Chapter 1 - Introduction

In recent years there has been increasing interest in determining the behavior of a structure in the post-elastic region, i.e. after the appearance point of raw damage.

Shear walls are vertical walls that are designed to receive lateral forces from diaphragms and transmit them to the ground. The forces in these walls are predominantly shear forces in which the fibers within the wall try to slide past one another.

When you build a house of cards, you design a shear wall structure, and you soon learn that sufficient card "walls" must be placed at right angles to one another or the house will collapse. If you were to connect your walls together with tape, it is easy to see that the strength of this house of cards would significantly increase. This illustrates a very important point, in which the earthquake resistance of any building is highly dependent upon the connections joining the building's larger structural members, such as walls, beams, columns and floor-slabs.

Shear walls, in particular, must be strong in themselves and also strongly connected to each other and to the horizontal diaphragms. In a simple building with shear walls at each end, ground motion enters the building and creates inertial forces that move the floor diaphragms. This movement is resisted by the shear walls and the forces are transmitted back down to the foundation.

The seismic recordings in near to fault areas have provided clear evidence that ground motion in the near field of a rupturing fault differs from far field ground motions, as inherently it possess pulse-type character. During fault rupturing, the ground motion is significantly affected by the faulting mechanisms, direction of rupture propagation relative to the site & the static deformation of ground correlated with fling step effects. Particularly, in the rupture direction pulse events arrive in a single coherent time; result in a long - period pulse of motion- a shock wave effect- that occurs at the beginning of the record. The phenomenon is called forward directivity similar to the Doppler effect.

The goal of this thesis is to contribute to the knowledge and understanding of the near field ground motion effects on the seismic response of the building.

Accordingly, typical shear wall building has been used in this study. The limit states are defined according to the criteria of Hazus Manual and a total of 21 near field ground motion have been utilized which was recorded during different earthquakes in different regions of the world.

To study used an existing 8 storey construction of reinforced concrete with shear walls. The building is located in Athens, Plastira Street, number 118.

The thesis consists of 9 chapters

The first chapter is the introduction stating briefly the contents of the entire thesis and each chapter.

The second chapter analyzes is an introduction in the seismic risk assessment, about the 2 methods of determining seismic hazard (DSHA and PSHA) and the local site effects.

The third chapter describes the methodology of HAZUS, damage states. In this chapter we describe also how we use the SAP 2000 software in the non-linear analysis.

The fourth chapter talks about the characteristics of ground motion during seismic loading near field. We give some basic definitions for the phenomenon of near-field, such as rupture directivity and the remaining movement and some mathematical models have been proposed for the customization of sizes used in the study of a seismic event.

The fifth chapter describes the building we study and the loads that are applied.

The sixth chapter are presented the results from the pushover analysis and the plot of the fragility curves.

The seventh chapter, are presented the ground motions used for this study.

The eighth chapter are presented the results taking into account the HAZUS methodology.

The ninth chapter are revealed the conclusions based on the results from the previous chapter.

Chapter 2 – Seismic Risk Assesment

2.1 Introduction

Seismic Risk Assessment (SRA) involves determining the adverse consequences that at people and society might suffer as a result of future earthquakes. There are three components to seismic risk assessment : the seismic hazard, the vulnerability of structures in the region and the expected losses that result from damage.

Seismic hazard assessment methodologies are used to estimate the expected level of ground shaking at a given location. The ground shaking level depends on the earthquake source, the effects of the wave travel path and the local site conditions. Source characteristics that affect the ground shaking include the magnitude and the type of fault. Travel effects include the distance from the earthquake source to the sight of interest and the geology through which the seismic waves travel. The effects of local site conditions depend on the geology at the site and include soil amplification, liquefaction and landslides.

2.2 Background

Seismic risk refers to the risk of damage from earthquake to a building, system, or other entity. Seismic risk has been defined, for most management purposes, as the potential economic, social and environmental consequences of hazardous events that may occur in a specified period of time. A building located in a region of high seismic hazard is at lower risk if it is built to sound seismic engineering principles. On the other hand, a building located in a region with a history of minor seismicity, in a brick building located on fill subject to liquifaction can be as high or higher risk.

Seismic risk can be defined quantitatively as the product of Seismic Hazard (H) & the Vulnerability (V)

$$R = H * V \qquad \text{(Equation 2.1)}$$

As shown in Eq.2.1, high seismic hazard does not necessary mean high seismic risk, and vice versa.

In terms of natural disasters, risk refers to the expected losses from a given hazard to a given element at risk, over a specified future time (UNDRO, 1979). Seismic risk, therefore, refers to expected losses due to future earthquakes. It is comprised of four elements: hazards, location, exposure and vulnerability. In order for the seismic risk to exist, all four elements must be present. Figure 2-1 illustrates this concept.

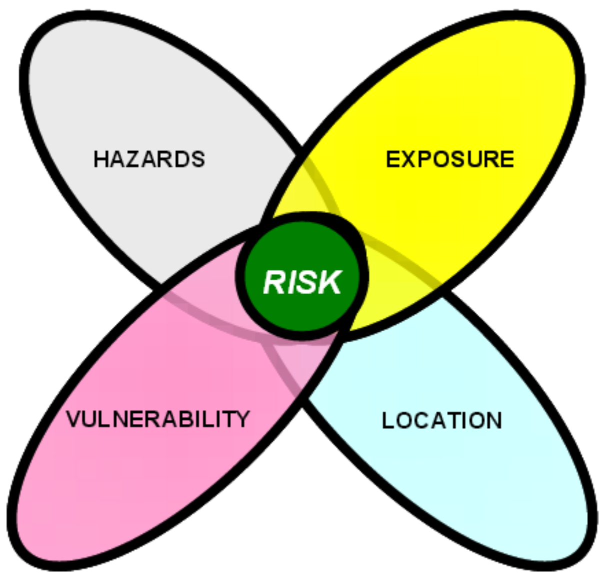

Fig 2.1 - Components of Seismic Risk (FEMA, 2007)

Fig2.2 Comparison of seismic hazard and risk. Seismic hazard: earthquake triggered rock fall. Vulnerability: car, its driver, and pedestrians. Consequence: struck by a rock fall. Seismic risk: the probability of being struck by a rock fall during the period that the car or pedestrians pass through the road section

There is no risk (i.e., no probability that the car or pedestrians could be hit by a rockfall) if the driver decides not to drive or pedestrians decide not to go through the road (i.e., no vulnerability). This example also demonstrates that engineering design or a policy for seismic hazard mitigation may differ from one for seismic risk reduction. Here, the seismic hazard (rockfall) may or may not be mitigated, but the seismic risk can always be reduced by either mitigating the seismic hazard (i.e., building barriers and other measures), reducing the vulnerability (i.e., limiting traffic or pedestrians), or both. Therefore, it is critical for engineers and decision-makers to clearly understand seismic hazard and risk.

Seismic hazard is defined as the study of expected earthquake ground motions at any point on earth. The expected level of shaking at the site or region of interest is calculated based on the characteristics of the areas seismic sources, the attenuation of seismic waves from the epicenter to the site and the local site conditions (location). Seismic hazard assessment can be either deterministic or probabilistic. Deterministic Seismic Hazard Assessments (DSHA) are scenario studies conducted to determine the effects of a single earthquake. Probabilistic Seismic Hazard Assessment (PSHA) takes into account all possible earthquakes that can occur in the region from various sources using Magnitude-Recurrent relationships. These relationships describe the distribution of earthquake magnitudes for a given period of time for each earthquake source zone. Results of PSHA are typically presented in the form of a curve displaying the probability of annually exceeding a given ground motion level.

Seismic hazard assessment uses “reference” ground conditions, typically rock or firm soil, to determine the attenuation of ground motions. Local site conditions can have a significant effect on the level and characteristics of seismic shaking. For this reason, the location of a site or region of interest needs to be factored into the calculation of seismic risk. Site conditions refer to the geologic, topographic and soil characteristics that can have an influence on the amplitude, frequency content and duration of the seismic shaking. Local site conditions are also necessary to determine the liquefaction and landslide potential.

Exposure is defined as the valuables that could suffer losses as the result of earthquake shaking. These valuables can be either economic or social and include human lives, infrastructure and business revenue. For example, a grocery store has its occupants, the value of the building, the value of its contents and potential revenue exposed to the natural hazard present in the region. Risk assessments for large areas require a comprehensive inventory to store exposure data and classify structures into groups according to their use, structural characteristics and importance.

The seismic vulnerability of a structure refers to how well it will perform under earthquake loading. It is essentially the sensitivity of the exposed structures to the expected seismic hazard in a region. Structural vulnerability is typically defined by motion-damage relationships which define the probability of damage to a structure given the level of ground shaking. These relationships can be grouped into two categories: intensity based and engineering parameter based. Intensity base relationships are typically developed based on expert opinion and express the probability of damage given the earthquake intensity using damage probability matrices (DPM). Engineering parameter based methodologies typically use spectral acceleration or spectral displacement in the form of demand spectra to describe the input ground motions. The building characteristics are represented by capacity curves and the building vulnerability is predicted though the use of fragility curves.

Vulnerability (V) is expressed in a quantitative terms as the probability for a given seismic intensity (I) point to a fault (D).

$$V = (P / I) \qquad \text{(Equation 2.2)}$$

The value of vulnerability ranges from 0 to 1. It can be further sub-divided into, structural and non-structural, wherein a first approach the structural vulnerability can be considered as the most important from construction point of view. However, the non-structural vulnerability is likely to cause equally serious damage even in low-intensity seismic events.

2.3 Deterministic Seismic Hazard Assessments (DSHA)

A basic DSHA is a simple process that is useful especially where tectonic features are reasonably active and well defined. The focus is generally on determining the maximum credible earthquake (MCE) motion at the site. The steps in the process are as follows:

1. Identify nearby seismic source zones - these can be specific faults or distributed sources

2. Identify distance to site for each source (nearby distributed sources are a problem)

3. Determine magnitude and other characteristics (i.e. fault length, recurrence interval) for each source

4. Establish response parameter of interest for each source as a function of magnitude, distance, soil conditions, etc., using either the envelope or the average of several ground motion attenuation relationships

5. Tabulate values from each source and use the largest value

Where the DSHA is based on tectonic features, it tends to be conservative since the maximum earthquake the fault is "capable" of generating is assumed to occur at the location on the fault closest to the site. DSHA is frequently used in California due to the knowledge of faults and the region's high seismicity.
When a distributed source is considered in the analysis, a distance must be determined. This presents much more of a problem for nearby distributed sources than those which are distant. Often, engineering judgment is used or a back calculation is employed to give the desired answer.

The DSHA method is simple, but **it does not treat uncertainties well**. Rudimentary statistics can be incorporated into the procedure by taking one standard deviation above median at each step (magnitude, PGA, etc.), which gives a very big, very conservative estimate. However, the DSHA does not account for the probability of an earthquake occurring on a fault.

2.4 Probabilistic Seismic Hazard Assessments (PSHA)

In order to assess risk to a structure from earthquake shaking, we must first determine the annual probability (or rate) of exceeding some level of earthquake ground shaking at a site, for a range of intensity levels. Information of this type could be summarized as shown in Figure 1.1, which shows that low levels of intensity are exceeded relatively often, while high intensities are rare. If one was willing to observe earthquake shaking at a site for thousands of years, it would be possible to obtain this entire curve experimentally. That is the approach often used for assessing flood risk, but for seismic risk this is not possible because we do not have enough observations to extrapolate to the low rates of interest. In addition, we have to consider uncertainties in the size, location, and resulting shaking intensity caused by an earthquake, unlike the case of floods where we typically only worry about the size of the flood event. Because of these challenges, our seismic hazard data must be obtained by mathematically combining models for the location and size of potential future earthquakes with predictions of the potential shaking intensity caused by these future earthquakes. The mathematical approach for performing this calculation is known as Probabilistic Seismic Hazard Analysis, or PSHA.

With PSHA, we are searching for an elusive worst-case ground motion intensity. Rather, we will consider all possible earthquake events and resulting ground motions, along with their associated probabilities of occurrence, in order to find the level of ground motion intensity exceeded with some tolerably low rate. At its most basic level, PSHA is composed of five steps.

1.Identify all earthquake sources capable of producing damaging ground motions.

2. Characterize the distribution of earthquake magnitudes (the rates at which earthquakes of various magnitudes are expected to occur).

3. Characterize the distribution of source-to-site distances associated with potential earthquakes.

4.Predict the resulting distribution of ground motion intensity as a function of earthquake magnitude, distance, etc.

5. Combine uncertainties in earthquake size, location and ground motion intensity, using a calculation known as the total probability theorem.

2.5 Hazard Analysis

Hazard is defined as the process of quantitatively estimating the ground motion at a site or region of interest based on the characteristics of surrounding seismic sources. This study primarily composed of geological and seismological disciplines with input from civil engineering (FEMA, 1989). In this respect, the term seismic hazard has a technical meaning restricted to the behavior of the ground, apart from any effects on the built environment. The basic methodology of hazard analysis is comprised of regional seismicity, seismic waves attenuation from the epicenter to the site, and local site amplification, which are illustrated in Figure 2.3

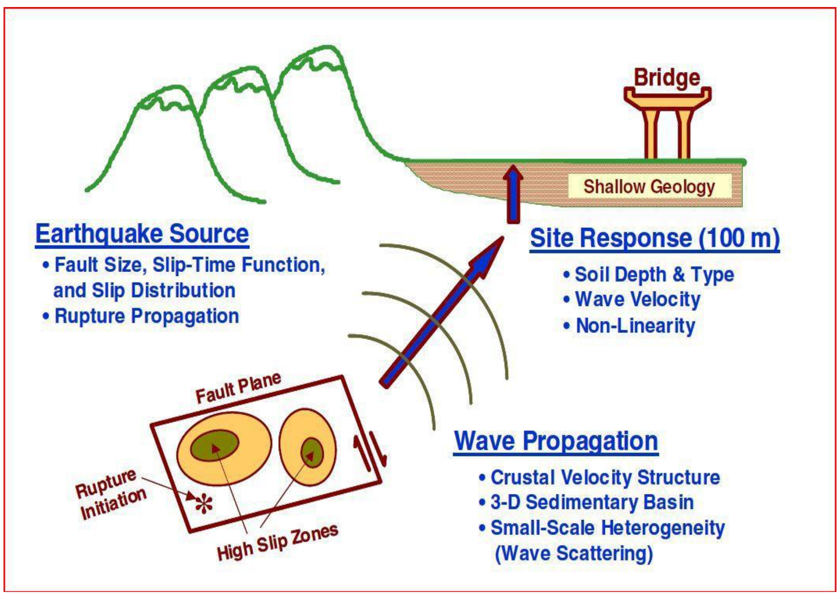

Fig 2.3 Hazard components (Regional Seismicity, Wave Attenuaton, Site response)

2.6 Local site Effects

Local geologic and soil conditions can significantly influence ground motion characteristics such as magnitude, frequency content, and duration (Kramer, 1996, Marcellini et al., 2001). Regional seismicity can be varied based on the local ground response, basin effects & surface topography. Accurate assessment of local ground response is essential in determining the seismic motion at the ground surface as well as the potential of liquefaction and ground failure. Surface waves generation are typically influenced by the basin effects that include wave reflection and surface waves generation at the basin edges (Figure 2.4). The effect of surface topography plays a vital role in local site effect such a by variation of the seismic wavelength, maximizing crest amplification at the site. Measuring these properties over a dense grid, and combining with hazard analysis, a detailed soil map can be developed that reveals not only the soil parameters required to obtain site-specific response spectra, but also the potential of liquefaction and ground motion. The process of developing such detailed maps is called microzonation.

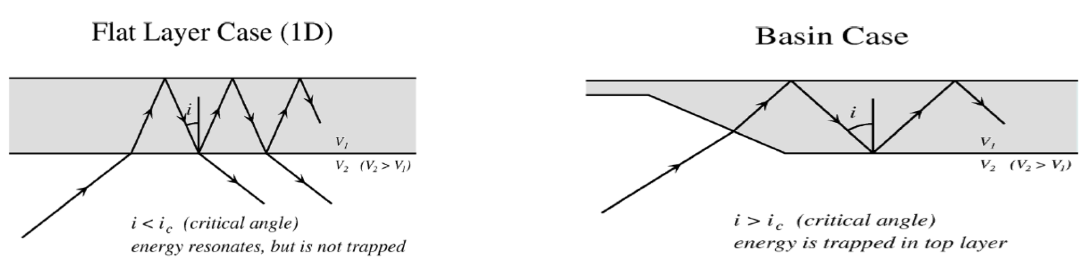

Fig 2.4 local site conditions (flat and basin cases)

2.7 Exposure

Exposure is defined as the valuable components that could suffers losses as a result of seismic event. These valuables can be structure & content, business revenue, human lives and other valuables that may lead to potential loss in a shaking event. Building exposure information for a region requires a standard systematic inventory system that classifies the structures according to their type, occupancy, and function so that realistic estimates of seismic risk and loss can be made. This system, which was also utilized in the HAZUS Earthquake Loss Estimation Methodology and Software (FEMA, 1999), is tabulated as:

CONSTRUCTED FACILITIES	DESCRIPTION
General Building Stock	Residential commercial Industrial
Essential Facilities	Hospital Police Station School
High Essential Loss Facilities	Power plant, Dams Military Installation
Transportation System	Highways Railways Bridges Airport
Utility System	Waste water Electric power Communication System
Hazardous System	Radioactive substance Toxic material Explosive chemicals

Table 2.1 Brief inventory in accordance with the FEMA-1999

The main point of the preliminary study design is the distribution (classification) of inventory data in broad categories. The way classification is indicated by the characteristics of the building and seen from the frequency with which they occur. Through standardization aimed at speeding up the whole process it significantly reduced the volume of data (e.g. four buildings with common characteristics are 4 units of the same class rather than four different divisions) on the other hand, and far more important, because it is unusual to consider separately the properties of each building. It is clear that is a restricted, number of buildings with known average properties and then is left to the discretion of the researcher for the separation and classification of data which may be available. The regular category also introduces further inaccuracy in effect for this is absolutely the best choice general categories. Therefore, studies on risk general building block is desired an additional grouping of inventory data on the basis of the use (occupancy) of the building. This is considered necessary, because often the amount of financial losses an earthquake caused by non-structural limits, given better depending on the category of structure. In the event that similar buildings undergo same structural fault, the cost of restoring the one with the most expensive equipment (eg. bank-warehouse) differs significantly from the other discrimination which cannot be described by classification in accordance with the structural type.

2.8 Vulnerability

Methods of vulnerability analysis vary based on the exposure information and the complexity of the approach (for detailed see below section). Vulnerability of structures to ground motion effects is often expressed in terms of fragility curves or damage functions that take into account the uncertainties in the seismic demand and capacity. Fragility functions can be developed for buildings or its components depending on how detailed the risk analysis is performed. Early forms of fragility curves were developed as a function of qualitative ground motion intensities largely based on expert opinion. Recent developments in nonlinear structural analysis have enabled development of fragility curves as a function of spectral parameters quantitatively related to the magnitude of ground motion. Fig. 2.5 shows the typical seismic demand and structural capacity curves together with their uncertainties expressed in terms of probabilistic distributions.

Based on these curves and the associated uncertainties, the fragility curves shown in Fig. 2.5 can be constructed for various damage states. Since each damage level is associated with a repair/replacement cost, the probabilistic estimates of the total cost can be estimated using these curves once the hazard is known. This can be achieved by use of predefined representative fragility curves developed for structures in the same class, or custom damage curves developed through nonlinear analysis of individual structures.

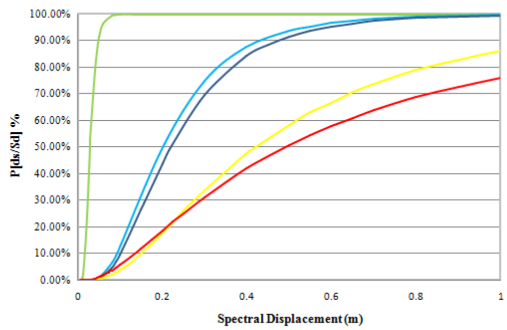

Figure 2.5 Fragility curve for damage state

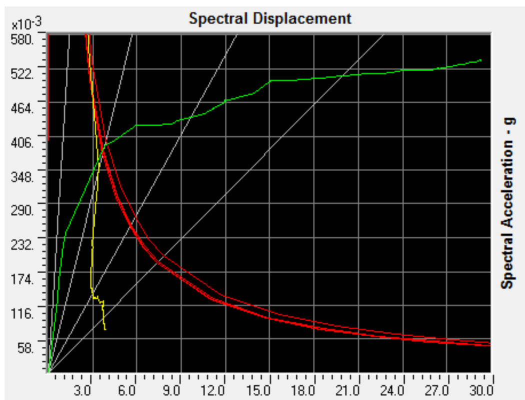

Figure 2.6 Seismic demand & Capacity curves

Vulnerable or damageable curves is the primarily element in estimating the probability of different damage limit state for building in building components as a function of spectral displacement. Thus, development of the realistic fragility curves for the building stock and life lines constitute an essential role in estimating the seismic risk.

2.8.1 Vulnerability Assessment Methodologies

The seismic vulnerability of a structure can be described as its susceptibility to damage by ground shaking of a given intensity. The aim of a vulnerability assessment is to obtain the probability of a given level of damage to a given building type due to a scenario earthquake. The various methods for vulnerability assessment that have been proposed in the past for use in loss estimation can be divided into two main categories: **empirical** or **analytical**, both of which can be used in hybrid methods (Figure 2.5).

A vulnerability assessment needs to be made for a particular characterization of the ground motion, which will represent the seismic demand of the earthquake on the building. The selected parameter should be able to correlate the ground motion with the damage to the buildings. Traditionally, macroseismic intensity and peak ground acceleration (PGA) have been used, whilst more recent proposals have linked the seismic vulnerability of the buildings to response spectra obtained from the ground motions.

- ***Empirical methods*** (based on statistical processing actual data). The approach used data faults observed in previous earthquakes, particularly in America and in Japan, in order to assess the vulnerability curves after statistical processing (Basoz and Kiremidjian, 1998, Yamazaki et al, 2000, Shinozuka et al. , 2003). The vulnerability curves describe the possibility for a given seismic intensity, damage to the building is equal to or greater than a specified value and expressed with accessories cumulative allocations. They generally refer to different categories of buildings, which are determined by the type. There is also the assumption that buildings with similar structural characteristics will be present and similar behavior for a given seismic excitation.

- **Methods based on the *judgment of the engineer* (expert judgment).** This is an alternative way of prediction seismic behavior buildings, where instead of the statistics mentioned above is now the experience. These methods are based on the statistical treatment of "crisis" experienced engineers, information about the behavior of the building, so as to create registers fault probability and to determine the vulnerability curve. In this category are methodologies developed mainly in America by the Applied Technology Council (ATC, 1985 and ATC,1991) Pacific Earthquake Engineering Research (PEER) Center (Porter, 2004)

- ***Analytical Methods***. These methods tend to feature slightly more detailed and transparent vulnerability assessment algorithms with direct physical meaning, that not only allow detailed sensitivity studies to be undertaken, but also cater to straightforward calibration to various characteristics of building stock and hazard. The analysis process includes the following steps: 1) Determination of imported seismic motion 2) simulation of building 3) definition of the indicator and the stations fault 4) Assessment of the uncertainties involved in the assessment of imported seismic motion and the strength of construction, and the establishment of the indicator and the station's fault 5) Calculation of vulnerability curves on the basis of the results of the seismic response of the building. The latter can be derived by rigid dynamic analysis (e.g. , Shinozuka et al. , 2003, Karim and Yamazaki, 2001), dynamic spectral analysis (Hwang et al. , 2000) or statistical analyzes for irremediable (Shinozuka et al. , 2003, Shinozuka et al. , 2000, Mander and Basoz, 1999)

- Methods based on ***empirically proven vulnerability indicators*** are aimed at a preliminary hierarchical classification of buildings which is carried out by scoring through a questionnaire, the main features affecting the seismic behavior of a building and calculating in this way an overall index structural vulnerability. Respectively, calculated indicators associated with the susceptibility and the territory and in several cases with the importance of the building, considering that an overall index notion of building. The classification of buildings is via a function, by adding or multiplying the scores given for each category parameter, and is often used weighting factors in order to take account of the importance of each parameter. The determination of the individual scores obtained either by the statistical processing of data from faults in previous earthquakes either on the basis of the quantified "crisis" of seasoned engineers. Several such methods have been developed internationally: ATC-6-2, (ATC, 1983), Kawashima & Unjoh (1990), Kim (1993), Pezeshk et al. (1993), hotel Buckle & Friedland, (1995), Basoz and Kiremidjian (1995) and in Greece from the OASP (2002).