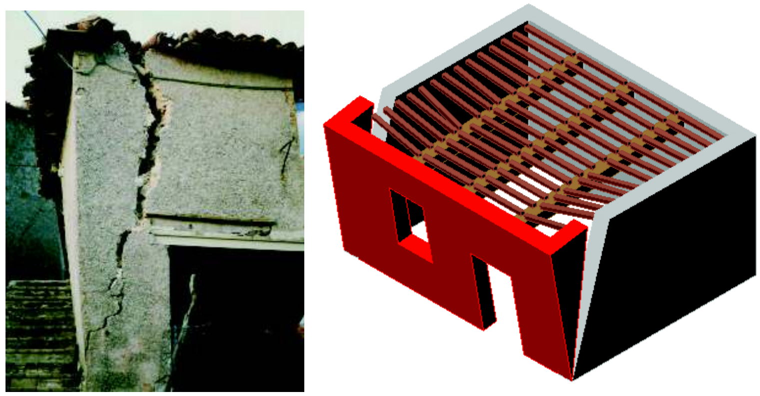


Figure 7.2.4 *In this masonry building it is possible to see the overturning of the wall caused by a poor connection of the roof to the wall.*

Basic concepts of the Umbrian regional law for seismic prevention

The regional law for seismic prevention gives financial resources to that people who decide to make strengthening interventions on their masonry buildings. The subject who can ask for financing is the whole aggregation of buildings. In fact, the quake of 1997 showed how strong can be the interactions among adjacent buildings and how unrealistic can be the analysis of the single building if it is in the contest of the aggregation. Each aggregation is formed of several buildings (here named "Structural Units" or U.S. or S.U.) which can be defined thanks to structural and historical considerations. We have to evaluate the vulnerability of every U.S. with a purely conventional procedure consisting in a relief of the structural deficiencies of the building (considering the interaction with adjacent buildings) and then in a comparison of the situation found with the corresponding numerical or qualitative thresholds. All the thresholds are tabulated for every element of vulnerability. The whole aggregation can be defined "vulnerable" if at least one of its U.S. is vulnerable. In this case the aggregation can ask for financing. Then, it will be established a priority (based on exposure and danger criteria) among all the constructions that exceed the vulnerability threshold. This is necessary to choose the first financeable constructions, cause the limited resources. The financed aggregations shall write up the executive design of the strengthening intervention that will pursue the elimination of all the structural deficiencies in the aggregation and not only the one marked in the relief phase. It shall be realized a minimum obligatory series of strengthening interventions. Besides, the technical specifications of the law suggest some possible strengthening interventions.

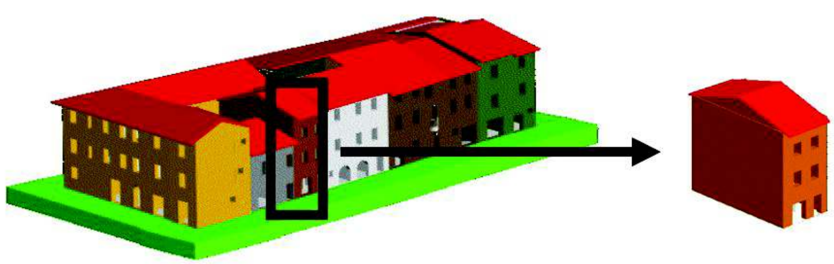


Figure 7.2.5 *The aggregation could be defined as a construction delimited by open spaces (left image). It is formed by Structural Units (U.S.) which could be defined as portions of the aggregation which have a Unitarian static and seismic behaviour.*

U.S. are defined thanks to structural criteria (i.e. a rigid floor defines a single U.S. or two parts with a different kind of masonry are two U.S.) and thanks to historical criteria, according to age of construction of the several parts.

Evaluation of the quality of masonry

It consists in the evaluation of five aspects. The higher score means the presence of the five parameters and a good quality of masonry. The evaluation can be done in a qualitative way just like in the figure on the right.

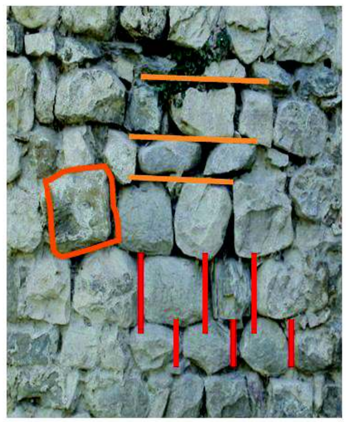


Figure 7.2.6 *Example of the evaluation of the quality masonry in a qualitative way(Source Angeletti, Borri, Longhi, Nasini, Severi (2004) "The law for seismic prevention in Umbria, Italy")*

- <u>OR</u>: horizontal courses (from 0 up to 2 points)

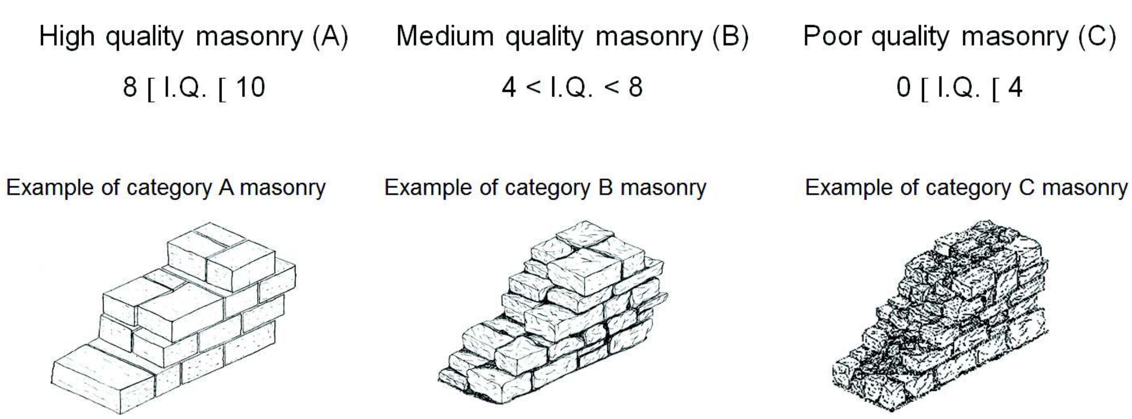
- <u>SG</u>: not-aligned mortar vertical joints (from 0 up to 2 points)

- <u>FD</u>: squared shape and big dimension of stones or bricks (from 0 up to 2 points)

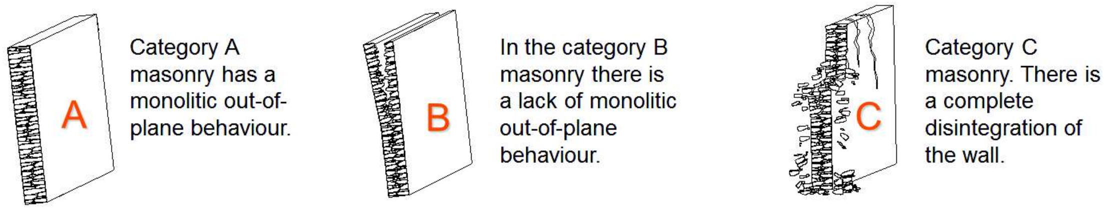
- <u>PD</u>: presence of "diatoni" (stones connecting two separated leaves of the wall) (from 0 up to 3 points)

- <u>MA</u>: good quality of mortar (from 0 up to 1 point).

Quality Index: I.Q. = OR + SG + FD + PD + MA (from 0 up to 10 points)



Out-of-plane behaviour of quality A, B and C masonry



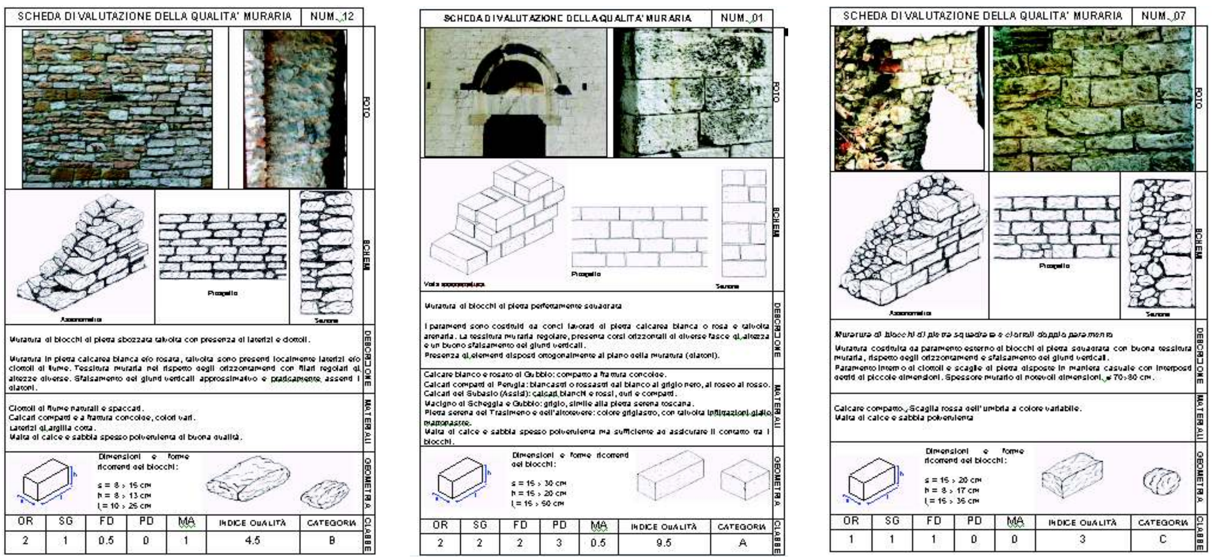


Figure 7.2.7 *Examples of tables about typical Umbrian masonry (Source Angeletti, Borri, Longhi, Nasini, Severi (2004) "The law for seismic prevention in Umbria, Italy")*

In order to show the correct use of the method of analysis of masonry proposed in the law, it has been developed an appendix of the law with a series of tables showing some kind of typical Umbrian masonry. Each table shows a photograph of the masonry, the axonometric view, the section and the front view of the masonry, a brief description of its characteristics. In the lower row it is possible to find the score of the five parameters necessary to express the judgment on the masonry. The evaluation of these parameters can be made on one squared masonry zone of 1m x 1m. In such zone it will be necessary to remove the plaster if it is present.

Approximated evaluation of effectiveness of connections between perpendicular walls

The effectiveness of connection between perpendicular walls can be conventionally and quickly evaluated. We have to determine the percentage of stones (or bricks) crossing two imaginary vertical lines representing the orthogonal wall to that one considered (figure on the left).

If this percentage is advanced to a prefixed limit then we can say that the connection between the walls exists. We have also to consider the dimension of the stones crossing the imaginary lines and the quality of mortar.

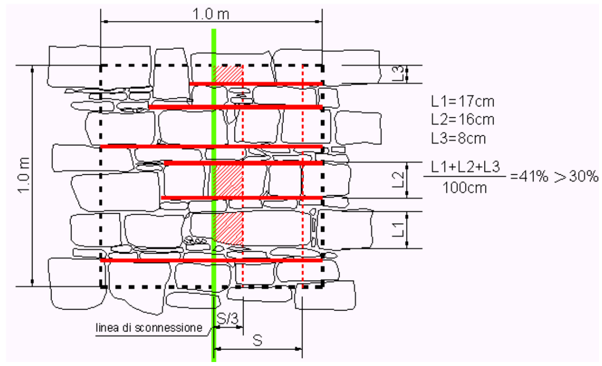
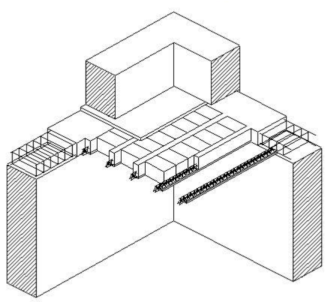


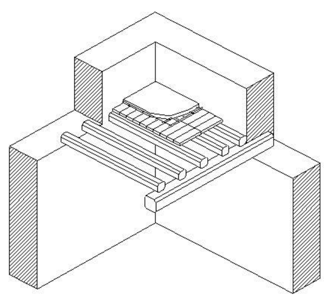
Figure 7.2.8 *Example of evaluation of effectiveness of connections between perpendicular walls (Source Angeletti, Borri, Longhi, Nasini, Severi (2004) "The law for seismic prevention in Umbria, Italy")*

Approximated evaluation of effectiveness of connections between walls and floors

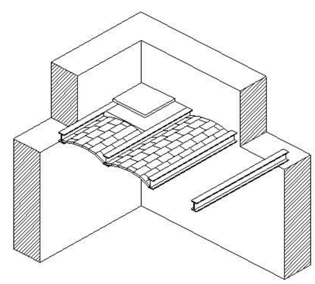
The purely conventional evaluation of effectiveness of connections between walls and floors is based on the observation of the kind of floor. A floor with reinforced concrete ring beam (figure on the left) can be considered connected to the perimetral walls; timber floors (central figure) and iron floor (right figure) generally are not connected to the walls. Sometimes it is possible to see timber or iron floors strengthened with a reinforced concrete slab and steel anchors grouted into existing walls; in this case we have a floor well connected to the walls.



Floor with reinforced concrete ring beam



Wooden beams floor



Iron "I" beams and brick arches floor

Definition of structural deficiencies of the U.S.

The various elements of vulnerability are divided in three classes: "Class a" elements are the most important. "Class b" elements are local deficiencies. "Class c" elements consider the interaction of adjacent U.S. Then we can find also "class a" elements locally and, in this case, we have "class a* "elements of vulnerability. In the following tables we can read the description of the numerical or qualitative thresholds which define the presence of the element of vulnerability in the U.S.

Intrinsec vulnerability		Thresholds
a.1)	No connection between perpendicular walls	> 60% of all the wall-crosses in a level
a.1)*		local
a.2)	No connection between floors and walls	> 60% in a level
a.2)*		local
a.3)	No tying elements	> 60% in a level
a.3)*		local
a.4)	No sufficient shear-resistent area	ξ ≤ ξ' or η ≤ η' (tab. 4) in a level
	Torsional effects	a / L ≤ 0,4 or b / L ≥ 0,3 in a level with rigid floor (tab. 6)
a.4)*	No sufficient shear-resistent area	ξ ≤ ξ' or η ≤ η' (tab. 5) in a level
a.5)	Bad quality masonry	C masonry: 50% in a level (tab. 3 e 4)
a.6)	Deterioration and static insufficience	A level with 50% of masonry or all the floor deteriored
		Am/At ≤ (Am/At)CR (tab. 9)
b.1)	High height-to-thickness ratio of the walls	b ≤ bCR local (tab. 7 e 8)
b.2)	Irregular distribution of the openings	R = AM / AT ≤ 0,2 in a facade
b.3)	Pushing elements	Not buttressed roofs, vaults, arches; floors at different height on the same wall
b.4)	Addictions causing not homogeneus structural behaviour	Balconies closed with infill masonry, elements that change the mass distribution
b.5)	Walls without vertical continuity	Walls or columns built over not rigid floors, beams or vaults.
b.6)	Excessive variations of resistant area from a plan to the other	Increasing resistant area ΔA ≥ 30% from a storey to the upper one
b.7)	Not structural vulnerable elements	Not well anchored balconies, chimneys
b.8)	Foundation settlement	Cracks caused by foundation settlement
Induced vulnerability elements		**Thresholds**
c.1)	Pushing vaults and arches in the adjacent U.S.	Vaults or arches of the adjacent U.S. pushing on the walls of the analyzed U.S.
c.2)	Pushing roofs or floors in the adjacent U.S.	Δh > 1 m being Δh = difference of height between the roofs or floors of the two U.S.
c.3)	Not aligned facades	Not aligned facades without tying elements
c.4)	Head position of the U.S.	No connection and no tying elements in the head wall of the U.S.
c.5)	Insufficient wideness of seismic joints	d < H / 100 being H = height of the lower US and d = joint wideness
c.6)	Different stiffness between adjacent U.S.	• different total height (ΔH > 3 m) • different constructive technique or material

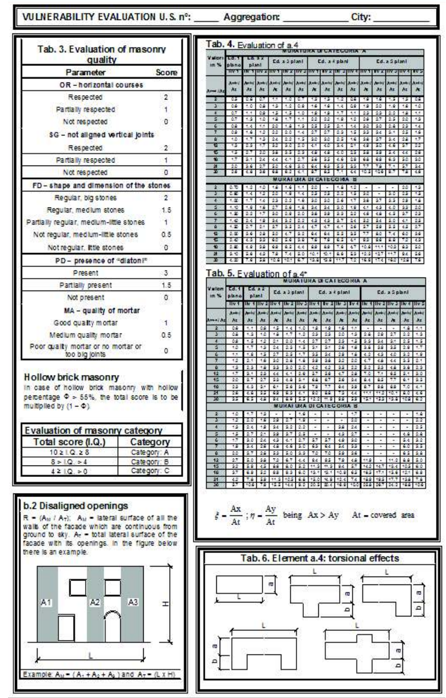


Figure 7.2.9 *Table for assessing the structural deficiencies (Source Angeletti, Borri, Longhi, Nasini, Severi (2004) "The law for seismic prevention in Umbria, Italy")*

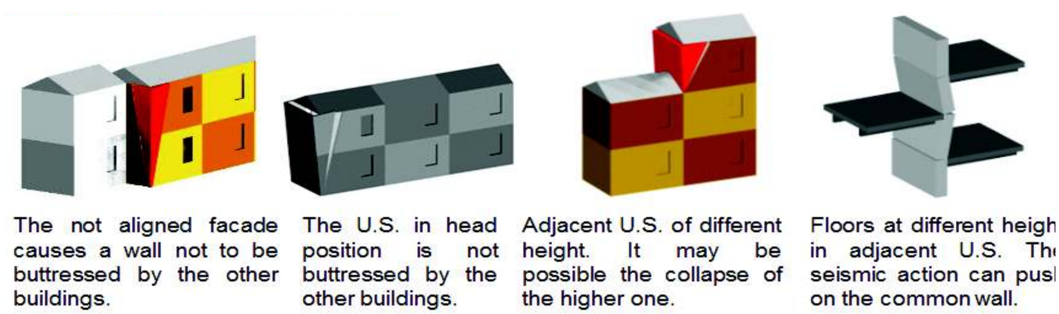


Figure 7.2.10 *Examples of induced vulnerability (Source Angeletti, Borri, Longhi, Nasini, Severi (2004) "The law for seismic prevention in Umbria, Italy")*

Definition of vulnerability of single U.S. and of aggregation

We can say the U.S. to be vulnerable if: 1) we found at least one of the "class a" elements; 2) we found at least a particular association of two "class b" or "class c" elements in the same part of the building; 3) we found at least a particular association of one "class b" or "class c" element with a "class a*" localized element. All these associations define vulnerable situations which do not derive from a numerical model of the building but simply from the observation of the real seismic behaviour of the construction. The table below reassumes all the vulnerable associations between the structural deficiencies. Finally, the whole aggregation can be defined “vulnerable” if at least one of its U.S. is vulnerable. In this case the aggregation can ask for financing.

Soglie definite da un solo elem. di vuln.						
a1	a2	a3	a4	a5	a6	c5
1	2	3	4/5/7	4/5/6	6	7

Soglie definite da un'associazione di due elementi di vulnerabilità																	
	a1*	a2*	a3*	a4*	b1	b2	b3	b4	b5	b6	b7	b8	c1	c2	c3	c4	c6
a1*		1/2	1/3		1/4/5	1/5	1/3	1/4	1/5/6	1/5	1/8	1/9	1/3	1/3	1/5	1/5	
a2*	1/2		2/3		2/4/5	2/5	2/3	2/4	2/5/6	2/6	2/8		2/3	2/3	2/5	2/5	
a3*	1/3	2/3			3/4/5		3	3/4					3		3/5	3/5	
a4*						4/5	3/4/5			4/5		4/5/9	3/4/5	3/4/5		4/5	
b1	1/4/5	2/4/5	3/4/5				3/4/5	4/5				4/5/9	3/4/5	3/4/5	4/5		
b2	1/5	2/5		4/5													
b3	1/3	2/3	3	3/4/5	3/4/5												
b4	1/4	2/4	3/4		4/5												
b5	1/5/6	2/5/6															
b6	1/5	2/6		4/5													3/7
b7	1/8	2/8															
b8	1/9			4/5/9	4/5/9												
c1	1/3	2/3	3	3/4/5	3/4/5												
c2	1/3	2/3		3/4/5	3/4/5												1/2/7
c3	1/5	2/5	3/5		4/5												3/4/.5
c4	1/5	2/5	3/5	4/5													
c6										3/7				1/2/7	3/4/5		

Figure 7.2.11 *Table of the vulnerable associations between the structural deficiencies. Coloured cells define a vulnerable association between the structural deficiencies reported in the corresponding row and column. The upper part of the table regards the structural deficiencies that define a vulnerable U.S. without association. Numbers in the cells represent the category of intervention that can resolve the vulnerability problems of the analyzed U.S.*

The priority scale among the aggregations asking for contribution

It will be established a priority among all the aggregation that exceed the vulnerability threshold. This is necessary to choose the first financeable constructions because it is not possible to give financial resources to all the vulnerable constructions. The priority is based on the danger and exposure criteria reassumed in the table below. A score from 1 up to 3 will be assigned to each one of the following ten aspects. The total score defines the level of priority of the aggregation.

SEISMIC PREVENTION: PRIORITY FOR FINANCIAL RESOURCES	
1	Number of vulnerable U.S.
2	Total number of houses with people living inside
3	Vulnerable U.S. - Total number of U.S. ratio
4	Aggregations located in grounds with seismic amplification factor
5	Wideness of the streets around the aggregation
6	Maximum height of the aggregation
7	Aggregation that, if it collapse, stops the access to strategic buidings
8	Maximum heigh – street wideness ratio
9	Aggregation with public buildings inside
10	Historical or architectural interesting buildings inside the aggregation

Table 7.2.1 *Table showing the priority for financial resources in seismic prevention (Source Angeletti, Borri, Longhi, Nasini, Severi (2004) “The law for seismic prevention in Umbria, Italy”)*

Executive design and strengthening interventions

The financed aggregations shall write up the executive design of the strengthening provisions, that will pursue the elimination of all the structural deficiencies in the aggregation and not only the one marked in the relief phase. It shall be realized a minimum obligatory series of strengthening provisions. Besides, the technical specifications of the law suggest some possible strengthening interventions. In the table of the vulnerable associations there are some numbers representing the kind of provisions that can resolve the structural deficiencies. They are:

1) realization of effective connections between perpendicular walls

2) realization of effective connections between floors and walls

3) realization of tying elements

4) lateral load resistance increase

5) openings regularization

6) restoration of static resistance of floors and walls

7) realization of seismic joints

8) connection of not structural elements

9) increase of foundations resistance

The executive design shall contain a relief with all the structural deficiencies of the aggregation. They will be represented by those symbols.

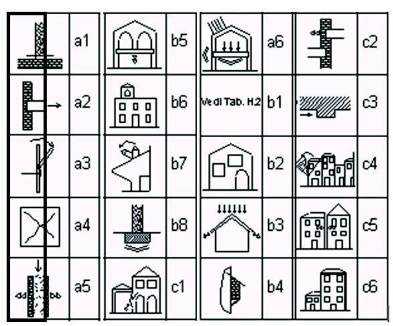


Figure 7.2.12 *Symbols representing the structural deficiencies of the aggregation*

Application example: San Pellegrino test

In order to try how difficult could be the application of the technical specification of the law, some tests regarding existing buildings have been carried out before the publication of the law. One of these tests is now represented. It regards an aggregation of three U.S. in a little village called san Pellegrino, near Perugia (Umbria).

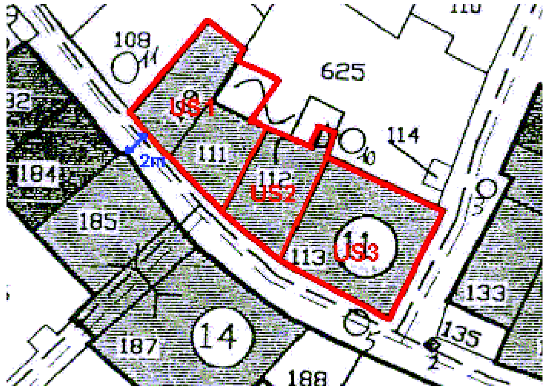


Figure 7.2.13 *In this figure it is possible to see a panoramic view of the aggregation. Its dimensions are approximately 30m x 11m. It is formed by three U.S. Each U.S. is a four storey masonry building.*

Figure 7.2.14 *In this figure there is a photographic view (from North) of the aggregation. Some lower portions of the aggregation are visible.*

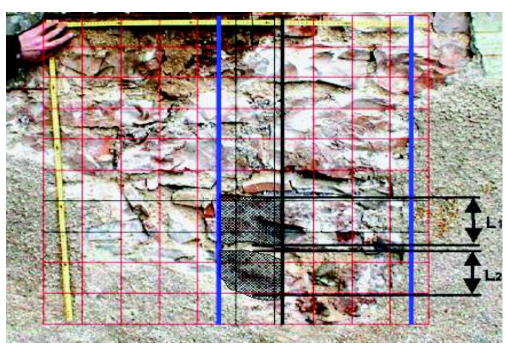


Figure 7.2.15 *Conventional evaluation of the effectiveness of connection between perpendicular walls. The removal of plaster took 20 minutes.*

Soglie definite da un solo elem. di vuln.						
a1	a2	a3	a4	a5	a6	c5
X	X	X	X			

Soglie definite da un'associazione di due elementi di vulnerabilità																	
	a1*	a2*	a3*	a4*	b1	b2	b3	b4	b5	b6	b7	b8	c1	c2	c3	c4	c6
a1*		X	X		X		X	X								X	
a2*	X		X		X		X	X								X	
a3*	X	X			X		X	X								X	
a4*							X									X	
b1	X	X	X				X										
b2																	
b3	X	X	X	X	X												
b4	X	X	X														
b5																	
b6																	
b7																	
b8																	
c1																	
c2																	
c3																	
c4	X	X	X	X													
c6																	

Figure 7.2.16 *The table of vulnerable elements association regarding U.S. 1. Marked cells represent a vulnerability threshold of the U.S.*

In the figures below there is an example of the relief of structural deficiencies. The example regards U.S. 1. As it is possible to see, symbols of structural deficiencies have been used.

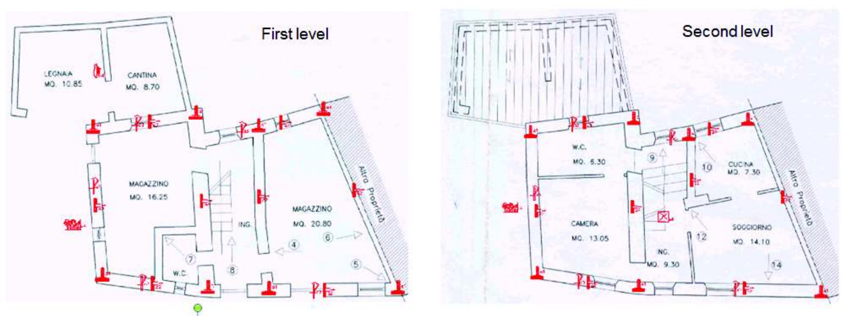


Figure 7.2.17 *example of the relief of structural deficiencies (Source Angeletti, Borri, Longhi, Nasini, Severi (2004) "The law for seismic prevention in Umbria, Italy")*

Bibliography:

Prof. P. Angeletti, Prof. A. Borri, Eng. F. Longhi, Eng. U. Nasini, Eng. A. Severi (2004) "*The law for seismic prevention in Umbria, Italy" - 2004 annual meeting Eartquake Engineering Research Institute, Los Angeles, California, USA, February 4 - 7, 2004 - with a contribution of Eng. Alessandro De Maria for the synthesis*

7.3 Bulgarian Case Study

Bulgaria's territory belongs to the Earth's dangerous earthquake zones. The world's most violent and frequent earthquakes happen in the Pacific seismic belt – around 75-80%. Bulgaria is among the most active nodes in Europe, which belong to next global seismic zone – the Alpine-Himalayan. This is where the remaining 15-20% of the shocks over the world takes place. In the Balkans, however, they are 2-3 times weaker and less frequent than the most active places in the Pacific zone. Therefore the region, including our country, belongs to the second rank of the dangerous places on the planet. (Fig.7.3.1)

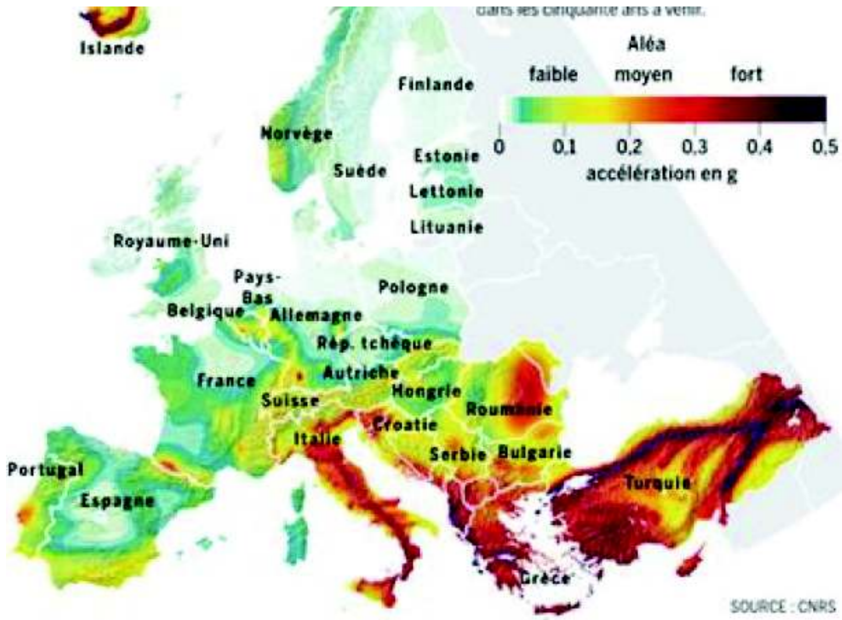


Figure 7.3.1 *Map of seismic activity in Europe (from: www.cnrs.fr)*

At the same time their number in our country is significantly smaller compared with Turkey or Greece, where the earthquakes are also shallow. In neighboring Romania, the tremors are even rarer, but much deeper – 100-200 km of depth, which causes major damage. Such areas are Vrancea and the Helenska arch. They affect large distances, as is the example of Vrancea's earthquake of 1977 (Fig. 7.3.2).

Figure 7.3.2 *Earthquake from 1977 in Vranca and his reflection in Silistra, Bulgaria (EMSC)*

The earthquakes with an epicentre in the Aegean Sea have an impact as well.

Figure 7.3.3 *Aegean earthquake from 24.05.2014 (http://earthquake-report.com/) and his reflection in Kardjali, Bulgaria*

Seismic risk identification

The earthquake zone of the Balkans has its own specific. Most of the earthquakes are shallow with earthquake focus of 60km in the earth crust, which intensifies the effects on the surface. When population density is high, and the number of buildings is as well, there is a threat of significant consequences even when the earthquake is relatively weak.

The seismic activity in Bulgaria is high – 97 of 100% of its territory is under earthquake threat.

The map of the Geophysical Institute of the Bulgarian Academy of Science (Fig. 4) shows recent earthquake epicenters, with those of magnitude 7.0 and higher shown with red colour. They have occurred in:

- South-West Bulgaria
- Central South Bulgaria
- Central North Bulgaria
- North-East Bulgaria (in the sea)

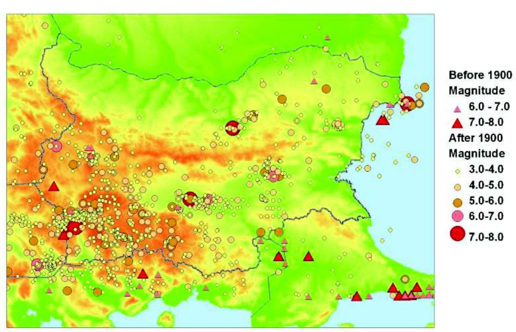


Figure 7.3.4 *Map of seismic activity in Bulgaria (NIGGG, BAS)*

Earthquake danger in Bulgaria

According to the Geophysical institute of BAN, as a whole, 98 % of the territory of Bulgaria will be subjected to seismic impact with intensity of 7th and higher degree.
51% will be of 7th degree, 28% of 8th degree, and 19% of 9th degree or higher. 6 340 000 people, which is about 80% of the country's population, live in these areas. The damages in the regions could be partial or full – 26% of the buildings. In areas where the intensity could get 8th or 9th degree on the scale of MSK-64 live around 5 900 000 people, which is 74% of the country's population (Analyses of the seismic risk in: National program for protection from natural disasters (2009-2013), passed by the Government of Bulgaria, 2009,
http://www.strategy.bg/StrategicDocuments/View.aspx?lang=bg-BG&Id=550).

Seismological researches prove beyond any doubt the real earthquake treat in Bulgaria. Science gives warning about the danger and evaluates the consequences of it. The earthquakes in the beginning of the 20th century are already forgotten and people live in perception of safety. Experience of past quakes here and around the world shows that regretfully the society takes measures post-factum, after the disaster happens.

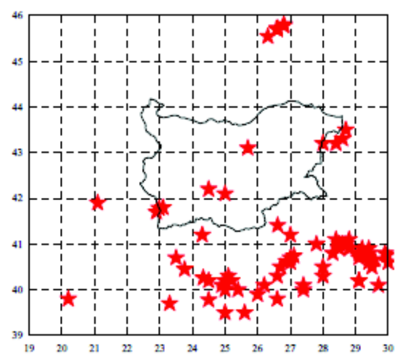


Figure 7.3.5 *Documented earthquakes with magnitude 7.0 and higher (NIGG, BAS, Bulgaria)*

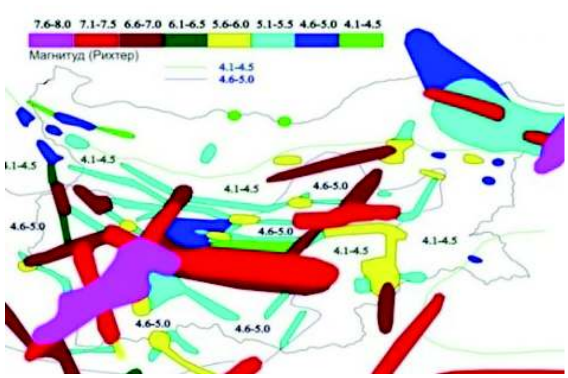
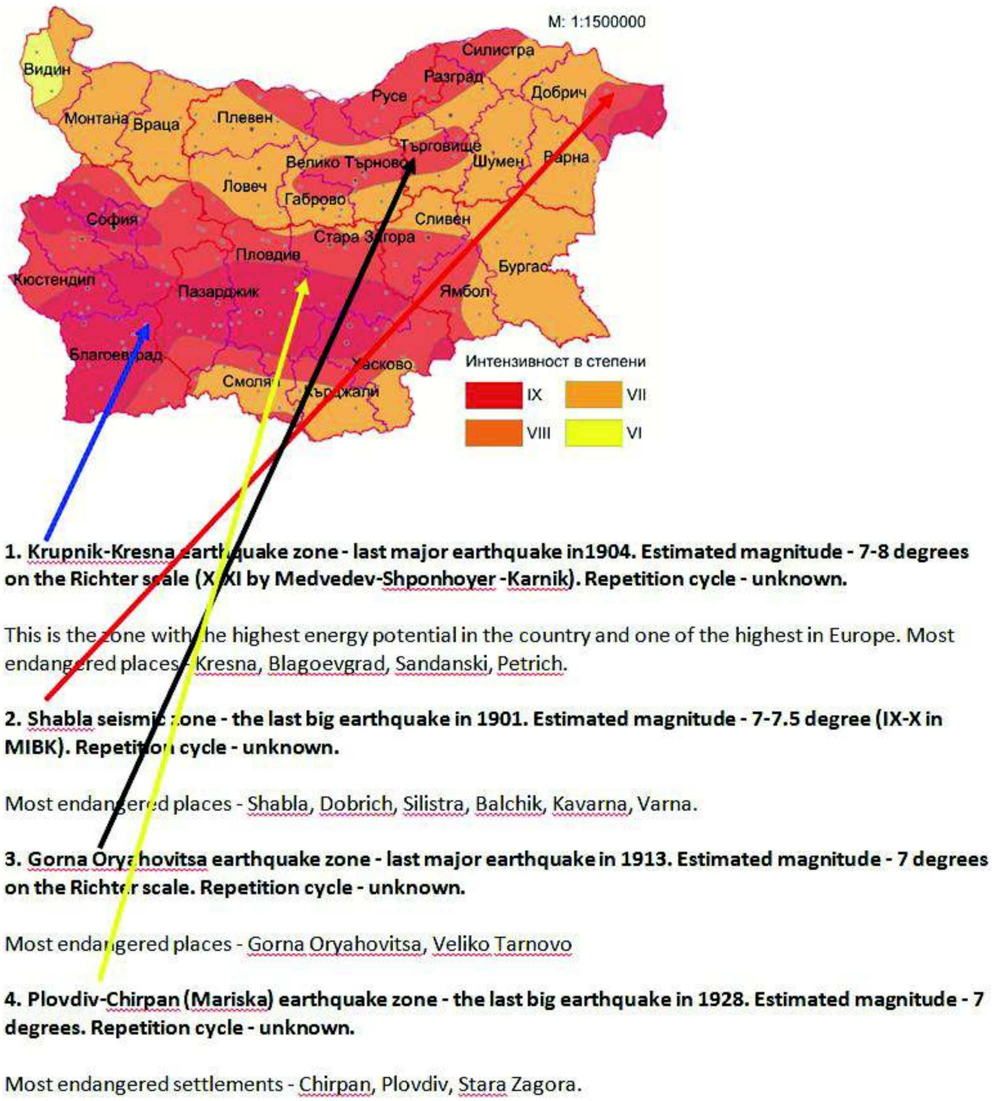


Figure 7.3.6 *Map of possible seismic focus in Bulgaria (PSF)*



1. Krupnik-Kresna earthquake zone - last major earthquake in1904. Estimated magnitude - 7-8 degrees on the Richter scale (X-XI by Medvedev-Shponhoyer -Karnik). Repetition cycle - unknown.

This is the zone with the highest energy potential in the country and one of the highest in Europe. Most endangered places - Kresna, Blagoevgrad, Sandanski, Petrich.

2. Shabla seismic zone - the last big earthquake in 1901. Estimated magnitude - 7-7.5 degree (IX-X in MIBK). Repetition cycle - unknown.

Most endangered places - Shabla, Dobrich, Silistra, Balchik, Kavarna, Varna.

3. Gorna Oryahovitsa earthquake zone - last major earthquake in 1913. Estimated magnitude - 7 degrees on the Richter scale. Repetition cycle - unknown.

Most endangered places - Gorna Oryahovitsa, Veliko Tarnovo

4. Plovdiv-Chirpan (Mariska) earthquake zone - the last big earthquake in 1928. Estimated magnitude - 7 degrees. Repetition cycle - unknown.

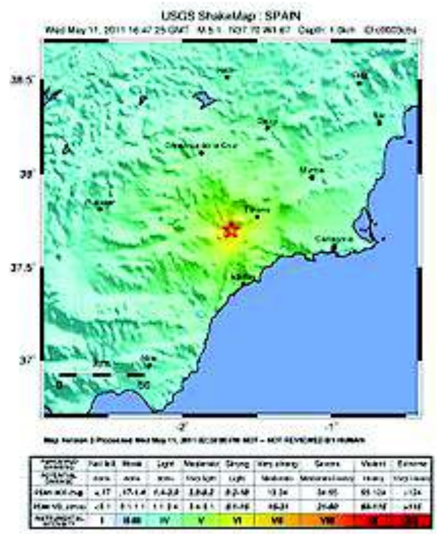
Most endangered settlements - Chirpan, Plovdiv, Stara Zagora.

Figure 7.3.7 *Most endangered settlements (NIGGG, BAS)*

Besides the above mentioned most risky zones in the country, there are many less dangerous with possible maximum magnitude of 6.5 to 7 degree. These are Sofia, Provadia and Yambol zones.

7.4 Spanish Case Study

LORCA EARTHQUAKE, 2011



Date	11 May 2011
Magnitude	5,1 M_W 5.3 M_S
Maximum intensity	Grade VIII in Mercalli scale
Seismic **acceleration horizontal**	0,36g
Depth	1 km
Duration	4-25 seconds
Epicentre coordinate	37°41′49″N 1°33′22″OCoordenadas: 37°41′49″N 1°33′22″O (map)
Consequences	
Affected areas	Lorca, Región de Murcia, Spain
Aftershocks	131
Víctims	9 death, and 324 injured, 3 serious injuries

Figure 7.4.1 *2011 Lorca Earthquake (USGS)*

Lorca earthquake of May 11, 2011 mainly shook the town of Lorca in Murcia, Spain, at 18:47 local time (16:47 UTC). Its epicentre was located in the Alhama de Murcia Fault (FAM) and its effects were felt throughout the region of Murcia. It was preceded by a premonitory earthquake of 4.5 occurred at 17:05 local time on the same day. The earthquake was also felt in the provinces of Almeria, Albacete, Granada, Jaen, Malaga, Alicante, Ciudad Real and parts of the city of Madrid where the type of soil amplifies movements in certain barrios (Fig. 7.4.1).

Multiple aftershocks occurred after the main event, while the biggest aftershock occurred at 22:37 local time, (M=3.9). It is worth to mention that Murcia region is the most active seismic zone of Spain, although the Lorca town is not among the most dangerous in it.

Magnitude and location

The main earthquake was magnitude 5.1 (Mw) with epicenter approximately 2km northeast of the town of Lorca. The epicenter was located in the basement of Barranco Hondo (Lorca) and the hypocenter of the earthquake was very shallow, about 1000m deep. The quake was felt throughout the southeast peninsula, especially in the region of Murcia. In the area the plate boundary between the Eurasian plate and the African plate is located. The earthquake was a result of fault rupture. The length of this fault is about 40 - 50km. Initial estimates of the United States Geological Survey reported a magnitude of 5.3 (Mw); while the Euro-Mediterranean Seismological Centre estimated the magnitude at 5.2 (M_L).

Figure 7.4.2 *Lorca railway station, damaged after the Lorca earthquake (https://commons.wikipedia.org)*

The earthquake was shallow with moderate magnitude. It was felt throughout the region of Murcia. In Lorca, near the epicentre an intensity of VII on the Mercalli scale was estimated.

Damages caused by the earthquake

Figure 7.4.3 *Church of Santiago, soon after the earthquake (https://commons.wikipedia.org)*

A lot of public buildings, homes and monuments of historical heritage have been affected from the earthquake (Fig. 7.4.2, 7.4.3). The most affected areas were the La Vina and the historic center where many masonry buildings left with their facades. An estimated 80% of homes were damaged, with some to be demolished in the following months (Fig. 7.4.4). In early September, the deadline established by Royal Decree Law to demolish ruined houses finished, the number of demolished homes was 1164 and a number of other buildings. Despite the high number of homes affected it is noteworthy that only a building collapsed during the quake.

Figure 7.4.4 *Demolition of a building at Santa Fe Jerome, a common scene in the months following the earthquake (https://commons.wikipedia.org)*

Educational and healthcare buildings have been affected from the earthquake to a greater or lesser extent. Ros Giner Institute (built in 1972) was demolished due to structural damage and Institute Ramón Arcas Mecca (building of 1956) was partially collapsed. The demolition of the institute is postponed to preserving sculptures by Miguel Fisac Serna, who was awarded the National Prize for Architecture in 2003. Other public buildings were affected as the Music Conservatory Narciso Yepes, the Commissioner of the National Police and Civil Guard headquarters, which was also demolished due to the severity of the damage house.

State infrastructure was also damaged. Viaducts and tunnels of the Mediterranean motorway A-7, well withstood the quake and reported only minor damage. In rail infrastructure, railway Sutullena Lorca was seriously damaged on the top floor, which was demolished for safety. In water infrastructure, the Segura basin reported that no problems were recorded in the reservoirs of Puentes and Valdeinfierno and a landslide occurred on two houses sharing water from the reservoir.

The cultural heritage Lorca's historic center has been greatly affected. The Mayor of Lorca confirmed that this earthquake has caused a major disaster for the heritage, with 33 historic buildings affected, including the Castle of Lorca. According to the Minister of Culture of the Region of Murcia, Lorca has suffered the greatest heritage catastrophe of Europe since the Assisi earthquake in 1997.

The earthquake left nine fatalities, including two pregnant women and a child of 14 years old, and 324 injured people. Two days after the earthquake the state funeral was officiated with only four coffins as other families chose privacy. The Mass was celebrated by the Bishop of the Diocese of Cartagena, with the presence among others of the Princes of Asturias, the Spanish Prime Minister, the Minister of Development, and the President of the Murcia. The funeral was attended by nearly three thousand people and was held at the fairgrounds in Santa Quiteria because of damage to the temples of the city.

Figure 7.4.6 *Indicatives in green, yellow, red and black in different buildings (https://commons.wikipedia.org)*

Civil Protection and Emergency Military Unit (UME) began to assess the damage, making available to the citizens of Lorca a makeshift office in the Plaza of Spain, where they were informed about the state of their homes (Fig. 7.4.6). On the walls and doors of houses, Civil Protection devised a system of colours: a green painted or sticker indicating that it could reach the house safely and inhabit a yellow indicated that it could come to collect belongings and get out and a painted or red sticker informing that you cannot access the house due to structural damage.

Legal Framework

First Royal Decree-Law

On 13 May, the Council of Ministers approved Royal Decree Law 6/2011 which the first aid and compensation to alleviate the damage of the earthquake were established. On Tuesday May 17 was signed in the city of Murcia the agreement for the management of aid from the Ministry of Development, the Autonomous Region and the city of Lorca. According to this agreement, financial aid would be provided by 50% by the Ministry and the regional administration. A Decalogue of simple recommendations prepared by Civil Protection "Plan Contigo", the project of the Police and the Civil Guard was in the social network:

• First, if somebody is indoors, he should stay indoors and cover under a sturdy piece of furniture such as a table or desk, away from windows, mirrors and objects that they may fall.

• After the earthquake when someone evacuates the building, he should never use the lift, only the stairs. Outside everybody should stay away from buildings facades, trees, utility poles or bridges, at open spaces.

• If the earthquake occurs while someone drives, it is advisable to stop the vehicle, park in an area away from walls or facades and stay indoors.

• In any case, Civil Protection advises to remain calm, turn on the radio or television to stay informed, follow the advice of authorities and use the telephone only for emergency calls.

Insurance Compensation Consortium

The day after the earthquake, the Ministry of Finance reported that the Insurance Compensation Consortium (CCS), a public body under this Ministry, would assume the cost of compensation arising from the earthquake. In a first assessment the estimated compensation total cost would be about 36 million €. However, on May 15 the Minister of Finance increased the total amount of compensation to approximately 70 million €. As of November 4, applications were 30041, of which 28665 had been fully paid and 459 had received some type of advance payment. The total amount paid by the Insurance Compensation Consortium at that date (November 4) clearly exceeded the first assessments with 262.9 million €. The May 11, 2012, coinciding with the first anniversary of the earthquake, the Consortium reported that of the 31861 requests for compensation had resolved 31562 for an amount of 411.3 million € in late compensation or advances.

The government created, after approval by the council of ministers, a commissioner to coordinate and monitor State measures for rebuilding the city of Lorca. For the recovery of assets, the Ministry of Culture prepared a Master Plan for Recovery of Cultural Heritage of Lorca that included restoration of 75 monuments with a budget of approximately 51 million €. This plan was approved on 28 October by the Council of Ministers.

Second Royal Decree-Law

In the same cabinet, the government established complementary to those of RDL 6/2011 measures being elaborated RDL 17/2011 and thus meeting a proposition of law, presented by the Popular Parliamentary Group in the House of Representatives and approved by unanimously on 13 September.

Third Royal Decree-Law

With the victory of the Popular Party in the general elections, the new government decided to adopt Royal Decree Law 11/2012, with which it is intended to promote reconstruction and the arrival of the relief efforts.

Bibliography

- Ibargüen Soler, J.; Rodríguez Estrella, T. (1996). *Peligrosidad sísmica en la Región de Murcia*. 6th Spanish Congress and International Conference on Environmental Geology and Land-Use Planning. Univ. de Granada, pp. 407-425.
- Martínez Díaz, J. J.; Rodríguez-Pascua, M. A.; Pérez López, R.; García Mayordomo, J.; Giner Robles, J. L.; Martín-González, F.; Rodríguez Peces, M.; Álvarez Gómez, J. A. e Insua Arévalo, J. M. (2011) *Informe geológico preliminar del terremoto de Lorca del 11 de mayo del año 2011, 5.1* M_w. Instituto Geológico y Minero de España, Grupo de Tectónica Activa, Universidad Autónoma de Madrid y Universidad Rey Juan Carlos de Madrid. 47 págs.

Links

- Wikimedia Commons alberga contenido multimedia sobre el terremoto de Lorca de 2011.
- Wikinoticias tiene noticias relacionadas con el terremoto de Lorca de 2011.
- Reporte del terremoto de Lorca (en inglés).
- Terremoto en Lorca Noticia del 12 de mayo de 2011.
- Mapa de peligrosidad sísmica en la Región de Murcia, (IBARGÜEN Y RODRÍGUEZ ESTRELLA, 1996)
- Caída de la fachada de una iglesia - YouTube
- https://es.wikipedia.org/wiki/Terremoto_de_Lorca_de_2011 - cite_note-66

8. Glossary and Acronyms

- **Accelerogram**
  The recording of the acceleration of the ground during an earthquake.

- **Accelerograph**
  An instrument that records the acceleration of the ground during an earthquake, also commonly called an accelerometer.

- **Active fault**
  A fault that is likely to have another earthquake sometime in the future. Faults are commonly considered to be active if they have moved one or more times in the last 10,000 years.

- **Aftershocks**
  Aftershocks are earthquakes that follow the largest shock of an earthquake sequence. They are smaller than the main shock. Aftershocks can continue over a period of weeks, months, or years. In general, the larger the main shock, the larger and more numerous the aftershocks, and the longer they will continue.

- **Body waves:** A seismic wave that travels through the interior of the Earth and is not restricted to any boundary surface.

- **Disaster**
  An event that causes major disruption on the economy, society and the environment. Its origin or causes may be directly derived from natural phenomena, i.e. geophysical (as volcanic or seismic events that cause collapse of infrastructure, landslides or liquefaction, etc.) or climatic (as hurricanes, typhoons, tornadoes, major variation in rainfall both in terms of excess or deficit causing drought). Although usually not covered by the methodology, disasters may also have a human or anthropic origin as chemical spills, industrial accidents, or voluntarily caused events such as war, terrorist actions, etc.

- **Disaster risk reduction plan**
  A document prepared by an authority, sector, organization or enterprise that sets out goals and specific objectives for reducing disaster risks together with related actions to accomplish these objectives.

- **Early warning system**
  The set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss.

- **Earthquake**
  Term used to describe both sudden slip on a fault, and the resulting ground shaking and radiated seismic energy caused by the slip, or by volcanic or magmatic activity, or other sudden stress changes in the earth.

- **Earthquake hazard**
  Earthquake hazard is anything associated with an earthquake that may affect the normal activities of people. This includes surface faulting, ground shaking, landslide, liquefaction, tectonic deformation, tsunamis, etc.

- **Earthquake risk**
  Earthquake risk is the probable building damage, and number of people that are expected to be hurt or killed if a likely earthquake on a particular fault occurs.

- **Elastic energy:** The energy stored within the Earth during elastic deformation.

- **Emergency management**
  The organization and management of resources and responsibilities for addressing all aspects of emergencies, in particular preparedness, response and initial recovery steps.

- **Epicenter**
  The epicenter is the point on the earth's surface vertically above the hypocenter (or focus), point in the crust where a seismic rupture begins.

- **Exposure**
  People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses.

- **Fault**
  A fault is a fracture along which the blocks of crust on either side have moved relative to one another parallel to the fracture.

- **Focal depth**
  The focal depth refers to the depth of an earthquake hypocenter.

- **Focus or Hypocenter**
  The hypocenter is the point within the earth where an earthquake rupture starts. The epicenter is the point directly above it at the surface of the Earth that termed as focus.

- **Foreshocks**
  Foreshocks are relatively smaller earthquakes that precede the largest earthquake in a series, which is termed the main shock. Not all main shocks have foreshocks.

- **Hazard**
  A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

- **Intensity**
  The intensity is a number (written as a Roman numeral) describing the severity of an earthquake in terms of its effects on the earth's surface and on humans and their structures. Several scales exist, but the one most commonly used is the Modified Mercalli scale. There are a lot of intensities for an earthquake, depending on where you are, unlike the magnitude, which is one number for each earthquake.

- **Isoseismal (line)**
  An isoseismal (line) is a contour or line on a map bounding points of equal intensity for a particular earthquake.

- **Landslide**
  A landslide is a movement of surface material down a slope.

- **Liquefaction**
  A process by which water-saturated sediment temporarily loses strength and acts as a fluid, like when you wiggle your toes in the wet sand near the water at the beach. This effect can be caused by earthquake shaking.

- **Lifelines**
  Lifelines are structures that are important or critical for a community to function, such as roadways, pipelines, power lines, sewers, communications, and port facilities.

- **Lithosphere**
  The outer solid part of the Earth, including the crust and uppermost mantle. The lithosphere is about 100 km thick, although its thickness is age dependent. The lithosphere below the crust is brittle enough at some locations to produce earthquakes by faulting, such as within a subducted oceanic plate.

- **Magnitude**
  The magnitude is a number that characterizes the relative size of an earthquake. Magnitude is based on measurement of the maximum motion recorded by a seismograph. Several scales have been defined, but the most commonly used are: local magnitude (M_L), commonly referred to as "Richter magnitude," surface-wave magnitude (Ms), body-wave magnitude (Mb), and moment magnitude (Mw). All magnitude scales should yield approximately the same value for any given earthquake.

- **Main shock**
  The main shock is the largest earthquake in a sequence, sometimes preceded by one or more foreshocks, and almost always followed by many aftershocks.

- **Mitigation**
  Mitigation is the lessening or limitation of the adverse impacts of hazards and related disasters.

- **Natural hazard**
  Natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

- **Oceanic spreading ridge**
  An oceanic spreading ridge is the fracture zone along the ocean bottom where molten mantle material comes to the surface, thus creating new crust. This fracture can be seen beneath the ocean as a line of ridges that form as molten rock reaches the ocean bottom and solidifies.

- **P wave**
  A P wave, or compressional wave, is a seismic body wave that shakes the ground back and forth in the same direction and the opposite direction as the direction the wave is moving.

- **Plates:** Large, nearly rigid, but still mobile segments of blocks involved in plate tectonics that include both crust and some part of the upper mantle.

- **Plate tectonics**
  Plate tectonics is the theory supported by a wide range of evidence that considers the earth's crust and upper mantle to be composed of several large, thin, relatively rigid plates that move relative to one another. Slip on faults that define the plate boundaries commonly results in earthquakes. Several styles of faults bound the plates, including thrust faults along which plate material is sub ducted or consumed in the mantle, oceanic spreading ridges along which new crustal material is

produced, and transform faults that accommodate horizontal slip (strike slip) between adjoining plates.

- **Preparedness**
  The knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard events or conditions.

- **Prevention**
  The outright avoidance of adverse impacts of hazards and related disasters.

- **Public awareness**
  The extent of common knowledge about disaster risks, the factors that lead to disasters and the actions that can be taken individually and collectively to reduce exposure and vulnerability to hazards.

- **P-waves:** The primary or fastest wave travelling away from an earthquake source, consisting of a train of compressions and dilatations parallel to the direction of travel of the wave.

- **Recovery**
  The restoration and improvement where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors.

- **Resilience**
  The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions. The resilience of a community in respect to potential hazard events is determined by the degree to which the community has the necessary resources and is capable of organizing itself both prior to and during times of need.

- **Response**
  The provision of emergency services and public assistance during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected.

- **Richter scale**
  The Richter magnitude scale was developed in 1935 by Charles F. Richter of the California Institute of Technology as a mathematical device to compare the size of earthquakes. The magnitude of an earthquake is determined from the logarithm of the amplitude of waves recorded by seismographs. Adjustments are included for the variation in the distance between the various seismographs and the epicenter of the earthquakes. On the Richter Scale, magnitude is expressed in whole numbers and decimal fractions. Because of the logarithmic basis of the scale, each whole number increase in magnitude represents a tenfold increase in measured amplitude; as an estimate of energy, each whole number step in the magnitude scale corresponds to the release of about 31 times more energy than the amount associated with the preceding whole number value.

- **Risk**
  The combination of the probability of an event and its negative consequences.

- **Risk Assessment**
  A methodology to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend.

- **Risk management**
  The systematic approach and practice of managing uncertainty to minimize potential harm and loss.

- **S-wave**
  An S wave, or **shear wave**, is a seismic body wave that shakes the ground back and forth perpendicular to the direction the wave is moving.

- **Seismicity**
  Seismicity refers to the geographic and historical distribution of earthquakes.

- **Seismic hazard:** The physical effects such as ground shaking, faulting, landsliding, and liquefaction that underlie the earthquake's potential danger.

- **Seismic risk:** The likelihood of human and property loss that can result from the hazards of an earthquake.

- **Seismic waves:** Waves produced by an earthquake, including both body waves and surface waves.

- **Seismogram**
  A seismogram is a record written by a seismograph in response to ground motions produced by an earthquake, explosion, or other ground-motion sources.

- **Seismograph**
  A seismograph, or seismometer, is an instrument used to detect and record earthquakes. Generally, it consists of a mass attached to a fixed base. During an earthquake, the base moves and the mass does not. The motion of the base with respect to the mass is commonly transformed into an electrical voltage. The electrical voltage is recorded on paper, magnetic tape, or another recording medium. This record is proportional to the motion of the seismometer mass relative to the earth, but it can be mathematically converted to a record of the absolute motion of the ground.

- **Seismology**
  Seismology is the study of earthquakes and the structure of the earth, by both naturally and artificially generated seismic waves.

- **Subduction**
  Subduction is the process of the oceanic lithosphere colliding with and descending beneath the continental lithosphere.

- **Surface waves:** Seismic waves that follow the earth's surface only with a speed less than that of S waves. These are the Rayleigh and Love waves.

- **Tectonic plates**
  The tectonic plates are the large, thin, relatively rigid plates that move relative to one another on the outer surface of the Earth.

- **Tsunami**
  A tsunami is a sea wave of local or distant origin that results from large-scale seafloor displacements associated with large earthquakes, major submarine slides, or exploding volcanic islands.

- **Vulnerability**
  The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.

Acronyms

EERI Earthquake Engineering Research Institute

EPPO Earthquake Planning and Protection Organization

FEMA Federal Emergency Management Agency

GEER Geotechnical Extreme Events Reconnaissance

G.I. Institute of Geodynamics

GSCP General Secretariat for Civil Protection in Greece

INSARAG International Search and Rescue Advisory Group

ITSAK Institute of Engineering Seismology and Earthquake Engineering

MCEER Multidisciplinary Center for Earthquake Engineering Research

NOA National Observatory of Athens

OCHA Office for the Coordination of Humanitarian Affairs

RACCE Raising Awareness and Coping Children's Emotions project

SRA Seismic Rehabilitation Agency

TEI Technological Educational Institute

UNDRR United Nations Disaster Risk Reduction

UNISDR United Nations International Strategy for Disaster Reduction

USAR Urban Search and Rescue

USGS U.S.Geological Survey

NIGGG, BAS - National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences

9. References

ISDR (2009). UNISDR Terminology on Disaster Risk, 35p (www.unisdr.org/we/inform/terminology)

USGS. http://earthquake.usgs.gov/learn/glossary

Hazard Description chapter

Literature

Boyko, R., (2003). Classification and Description of the Secondary Effects Accompanying Earthquakes with Different Magnitudes. European Commission, DIRECTORATE GENERAL JRC JOINT RESEARCH CENTRE.

Environmental Literacy Council of National Science Teachers Association, (2007). Earthquakes, Volcanoes, and Tsunamis. National Science Teachers Association.

Kearey, P., (1993). The Encyclopedia of the Solid Earth Sciences. Blackwell Science Ltd.

Papazachos, B.C., Comninakis, P.E., Karakaisis, G.F., Karakostas, B.G., Papaioannou, Ch.A., Papazachos, C.B. and E.M. Scordilis (2000). A catalogue of earthquakes in Greece and surrounding area for the period 550BC-1999, Publ. Geophys. Laboratory, University of Thessaloniki, 1, 333pp.

Papazachos, B. & Papazachou, C., (1997). The earthquakes of Greece. P. Ziti & Co.

Pavlides, S., (2003). Geology of Earthquakes: Introduction to Neotectonics, Morphotectonics and Palaioseismology.

Press, F. & Siever, R., (1997). Understanding Earth. W. H. Freeman and Company.

Skinner B.J., Porter S.C., & Park J. (2004) Dynamic Earth: An introduction to Physical Geology. Wiley Inc.

Van Andel, T. H., (1985). New views on an old planet: Continental drift and the history of the earth. Cambridge University Press.

Van der Pluijm, Ben A. & Marshak, S., (2004). Earth structure. W. W. Norton & Company, Inc.

Yeats, R. S., Sieh, K. & Allen, C.R., (1997). The Geology of Earthquakes. Oxford University Press.

Internet resources

http://www.tulane.edu/~sanelson/geol204/index.html

http://www.usgs.gov

http://www.jma.go.jp

http://www.wikipedia.org/

www.elsevier.com/locate/geomorph

http://www.bgs.ac.uk/discoveringGeology/hazards/earthquakes/locatingQuakes.html http://racce.nhmc.uoc.gr/files/items/9/910/2_theoritical_booklet.pdf

http://racce.nhmc.uoc.gr/en/downloads/ekpai/videos.html

http://www.iris.edu/news/events/japan2011/

Greek Seismic Hazard Map chapter

EPPO website: www.oasp.gr

EU (1996). Guidance on risk assessment at work, 64p

OPUS (2005). Earthquake Risk Assessment Study, Earthquake Hazard and Risk Assessment Project, 76p

https://osha.europa.eu/en/topics/riskassessment/index_html

http://www.ready.gov/risk-assessment

http://earthquake.usgs.gov/research/hazrisk

Spanish Seismic Hazard Map chapter

BOE (1995) Decision dated 5 May 1995 of the Ministry of Home Affairs that publishes the agreement of the Council of Ministers to approve the Basic Civil Protection Planning Guidelines for Seismic Risk.

Tenerife Island Council. Risk Analysis. Chapter III of Tenerife Island's Civil Protection Regional Insular Emergency Plan.

Garcia C., A. (2014). Introducción al análisis de los riesgos geológicos (Introduction to the Analysis of Geological Risks). University of Granada.

Generalitat Valenciana (GVA) – Seismic Risk.

IGM (Instituto Geológico y Minero, the Geological and Mining Institute).

Impact analysis of geological risks in Spain. Assessment of losses due to earthquakes and flooding during the 1987-2001 period, and estimates for the 2004-2033 period.

IGN (Institúto Geográfico Nacional, the National Geographic Institute). Seismicity map.

Report on the Lorca earthquake of 11 May 2011.

Autonomous Government of Andalusia. Emergency Plan for Seismic Risk in Andalusia.

Pacuals S. G., Gonzalez L. S. and Alguacul A. L. (2012) "Análisis de Consecuencias y Actuaciones de Protección Civil en el Terremoto de Lorca (Murcia): Pre-Emergencia, Emergencia y Post-Emergencia" (Analysis of the Consequences and Civil Protection Actions in the Lorca Earthquake (Murcia): Pre-Emergency, Emergency and Post-Emergency).

Spain Civil Protection - Earthquakes.

National Civil Protection Plan for Seismic Risk.

Self-Protection Measures to be Carried Out During an Earthquake.

Tracking Report for Seismicity in the Gulf of Valencia (2013).

Analysis of Consequences and Civil Protection Actions in the Lorca Earthquake (Murcia): Pre-Emergency, Emergency and Post-Emergency. *Física de la Tierra*, Volume 24 (2012), pages 343-362.

Recommendations – Vademecum Remer.

Region of Murcia. Special Civil Protection Plan for Seismic Risk in the Region of Murcia.

Sanmartin-Burruezo M.P. et al (2015). Las medidas de salud pública ante una catástrofe: a propósito del terremoto de Lorca en 2011 (Public Health Measures in the Event of a Disaster: Resulting from the 2011 Lorca Earthquake). Salud Ambient magazine. p. 49-58

Vulnerability and Risk Assessment (1994). Disaster Management Training Programme (DMTP), United Nations.

Prevention and Mitigation chapter

E.P.P.O. (2012). Leaflet “Roles and Responsibilities”, Athens, 6p

E.P.P.O. (2014). Leaflet “Earthquake Planning Workshops”, Athens

E.P.P.O. (2012). “Code of structural interventions 2012 final harmonized text” Athens, 348p

FEMA (2011). “FEMA Mitigation and Insurance Strategic Plan”, 40p

ELSTAT (2009). Concise statistical yearbook 2009, 327p

FEMA. Website: http://www.fema.gov/what-mitigation

Website:http://www.britannica.com/EBchecked/topic/176199/earthquake/59574/ Methods-of-reducing-earthquake-hazards

K. Stylianidis, A. Sextos, D. Panagiotopoulou and M. Panoutsopoulou (2014). ”Pre-earthquake evaluation, assessment and strengthening of existing public buildings” International Workshop on Seismic Hazard and Earthquake Engineering, Technological Institute of Ionian Islands, Cephalonia, Greece, September 2014.

E. Lekkas, D. Minos – Minopoulos & E. Stefanidou (2010). “Emergency planning for the municipality of Kos, Kos Island, Greece” Geologically Active – Williams et al. (eds) Taylor & Francis Group, London, ISBN 978-0-415-60034-7

UNISDR (2009). “Terminology”, http://www.unisdr.org/we/inform/terminology

ISDR-PPEW (2005a). "Many of the points presented in this paper have been discussed and illustrated in the early warning web pages of the ISDR. The 4-element view of effective people-centred early warning systems is discussed at http://www.unisdr.org/ppew/whats-ew/basics-ew.htm and in ISDR-PPEW (2005b). ISDR Platform for the Promotion of Early Warning (PPEW), Bonn.

USGS Website. http://earthquake.usgs.gov/research/earlywarning

Preparedness chapter

EPPO (2014). "Protective Measures - Post Disaster Period", Athens, 16p

EPPO (2013). "Get Ready for the Earthquake. Follow 5 steps", Athens, 8p

EPPO (2012). "Model School Emergency Plan", Document 824/11-4-2012, 24p

GSCP (2012). "Civil Protection Actions on Earthquake Management", Circular 2450, 35p

UN/ISDR (2005). "Hyogo Framework for Action 2005–2015", *World Conf. on Disaster Reduction,* Kobe Japan.

U.S. Department of Homeland Security (2011). "National Preparedness Plan"

FEMA. website: *http://www.fema.gov/national-preparedness-cycle*

EPPO. website: *www.oasp.gr*

RACCE. website of "Raising Earthquake Awareness and Coping Children's Emotions" Project, *www.racce.nhmc.uoc.gr*

Ready. website: *http://www.ready.gov/are-you-ready-guide*

Response chapter

Anagnostopoulos S. (2003). "Peadab Post Earthquake Damage and usability assessment of Buildings - Post-Earthquake Emergency Assessment of Building Safety Field Manual" 61p

GSCP (2012). Circular (2450/9-4-2012) "Planning and civil protection actions addressed on earthquake risk issues"

EPPO (2014). "Protective Measures - Post Disaster Period", 16p

EPPO (2003) "Prevention & Mitigation of the Psychosocial Consequences of Earthquakes", Athens 103p

EPPO (2000) "One year after the Athens 7-9-199 Earthquake", Athens 15p

Martin J. Course "Earthquake Hazard and Emergency Management" Session "Earthquake Disaster Response and Recovery" (https://training.fema.gov /emiweb/downloads/earthquakeem)

Ocha United Nations Office for the Coordination of Humanitarian Affairs http://www.unocha.org/what-we-do/coordination-tools/insarag/overview

Pomonis A. (2002)."The Mount Parnitha (Athens) Earthquake of September 7, 1999: A Disaster Management Perspective" Natural Hazards 27**:** 171–199.

UNISDR (2009): "Terminology", http://www.unisdr.org/we/inform/terminology

University of Florida (1998): "The Disaster Handbook 1998 National Edition Institute of Food and Agricultural Sciences University of Florida - Section 3.7 The Role of G B.

Recovery chapter

Comerio M. C. (1998). “Disaster hits home: New policy for urban housing recovery”. Berkley and Los Angeles CA: University of California Press.

Dandoulaki M. (2008). “Spatial planning and earthquake protection in Greece”. PhD Thesis, National Technical University of Athens (in Greek).

ECPFE (2000). “Athens Earthquake of September 1999”. Newsletter iss. N. 3, Athens

EPPO (2014). “Protective Measures - Post Disaster Period”, Athens

GEER/EERI/ATC (2014). Earthquake Reconnaissance Cephalonia, Greece Events, Version 1.

Peacock W.C., Girard C. (1997). “Ethnic and racial inequalities in hurricane damage and insurance settlements”. In Peacock, W.C., Morrow, B. H., & Gladwin H. (eds). “Hurricane Andrew: Ethnicity, gender and the sociology of disasters” (pp. 135-145). London and New York Routledge.

Pomonis A. (2002).”The Mount Parnitha (Athens) Earthquake of September 7, 1999: A Disaster Management Perspective” Natural Hazards 27**:** 171–199.

Jie-Ying W., Lindell M. (2003). “Housing Reconstruction after Two Major Earthquakes: The 1994 Northridge Earthquake in the United States and the 1999 Chi-Chi Earthquake in Taiwan”

Johnson C. (2007). ”Impacts of prefabricated temporary housing after disasters: 1999 earthquakes in Turkey”. Habitat International 31 36–52

Quarantelli E. L. (1999). The Disaster Recovery Process: What We Know and Do Not Know from Research.” Newark: Disaster Research Center, University of Delaware.

UNDRO (1982). Shelter after disaster: Guidelines for assistance. New York: UNDRO.

UN/ISDR (2005). Hyogo Framework for Action 2005 – 2015. World Conference on Disaster Reduction - Kobe Japan.

UN World Conference on Disaster Risk Reduction, (2015). “Reconstructing after disasters: Build back better”. Ministerial Roundtable 14-18 March 2015, Sendai, Japan