Seismic Risk Evaluation for the eThekwini Municipality Area

By

Jennifer Eliana Martinez Ramirez

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University of KwaZulu-Natal

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Supervised by: Mrs M. Singh, Dr M. Akombelwa and Mr M. Chilufya

As the candidate's Supervisor I agree to the submission of this dissertation.

Mrs M. Singh
(Supervisor)

Date

Dr M. Akombelwa
(Co-Supervisor)

Date

Mr M. Chilufya
(Co-Supervisor)

Date

DECLARATION – PLAGIARISM

I, Jennifer Eliana Martinez Ramirez, declare that

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Jennifer Eliana Martinez **Date**

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ABSTRACT

Physical and infrastructural development of any city is vulnerable to seismicity, especially if nothing is done to avoid the impact it could have.

This research focuses on seismic risk evaluation in the eThekwini municipality area in the South African province of KwaZulu-Natal (KZN), which has had significant growth and investment over the recent years, increasing the vulnerability of the area's infrastructures.

This study aimed at calculating the percentage of risk that buildings have of being damaged due to earthquakes. The risk was assessed according to twelve structural trait categories available in South Africa.

Several methodologies exist to perform a seismic risk assessment; and most of them require detailed building information which is not easily available in KZN. The methodology used in this study, follows a probabilistic approach that quantitatively links the seismic hazard and seismic risk. Seismic hazard values were calculated based on a methodology that does not require knowledge of the seismic source zones.

In order to determine the risk, the standard process was used i.e. risk is a function of hazard and vulnerability. For the seismic hazard two processes were involved: assessment of the area-characteristic and site characteristic parameters, where values from other studies were used. The Hazard Risk Site program was used, which combines peak ground acceleration attenuation relations to provide a seismic hazard curve and the seismic vulnerability curves.

Finally the risk was calculated by combining both the seismic hazard curve with the vulnerability curves. The results are expressed in terms of expected percentage damage to buildings and the uncertainty interval thereof.

This research found that for a "severe" earthquake of Modify Mercalli Intensity VIII, where extensive damage to buildings could be expected, there is a very low annual probability of occurrence of 1.90×10^{-6}. This earthquake of MM Intensity VIII also has a return period of 527 000 years. However, for a "very strong" earthquake of MM Intensity VII, there is an annual probability of occurrence of 5.85×10^{-5} with a return period of 17 100 years, in which up to 80% of all structures could experience light damage. Three earthquakes of MM intensity VII have been recorded between the 20th and 21st Century in South Africa.

If one were able to determine the total estate and commercial value of the eThekwini area and these were used in conjunction with the results of this project; it would allow one to calculate the expected financial loss of the entire area.

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CHAPTER 1:INTRODUCTION

1.1 Introduction

"Although the incidence of major natural disasters has not increased, their effects are becoming more severe in the Third World because of the growing numbers of people and structures located in hazard-prone areas. Millions of people in these expanding urban populations are potential victims of disasters of cataclysmic proportions, and even the political and economic stability of many nations in Africa, Asia and Latin America can be threatened" (Havlick, 1986).

Earthquakes have long been feared as one of nature's most devastating natural hazards. When seismic waves reach the surface of the earth they give rise to what is known as ground motion. Strong ground motion causes buildings and other structures to move and shake in a variety of complex ways.

The scenario of losses due to earthquakes in the vicinity of a city depends on many variables; some of them are associated with the phenomenon itself, for example: characteristics of the earthquake, duration, and trajectory. Also, there are other variables related to the location of buildings like type and characteristics of the ground, topography and yet other variables arising from the physical characteristics and dynamics of the buildings like materials and structural configuration.

South Africa is considered to lie in a region of low to moderate seismicity. Yet if an earthquake were to occur in densely populated areas in South Africa, the damage to buildings not designed for seismic events will be significant. The current South African Building code, SANS 10160 (2009), has a section (4) dealing with seismic design. This is a new code that replaces and greatly expands on the scope and content of SABS 0160 (1989) regarding seismic design.

1.2 Background to the Problem

Although South Africa is considered to lie in a stable continental region, earthquakes are recorded and located daily by the Council for Geoscience (CGS) using the South African National Seismograph Network (SANSN), which comprises 23 broadband and extended short-period seismometers. Large tremors have been recorded that resulted in severe damage to infrastructure in nearby towns, farms, underground mines and even death in some circumstances. For that reason, it is necessary to consider the effects of these events.

In South Africa there are different types of seismicity, namely: natural and induced. The induced seismicity results from human activity, such as mining that causes changes in stress, pore pressure, volume and load in underground rock formations. These changescan result in sudden shear failures in the subsurface, releasing pre-existing shear stress on weakness zones, such as fault structures or fractures. The natural seismicity is of tectonic origin. The tectonic origin and mining related events are considered to be largely uncorrelated.

The earthquake risk, surrounding the area of Johannesburg, has been raised due to mining related events. It is also believed that the accumulation of water within old mine shafts up to several kilometres deep can trigger small to moderate sized seismic events.

On the 5th of March of 2005 a magnitude 5.3 event happened in Stilfontein, located in the Klerksdorp gold mining district, 200km west of Johannesburg. Above ground, the structural damage to property was relatively low. However, underground, substantial damage was observed within the mines.

The largest mine related earthquake in the history of South Africa occurred on the 5th of August of 2014 and it was centered near Orkney, 120 km southwest of Johannesburg, also in the Klerksdorp district. The earthquake measured 5.3 on the Richter scale, reaching as far as Botswana and was felt in the eThekwini area, KZN province, where some buildings were evacuated. There was one fatality and extensive damage to buildings in Orkney and the surrounding areas.

In the south-western Cape the level of seismicity tends to be relatively high. Natural seismicity characterises this area.

Historically, the most severe earthquake of magnitude 6.3 occurred on 29th of September of 1969 near Ceres, causing twelve lost lives and numerous damaged buildings in the town of Tulbagh.

A study on Mozambique seismicity revealed that earthquakes occurring in the South western part of Mozambique could have a devastating effect on South African structure (Pule and Saunders, 2009).

A magnitude 7 earthquake occurred near Chitobe in Mozambique's Manica province on the 23rd of February 2006. According to the United States Geological Survey (2006), the earthquake was felt throughout southern Africa with South African cities experiencing shaking of Modified Mercalli (MM) scale intensity level IV for Louis Trichardt and Phalaborwa, III for Durban and Middelburg, II for Johannesburg and Pretoria. The shaking levels of the event reveal a surprising trend that is counter-intuitive to normally observed damage from similar events, given that Durban is more than 1000km from the epicenter.

This earthquake affected high rise buildings in Durban. There were earth tremors, buildings were evacuated and there were reports of buildings walls collapsing.

An earthquake becomes a huge disaster when a large number of settlements are affected. Buildings in urban areas are highly vulnerable structures especially in areas with fast development and poor implementation of building regulations.

Seismic hazard is the probability of an earthquake with destructive capacity, in a given area and reference period. Seismic vulnerability is the cost to society of such an event if it did happen.

Seismic risk evaluation is then an estimate of the damages due to earthquakes over a given area and reference period. In mathematical terms, risk is the product of hazard and vulnerability (UNDHA, 1992, WMO, 1999)

Vulnerability assessment requires the determination of the degree of susceptibility to the threat. For urban scenarios plausible type and characteristics of the potential threat for the city need to be identified and also the level of damage it can cause.

In the eThekwini Municipality area, historically a fair amount of damage has occurred from earthquakes where potentially damaging intensities to infrastructure start from MM Intensity IV upwards. In Figure 1-1 it can be appreciated as the distribution of Isoseismal curves [curves delineating areas with different seismic intensities from each other in Modified Mercalli (MM) scale of Richter] for the 1932 St Lucia earthquake.

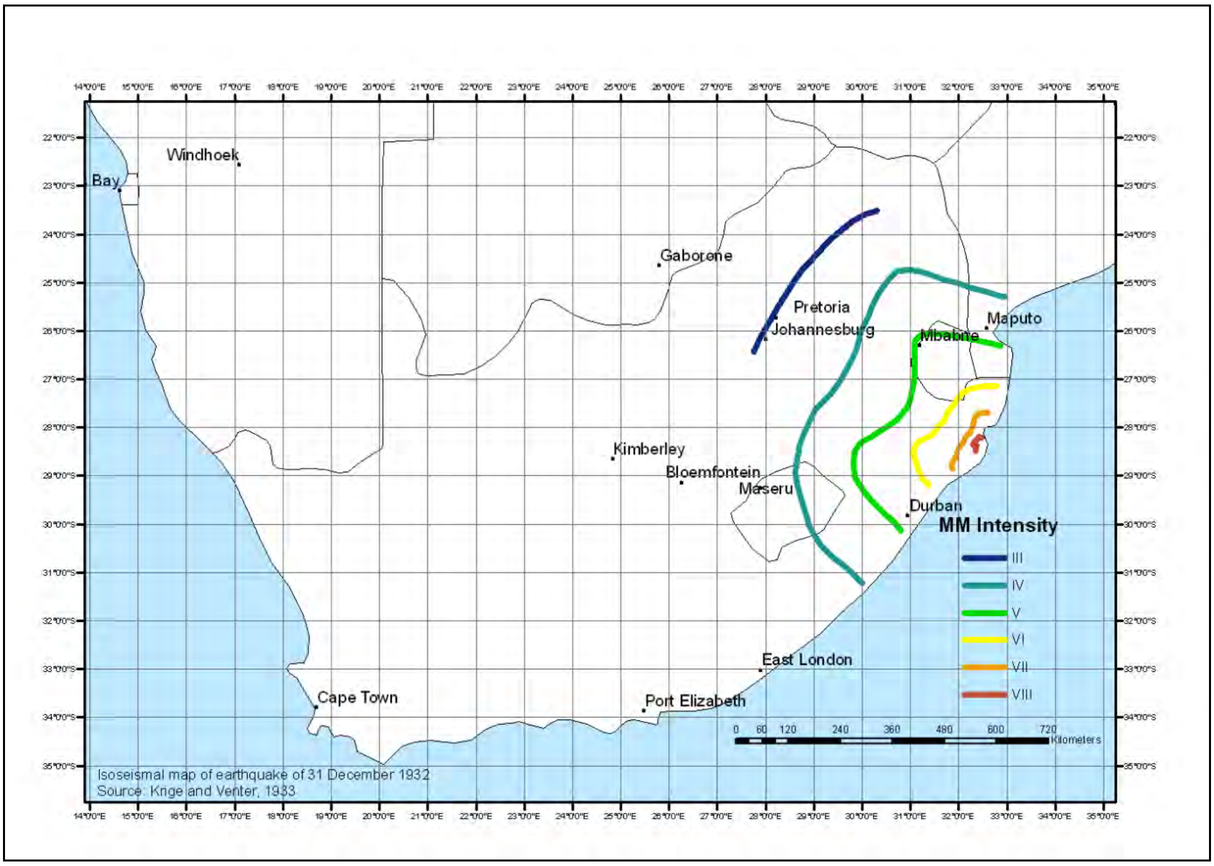

Figure 1-1 Isoseismal map of earthquake of 31-Dec-1932 (from Singh and Hattingh (2008))

This research is aimed at the assessment of seismic risk in the eThekwini municipality area, where the seismic hazard (defined as the probability of earthquakes with destructive capacity) has ground acceleration (PGA) value about 0.05g, according to the seismic risk map of South Africa, which is shown in Figure 2-5 of Chapter 2.

When designing and building structures, the probability that structures will be damaged by seismic activity and at what value of PGA damage will occur is critical. The minimum PGA value of interest is generally around 0.05g.

A probabilistic approach was considered ideal for this study because it provides a broad perspective of the seismic risk for the area and meaningful results which can be easily understood by people from a wide range of backgrounds.

1.3 Problem Statement

Physical and infrastructural development of any city is vulnerable to seismicity, especially if nothing is done to avoid the impact it could have.

Historically, potentially destructing earthquakes have been reported in the region since 1932 as shown in Figure 1-2. These earthquakes are reported to originate from a variety of sources even neighbouring countries like Mozambique. Note that the damage reported was significantly less than if such earthquakes occurred today, in view of today's greater population and infrastructure development.

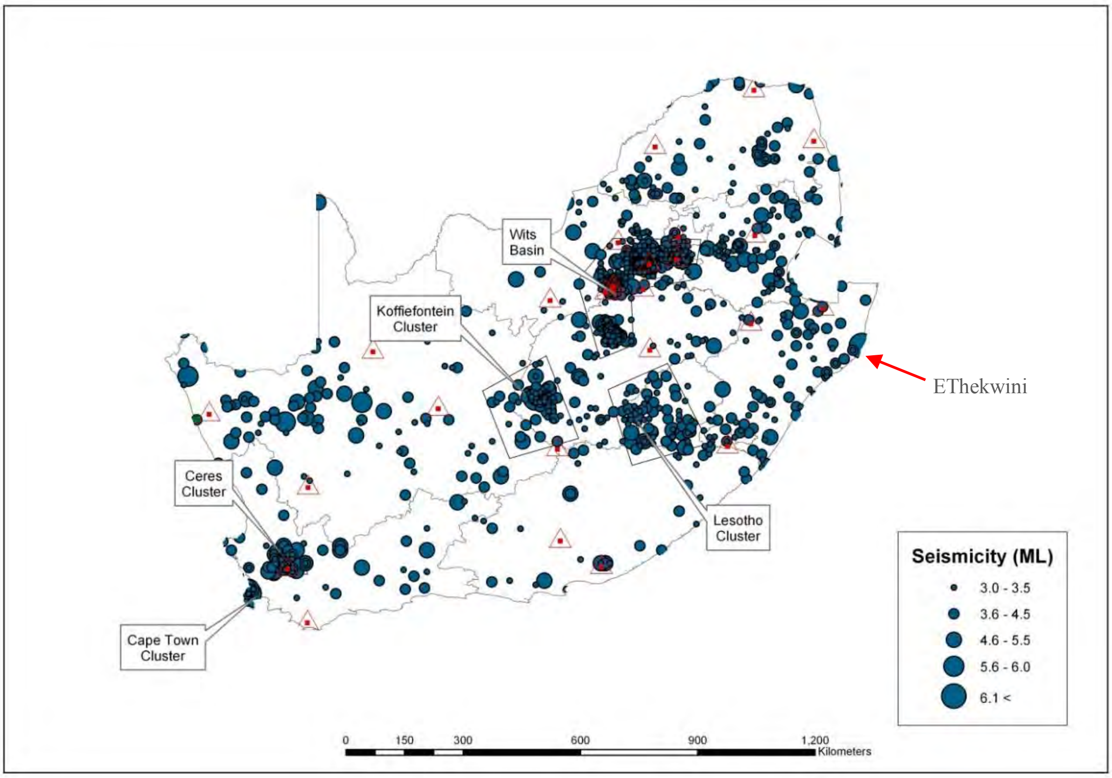

Figure 1-2 Map of Earthquakes 1620–2008 recorded in the South African National Seismological Database (SANSD), (from Singh et al. (2009))

This research focused on seismic risk evaluation in the eThekwini municipality area, which has had significant growth and investment over the recent years, increasing the vulnerability of the area's infrastructures.

This study aimed at calculating the probability of earthquake damage to buildings.

Decreasing probability of exceeding a certain level of damage implies a higher level of safety.

These results can then be used by government to warn relevant parties of the danger or to help with risk assessment.

1.4 Research Question

What is the probability that buildings will be damaged due to earthquakes in the eThekwini Municipality area?

1.5 Aims and Objectives

The aim of this study was to estimate the probability of damage that various classes of buildings in the eThekwini Municipality area may suffer due to earthquakes. The risk was assessed according to building classes existing in the study areas. To achieve the aim, the following objectives were undertaken:

1. To collect relevant data required to assess seismic hazard parameters, seismic vulnerability and ground motion attenuation equation through evaluating potential sources of data.
2. To review existing seismic risk methodologies by conducting a literature review.
3. To adopt the best methodology suitable for the area taking into consideration the data availability on seismic hazard and seismic vulnerability

1.6 Study Area

The eThekwini Metropolitan Municipality is located at latitude 29° 52'S and longitude 31° 01' E in the province of KwaZulu-Natal. It is considered as the largest city in the KwaZulu-Natal province and the third largest city in the country. The city has an area of 2, 291km^2 and according to the last official population statistics from the Census 2011, had a population of 3'442 361 people (Statistics South Africa, 2011).

A locality map of the eThekwini Municipality Area is shown in Figure 1-3.

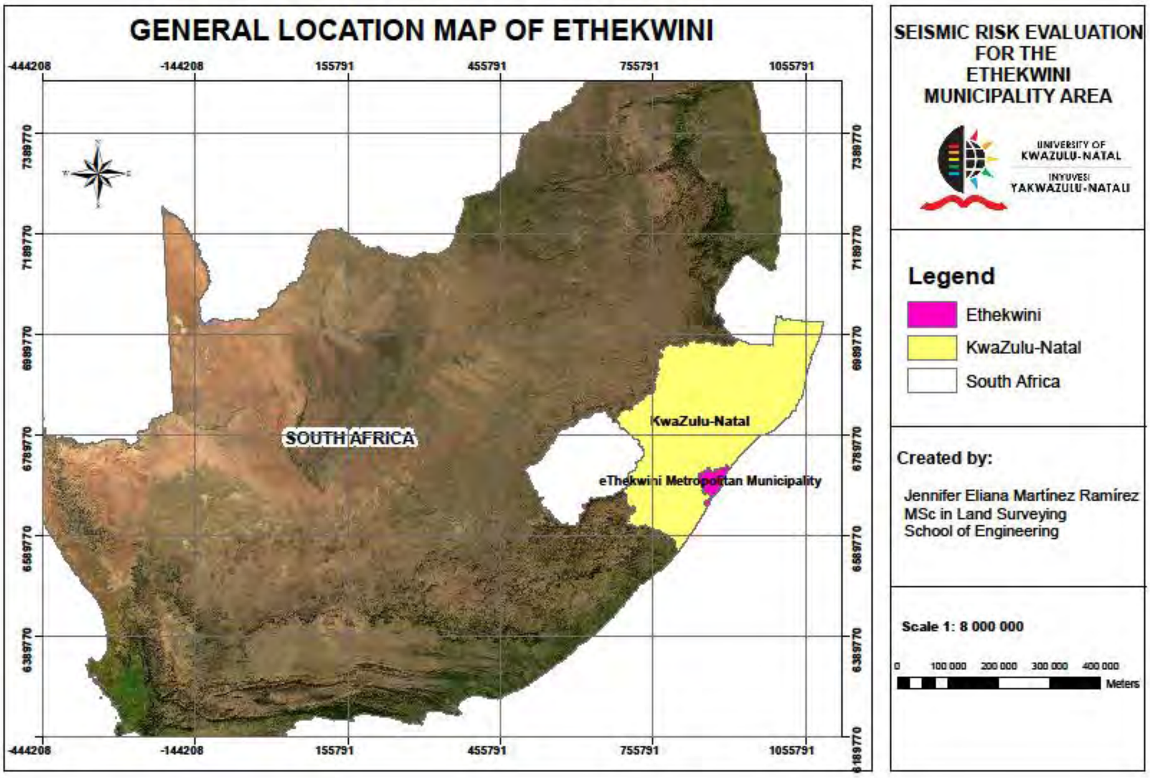

Figure 1-3 eThekwini Municipality area locality map

1.7 Thesis Organisation

Chapter 1 has provided the context in which this research was undertaken. The content of the other chapters of this thesis expands on the points outlined in this chapter and seeks to achieve the aim and provide an answer to the research question.

Chapter 2 presents the literature review to give a background to the matter covered in the project. It comprises two parts. The first part of the literature review contains a description of the seismic risk concept and its characteristics that are relevant to the study. The second part outlines the different approaches taken in previous research done on the matter.

Chapter 3 outlines the methodology used in this research. This was based on the most suitable techniques outlined in Chapter 2.

Chapter 4 presents the results obtained from the application of the methodology: seismic hazard curve, seismic vulnerability curves and seismic risk curves. The results of the expected damage to the different building types are shown. It also contains an analysis of these results.

Lastly, a conclusion is supported by the performance of this assessment. This is presented in Chapter 5 along with recommendations for future studies.

CHAPTER 2:LITERATURE REVIEW

2.1 Introduction

The purpose of this chapter is to source, review and discuss the existing seismic risk methodologies and studies relating to seismic hazard and seismic vulnerability. Various international and South African sources are collated.

There are three main components that determine seismic risk: the level of seismic hazard, the elements at risk (people and property) that are exposed to seismic hazards, and how vulnerable these elements are to the hazards; as shown in the following standard equation (FEMA, 2015).

$$Seismic\ Risk = Seismic\ Hazard + Elements\ at\ Risk + Seismic\ Vulnerability$$

Where,

Seismic hazard describes phenomena generated by earthquakes that have potential to cause harm. Seismic hazard occurs naturally and can be evaluated from instrumental, historical, and geological observations (Wang, 2006).

Elements at Risk may be the population, buildings, economic activities, public services, utilities and infrastructure, etc., at risk in a given area. This study focuses on buildings at risk have of being damage in the eThekwini municipality area.

Vulnerability is defined as the degree of loss to a given element at risk resulting from the occurrence of an earthquake of a given magnitude (Singh, 2006).

2.2 Seismic Risk Assessment

Earthquake damage or loss can be studied either by the deterministic or the probabilistic approach (Davies and Kijko, 2003). The former requires a deterministic seismic hazard assessment while the probabilistic approach requires the seismic hazard to be assessed on a probabilistic way. Figure 2-1 indicates these two different approaches available to quantify seismic risk.

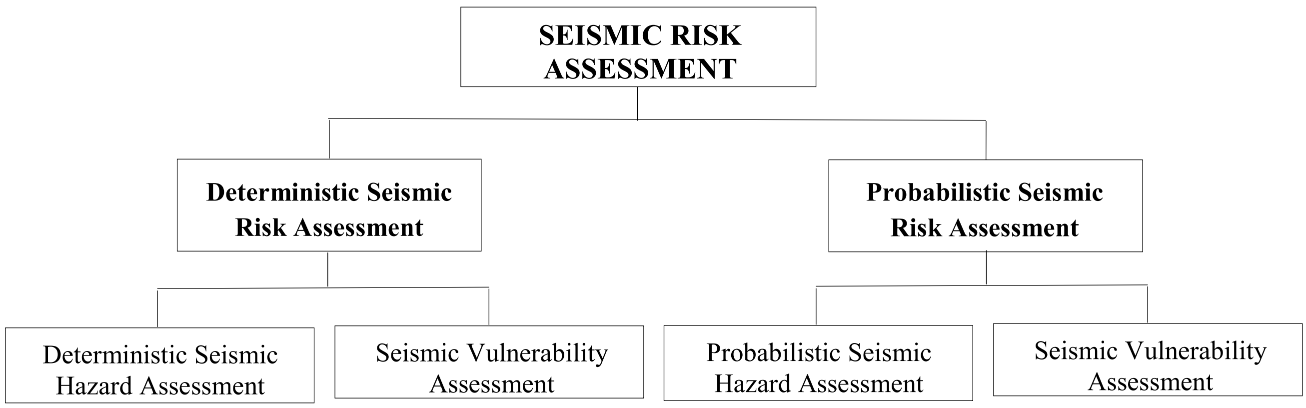

Figure 2-1 Seismic Risk Assessment Approaches

2.2.1 Deterministic Seismic Risk Assessment

A deterministic seismic risk assessment approach uses a single-valued event, known as the worst-case-scenario earthquake (Kijko et al., 2003). Based on this scenario, the expected ground motions is determined. Then, the expected damages arising from these ground motions are calculated.

This approach allows for the consideration of an extraordinary earthquake, producing a set of unusual damages. The insurance industry often uses this approach. This approach should be used when a clear strategy is required to deal with potential catastrophic losses.

2.2.2 Probabilistic Seismic Risk Assessment

A probabilistic seismic risk assessment methodology evaluates the probabilities for all degrees of damage arising from seismic events, including the extreme event considered in the deterministic procedure.

Most of the earthquake risk assessment models currently in use tend to be probabilistic in that they provide assessments of the probability distributions of damage based on a sample of scenarios that is considered most appropriate in the light of current knowledge (Kunreuther and Roth, 1998).

A probabilistic approach was considered ideal for this study because it provides a broad perspective of the seismic risk for the area and meaningful results which can be easily understood by people from a wide range of backgrounds.

2.3 Seismic Hazard Assessment

The contrasting deterministic and probabilistic approaches are reflected in different approaches to assessing seismic hazard:

2.3.1 Deterministic Seismic Hazard Assessment (DSHA)

During the Deterministic Seismic Hazard Assessment approach, a particular earthquake scenario is assumed. For every significant seismic source, the earthquake magnitude and location is taken along with its selected specified ground motion probability level (typically 0 or 1 standard deviation above the median), to establish individual earthquake scenarios. The distance from the epicenter to the site can be computed based on the location, with the magnitude, distance and number of standard deviations above the median for ground motion. A critical part of seismic hazard analysis is the determination of the Peak Ground Acceleration (PGA) and response acceleration (spectral acceleration) for an area or site (Abrahamson, 2006). The attenuation relation can be used to compute the ground motions for an individual earthquake.

Figure 2-2 shows graphically how three earthquake sources were identified for a site, the distances between the sources and the site and their PGA, highlighting the source with the strongest level of shaking, its source-to-site distance and its peak ground acceleration (Kramer, 1996).

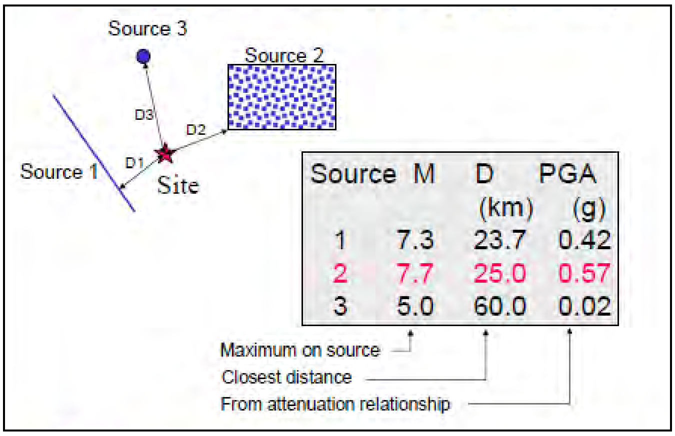

Figure 2-2 Example Deterministic Analysis (Kramer, 1996)

2.3.2 Probabilistic Seismic Hazard Assessment (PSHA)

The Probabilistic Seismic Hazard Assessment (PSHA) uses all possible and relevant deterministic earthquake scenarios and all possible ground motion probability levels. The set of scenarios should only include physically possible earthquakes (Abrahamson, 2006). Through attenuation relationships, ground motion descriptors such as peak ground acceleration (PGA) are calculated and the hazard is estimated (Hanks and Cornell, 2001).

Probabilistic Seismic Hazard Assessments were first carried out in the late 1960’s with the studies by Esteva (1967), (1968) and Cornell (1968). The methodology developed a theoretical relationship between a ground motion parameter and annual probability of exceedance at a site of interest based on particular statistical relationships of earthquakes and ground motion, for example the Gutenberg–

Richter relationship. Cornell's method was based on the assumptions of a Poisson distribution of earthquake occurrences. This procedure required specification of seismic sources or zones.

In addition to the attenuation relations, a seismic hazard calculation requires knowledge of the parameters used to define occurrence of earthquakes in the source zones. M_min is the magnitude below which no significant damage would occur. The upper bound magnitude M_max represents the maximum expected magnitude, the Gutenberg- Richter earthquake recurrence parameter b-value and the activity rate λ, which is the annual number of earthquakes above the lower bound magnitude, as can be seen in Figure 2-3.

The original formulation made by Cornell was modified by McGuire (1976), who included the uncertainties in the strong-motion prediction equation. Numerous alterations have been proposed since, but the fundamental mechanism of the calculations remains the standard methodology to determine the characteristics of strong ground motion for engineering design.

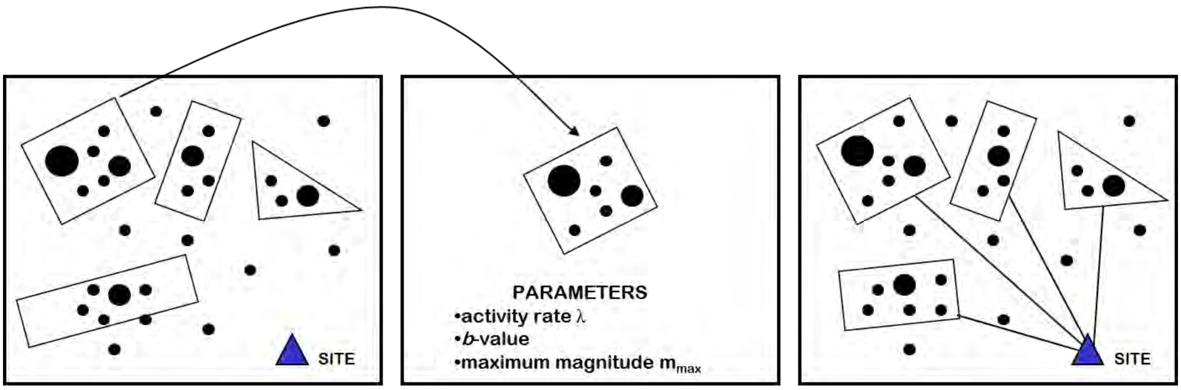

Figure 2-3 PSHA Deductive Procedure by Cornell (1968)

Later, Veneziano et al. (1984) presented a procedure where seismic zones and seismic parameters were not needed. Instead, their procedure was based on historical earthquake occurrences. This procedure is accordingly called the Historic Procedure. For areas with low seismicity, this procedure is considered unreliable at low probabilities. It does not account for incompleteness and uncertainty of earthquake catalogues.

Figure 2-4 shows in the top left the historic catalogue of earthquakes for a site. A ground motion function is assumed, allowing ground motion intensity to be predicted as a function of intensity (I) or magnitude (M). The distribution of ground motion can then be estimated, which gives the historical rate at which different levels of ground motion have been exceeded. Finally, the hazard function is produced and an annual rate of exceedance is obtained (McGuire, 1993).

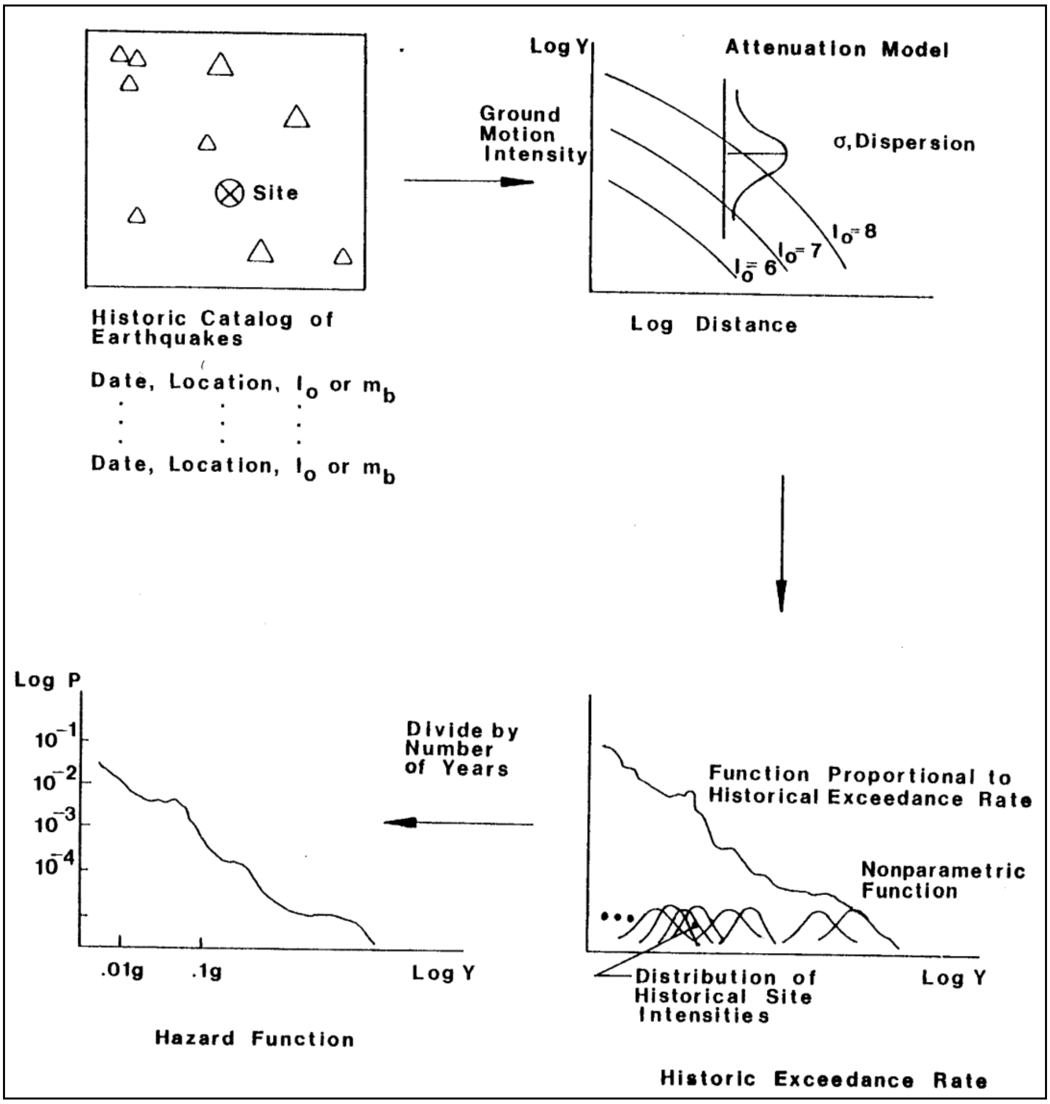

Figure 2-4 PSHA Historic Procedure by Veneziano et al. (1984)

Kijko and Graham (1998) later presented a new methodology for PSHA called the "Parametric Historic" procedure. This methodology combines the best features of the two previous procedures: the "Deductive" and the "Historic". It allows for the estimation of seismic hazard at individual sites without seismic source zones. For areas with high and low seismicity, the parametric historic procedure is considered to give a realistic assessment of the seismic hazard (Kijko and Graham, 1999).

To apply the parametric historic procedure, assessment of basic hazard parameters for the area in the vicinity of the specified site are required, such as seismic rate λ, Gutenberg-Richter b-value, m_{max}; and assessment of the amplitude distribution functions of the ground motion for the specified site. If the procedure is applied to all grid points a seismic hazard map can be obtained.

Probabilistic Seismic Hazard analysis requires the use of all available historical and instrumental earthquake data for the region.

A probabilistic technique that allows one to combine information from historical and recent instrumental catalogues was proposed by Kijko and Sellevoll (1992). The catalogue is divided into an incomplete part (historic) consisting of only the largest earthquake magnitudes, and a complete part, for which information was obtained from instruments. The complete catalogue includes only seismic events above a certain magnitude. One of the main advantages of this method is the possibility of including the largest known historical earthquake that occurred before the instrumental catalogue began. It also accepts incompleteness in the data where records are missing or when seismic networks were not in operation for various reasons.

In South Africa, Singh et al. (2009) performed a regional study that incorporated both historical and instrumental earthquakes and other multidisciplinary datasets from surface and deep geophysics, neo-tectonics and stress fields to build up a broad geodatabase to delineate source zones for the country. Saunders et al. (2013) collected and improved the catalogue and Midzi et al. (2013) completed isoseismal maps providing an atlas of intensity data points for the region to update the work done by Singh and Hattingh (2008). Bommer et al. (2014) conducted a probabilistic seismic hazard assessment for a potential nuclear power plant site on the coast of South Africa and defined a zonation through investigation of historical seismicity.

2.3.2.1 Annual Seismic Hazard

The *Expected Annual Damage* (EAD). consists of hazard contributions from each independently defined source and it is presented in the form of an annual seismic hazard curve (Godinho, 2007).

The Annual Seismic Hazard curve is used to determine how often a specified level of ground motion, characterised by PGA a, will be exceeded at least once within the specified time interval T of one year at the site of interest.

2.3.3 Seismic Hazard Maps

A seismic hazard map shows how earthquake ground shaking varies from place to place. The mapped hazard provides an estimate of the probability of exceeding a certain amount of ground shaking, or ground motion, in 50 years. The hazard level depends on the magnitudes and locations of likely earthquakes, how often they occur, and the properties of the rocks and sediments that earthquake waves travel through.

Seismic hazard maps have been used to help predict where earthquakes are most likely to occur and to improve safety in areas were earthquakes are common (USGS, 2015).

In South Africa, several regional seismic hazard studies have been carried out. Seismic hazard maps were prepared by Fernandez and Du Plessis (1992) as well as by Giardini and Basham (1993).

The South African National Standard presents its seismic hazard map of South Africa in the SANS 10160-4:2009 (see Chapter 4, Figure 4-6).

Another seismic hazard map available for the country was prepared by Kijko (2008)as shown in Figure 2-5. It is shown with 10% probability of exceeding particular peak ground accelerations in 50 years, measured in metre per second squared.

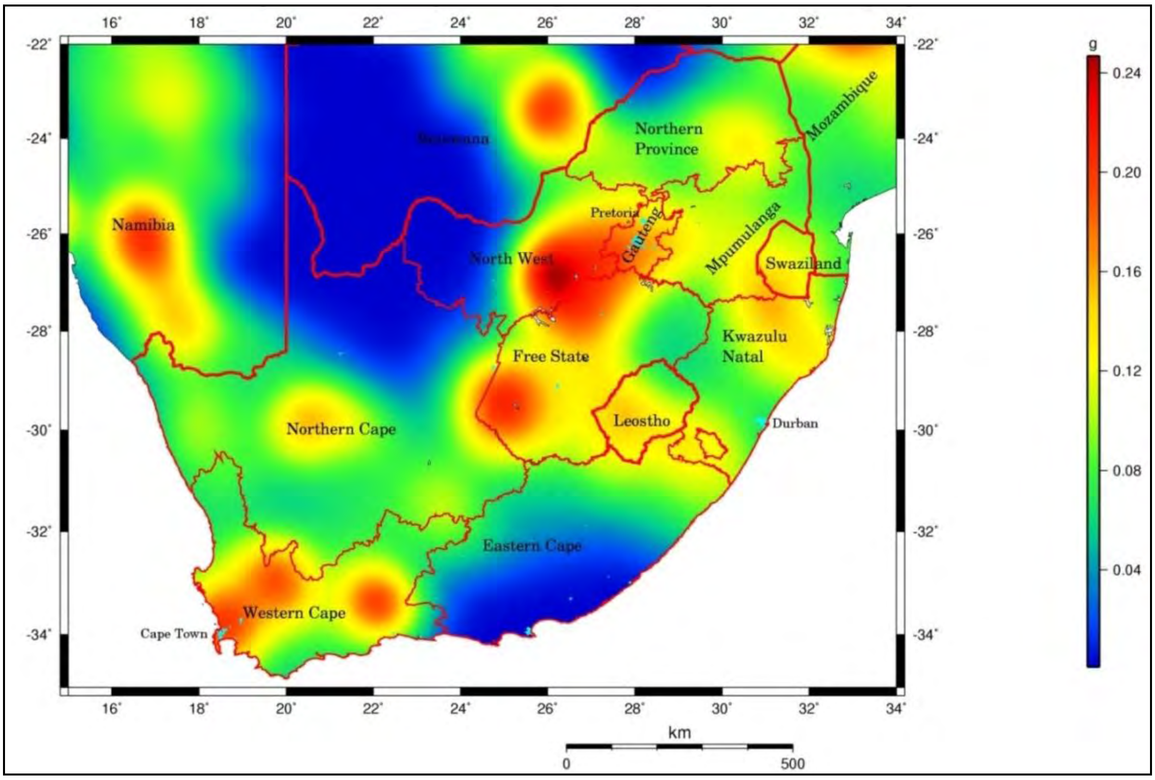

Figure 2-5 Seismic Hazard Map of South Africa (Kijko, 2008)

The region of eThekwini has a PGA value about 0,05 g, according to the seismic map of South Africa (Kijko, 2008) shown in Figure 2-5.

When designing and building structures, the probability that structures will be damaged by seismic activity and at what value of PGA damage will occur is critical. The minimum PGA value of engineering interest is generally around 0.05g (Davies and Kijko, 2003).

2.4 Seismic Vulnerability

The seismic vulnerability describes the expected degree of damage to a building resulting from a given level of seismic hazard. In urban areas, vulnerability is typically related to building design and quality, in extreme cases structures can collapse and injure people.

Several methods for vulnerability assessment have been developed and proposed in recent years as explained in the following sections.

Three types of vulnerability approaches have been used, namely: observed vulnerability methods (also referred as empirical approach or statistical methods) based on statistical observations of recorded damage data of past events as a function of the intensity; expert base methods and analytical methods, based on calculation of building structural response.

2.4.1 Observed vulnerability methods

Observed vulnerability methods are based on statistics of past earthquake damage data. One of the first to have systematically compiled statistics on damage to buildings from experiences after recent earthquakes was Whitman et al. (1973). From a survey of damage caused by the San Fernando earthquake of 9 February 1971 a damage probability matrix (DPM) was generated using different building types. The general form of such a damage probability matrix is shown in Table 3.3 (Chapter 3). Each number in the matrix expresses the probability that a building of a certain class will experience a particular level of damage as a result of a defined earthquake intensity.

The DPM has become a widely used form to describe the probable distribution of damage, adapted by many other methods. An example is the National Group for Earthquake Protection (GNDT - in Italian *Gruppo Nazionale per la Difesa dai Terremoti)* level I approach (Corsanego and Petrini, 1994). This is a DPM-based method, having three classes of vulnerability, from A to C, to each of which a DPM is ascribed. GNDT DPMs have been compiled from statistical data processed after the Irpinia earthquake (Braga et al., 1982). These data have been subsequently updated and regionalized on the basis of several earthquakes. Differently from the DPM proposed by Whitman, GNDT damage probability matrices make reference to MCS intensity rather than to MMI and describe the damage by means of a five point damage grading scale.

Coburn and Spence (1992) proposed another approach based on the statistical processing of data collected after different earthquakes from a range of different countries. Five different damage grades were considered. For each building type, the scatter of the intensity at which each individual structure passed a given damage threshold was assumed to be normally distributed. The damage distribution was expressed graphically by the probability of exceeding a certain damage grade given the seismic input expressed on a unitless intensity scale.

2.4.2 Expert-based methods

In 1985, the US Federal Emergency Management Agency (FEMA) undertook a comprehensive programme to provide expert-opinion earthquake damage estimates to all types of facilities, and loss methodology and data for use in estimating local, regional, and national economic impacts from earthquakes in California (Rojahn, 1985).

The ATC-13 (1985) report by the Applied Technology Council funded by FEMA, was the first attempt to codify the seismic vulnerability of buildings from expert judgment.

ATC-13 is one of the first major seismic risk projects to assess seismic risk in terms of damage probability matrices as proposed by Whitman et al. (1973). By using such matrices, it was possible to estimate the probability of a structure being in a particular damage state for a given MM ground shaking intensity and to estimate replacement value. ATC-13 essentially derived a damage probability matrix for 78 different earthquake engineering facility classes, 40 of which referred to buildings. The matrix was derived by asking 58 experts, based on their personal knowledge and experience, to estimate the expected percentage of damage and loss that would result to a specific structural type subjected to a given intensity. Despite the uncertainty related to the opinion of experts, this study remains the most complete source of damage data, and formed the basis of many subsequent loss studies and methodologies.

2.4.3 Analytical Approaches

In the United States and nowadays also in Europe, the most recent trends in the field of vulnerability evaluation for risk analysis use simplified mechanical models, essentially based on the Capacity Spectrum Method (Freeman, 1998).

In 2001, FEMA developed a methodology known as HAZUS (Hazard US) specifically for the U.S. built environment, but which is usually applied in other regions (Spence et al., 2003). Damage models were provided for the full range of building types and other infrastructure.

In HAZUS, damage models are in the form of lognormal Fragility Curves that relate the probability of being in, or exceeding, a damage state for a given earthquake demand parameter. The latest version, HAZUS-MH (Hazard US - Multi Hazard) V2.0 (FEMA, 2008), estimates the risk in three steps. Firstly, it calculates the exposure for a selected area. Secondly, it characterizes the level or intensity of the hazard affecting the exposed area. Lastly, it uses the exposed area and the hazard to calculate the potential losses in terms of economic losses, structural damage, etc. However, it is difficult to apply the HAZUS methodology in other parts of the world, due to the complexity and large quantity of input data required.

Other proposals for simplified analytical approaches make reference to displacement-based procedure rather than to force-based procedure. This is the case of the method developed by (Calvi, 1999) based on the assessment of the displacement capacity of a building corresponding to several limit states and of the displacement demand resulting from a displacement spectrum. Building typologies are identified on the basis of the period of construction, the number of stories and the construction material (reinforced concrete or masonry). Four limit states are considered taking into account structural and non-structural damage. For each type of building structure and for each limit state a structural model is defined in terms of secant stiffness corresponding to the maximum displacement of the limit state considered, from which the equivalent period of vibration is obtained, and a displacement demand reduction factor depending on the structure energy dissipation.

Calvi's method can evaluate the probability of occurrence of a certain limit state for a given displacement response spectrum. Apart from the methods shortly described above, a detailed treatment of analytical methods is provided by Miranda and Akkar (2002) and ATC (2002).

2.5 Seismic Risk in South Africa

Various studies have estimated the risk of damage due to seismic activity, to buildings in urban areas in South Africa.

The studies by Kijko et al. (2002), (2003) provided the seismic hazard and risk for Tulbagh in the Western Cape Province, where the strongest and most damaging tectonic earthquake of magnitude 6.3 occurred in South Africa.

A comprehensive study on seismic risk was made by Davies and Kijko (2003). A probabilistic seismic risk assessment was performed for various sites in South Africa. The study looked at the possible impact on the South African insurance industry. It expressed damage due to earthquakes following the conventions used in ATC-13 and by the insurance industry. Findings showed the expected level of damage among the building classes. It was concluded that is important to implement proper design procedures to avoid the impact that earthquakes could have on the South African buildings.

Pule (2014) studied the seismic vulnerability for four urban areas in South Africa. A deterministic approach was used to assess the expected damage. Damage was expressed in terms of intensity. Damage curves for twelve building classes in South Africa were obtained.

A seismic analysis of a typical South African Unreinforced Masonry Structure was done recently by Van der Kolf (2014). Seven possible worst-case scenarios where taken into consideration for a three-storey URM building using different types of dynamic analysis. Findings indicated that URM buildings are at risk of failure especially if sufficient ductility is not provided. Construction and material quality are vital for a good performance in the event of a moderate magnitude earthquake in South Africa.

CHAPTER 3:METHODOLOGY

3.1 Introduction

The methodology used for the estimation of expected damage due to earthquake is explained in this chapter. An overview of the research methodology is first outlined. That is followed by an explanation of the data requirements, the source of each data and the process applied to them.

3.2 Overview of Research Methodology

The first step in the methodology was to conduct a literature review in order to search and review existing methodologies on seismic risk assessments. This step was covered in Chapter 2.
Thereafter, existing data for the area was collected. This was then compiled and analysed in order to determine the best methodology for the study. A brief discussion of the data availability is presented in section 3.5.1.

Finally, the results obtained could then be analysed as in the following Chapter 4.

Figure 3-1 shows a flow diagram of the key components of the probabilistic seismic risk methodology.

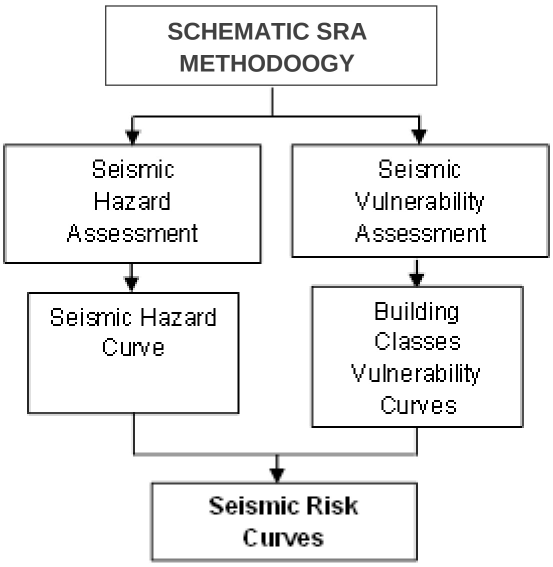

Figure 3-1 Schematic Representation of Key Components of the Probabilistic Seismic Risk Methodology

3.3 Probabilistic Seismic Risk Methodology

Several methodologies exist to perform a seismic risk assessment most of which require detailed building information which is not easily available in KZN. Accordingly a probabilistic approach was adopted that quantitatively linked the seismic hazard and seismic risk (Davies and Kijko, 2003). This methodology incorporated all the elements of seismic risk. Its main components were earthquake hazard, vulnerability and the final risk level. This method linked the seismic hazard and the seismic risk quantitatively. This was considered ideal for this study, because it provided a broad perspective of the seismic risk for the area and meaningful results which can be easily understood by people from a wide range of backgrounds. Estimation of seismic hazard values were calculated based on a methodology that did not require the knowledge of the seismic source zones.

In order to determine the risk the standard process is used (Carreño et al., 2007):

$$Seismic\ Risk = Seismic\ Hazard \times Seismic\ Vulnerability \tag{3-1}$$

Two main factors must then be calculated: Seismic Hazard and Seismic Vulnerability.

A detailed flow diagram of the methodology used is shown in Figure 3-2

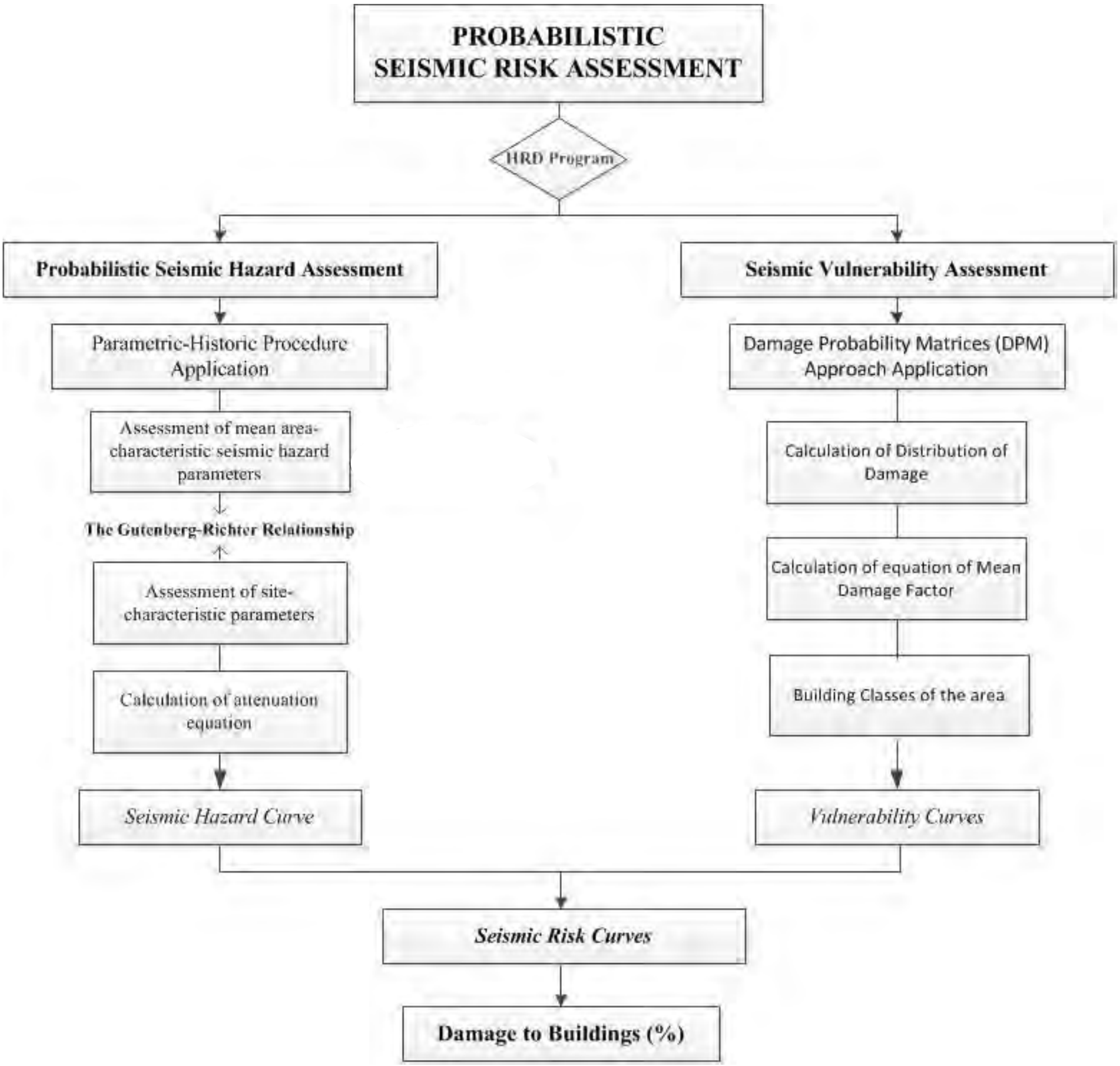

Figure 3-2 Detailed Methodology Flow Diagram

3.4 Software

To perform the probabilistic seismic risk assessment, the HRS (Hazard Risk Site) program was used. HRS is a MATLAB based computer code for assessment of seismic hazard and seismic risk. The code is capable of assessing the risk according to 12 different building classes. The HRS program implements the methodology outlined above.

3.5 Data Collection

3.5.1 Data Availability in South Africa

The task of researching potential sources of information on earthquakes and buildings and the availability of such sources was carried out for the eThekwini municipality area.

The research was started by requesting information from the eThekwini Municipality concerning building type, for all the buildings in the eThekwini Municipality. Information was sought regarding the number of floors, construction year and construction materials. Discussions were also held with people responsible for gathering this type of information.

It turned out that such information was not easily available. In order to access information held by the municipality one would have to approach the property owners individually for their consent. This consent would need to be produced to the municipal Information Officer. Also the information was not available in digital form; only analogue copies of the approved plans were kept. In order to find the information required, it would be needed to first identify the building (street address) and then extract the information from the microchip on which the building plans were recorded.

Most of the seismic risk assessment methodologies require detailed building information such as building structural data (Sarris et al., 2010) (Vicente et al., 2011). Building structural data refers to the age of structures, construction materials, number of storeys, etc. This was a critical consideration for choosing the best methodology to apply in the present study.

3.5.2 Data Input

The HRS program accepted two types of input data:

- ✓ Seismic event catalogue containing information on the strongest events that occurred in the vicinity of the site. It was assumed that for each event the following parameters are known: origin time, size of the seismic event (in terms of magnitude or focal intensity), and spatial location.

  The seismic catalogue used for the study, was a SA catalogue with updated data as of the end of 2006, provided by the Council for Geosciences.

- ✓ Seismic parameters in the vicinity of the site. The following seismic parameters were provided:
  1. Coordinates: Latitude, Longitude
  2. Depth
  3. Mean Activity Rate λ
  4. b – value of the frequency of magnitude Gutenberg-Richter distribution
  5. Minimum Magnitude m_{min} and the Maximum Magnitude m_{max}

6. Source characteristic magnitude

3.6 Probabilistic Seismic Hazard Assessment

A Probabilistic Seismic Risk Assessment begins with a Probabilistic Seismic Hazard Analysis (PSHA).

A parametric-historic approach (Kijko and Graham, 1998) for the calculation of seismic hazard was chosen. This methodology has been used extensively in areas of low seismicity.

The parametric historic approach is free from delineation of seismic sources. Some of the difficulties experienced in dealing with seismic sources are:

i. In some cases seismic sources or specific faults can often not be identified and mapped,
ii. The causes of seismicity are not understood,
iii. The delineation of seismic sources is highly subjective and is a matter of expert opinion and
iv. Often seismicity within the seismic sources is not distributed uniformly.

These difficulties all applied in the study area so the parametric historic approach was considered ideal for analysing and assessing seismic hazard in this project.

The specification of temporal and magnitude distributions of seismicity for the area was necessary. The most frequently used model of earthquake magnitude recurrence is the frequency-magnitude Gutenberg-Richter relationship (Gutenberg and Richter, 1944):

$$\log(n) = a - bm \tag{3-2}$$

Where,

- $n =$ number of earthquakes with a magnitude of m
- a and b = parameters

It is assumed that earthquake magnitude m belongs to the domain $m_{min} < m < m_{max}$

Where,

- $m_{min} =$ level of completeness of earthquake catalogue
- $m_{max} =$ is the upper limit of earthquake magnitude for a given seismic source

The parameter a is the measure of the level of seismicity, while b describes the ratio between the number of small and large events.

The Gutenberg-Richter relationship is truncated from the top by the maximum possible earthquake magnitude m_{max}.

The PSHA technique is a parametric approach requiring model parameters. In this case, the parameters were the area-specific mean basic hazard parameters. These parameters were needed in the application of the PSHA technique used.

The following steps needed to be completed for the probabilistic seismic hazard assessment.

3.6.1 Assessment of the Mean Area-Characteristic Seismic Hazard Parameters:

Under the above assumptions, the first step of PSHA was to assess the seismicity of the area where the seismic hazard was required. Seismicity was described by three mean basic hazard parameters of the area in the vicinity of the specified site:

a) Area-specific mean Seismic Activity Rate λ, which is equal to the parameter of the Poisson distribution
b) The b-value of the Gutenberg-Richter relationship
c) The maximum regional magnitude M_{max}, which is equal to the upper limit of earthquake magnitude

The values of the area-characteristic parameters were already calculated by Kijko (2014).

The approach followed in the calculation of these parameters was the maximum likelihood procedure (Weichert, 1980) (Kijko and Sellevoll, 1989) (McGuire, 2004).

The seismic event catalogue containing information on the strongest events that occurred in the vicinity of the eThekwini area was used to perform the needed calculations of the equations described in Chapter 2 and as below.

a) Estimation of Rate of Seismic Activity λ:

If successive earthquakes are independent in time, the number of earthquakes with magnitude equal to or exceeding a level of completeness, m_{min}, follows the Poisson distribution with the parameter equal to the annual rate of seismic activity λ.

The maximum likelihood estimator of λ is then:

$$\lambda = \frac{n}{t} \tag{3-3}$$

Where,

- n = number of events that occurred within time interval t.

b) Estimation of the rate of the b-value of the Gutenberg-Richter equation

For given m_{max}, the maximum likelihood estimator of the b-value of the Gutenberg-Richter equation can be obtained from the recursive solution of the following:

$$\frac{1}{\beta} = \bar{m} - m_{min} + \frac{(m_{max} - m_{min}).exp[-\beta(m_{max} - m_{min})]}{1 - exp[-\beta(m_{max} - m_{min})]} \tag{3-4}$$

Where,

- β = b ln10
- m = the sample mean of earthquake magnitude (Page, 1968).

  If the range of earthquake magnitudes $m_{min} < m < m_{max}$ exceeds 2 magnitude units, the solution of **(3-4)**can be approximated by the well-known Aki-Utsu estimator (Aki, 1965, UTSU, 1965)

$$\beta = \frac{1}{(\bar{m} - m_{min})} \tag{3-5}$$

c) Maximum Regional Magnitude m_{max}:

The best procedure (Kijko and Sellevoll, 1989, 1992) to utilize all the information contained in the seismic catalogue combines the macroseismic part of the catalogue (strong events only) with variable periods of completeness.

For the determination of m_{max} not all the earthquakes in the catalogue were included.

3.6.2 Assessment of the Site Characteristic Parameters

The second step involved the assessment of the specified site characteristic parameters describing the amplitude distribution of the selected ground-motion parameter. These parameters were estimated by the maximum likelihood procedure (Kijko and Graham, 1999) included in the HRD program, which combined the coefficients of PGA attenuation relations to provide a seismic hazard curve, expressed in terms of probability.

3.6.3 Attenuation Equation

The third step was to express seismic hazard in terms of peak ground acceleration. Since the induced motion of the ground is vibratory, the ground motion parameter responsible for damage (the acceleration), will vary with time as the energy radiated by the seismic event arrives at the site. The maximum value of the acceleration recorded at a particular site during the event is called the peak ground acceleration (PGA).

It is necessary to calculate the conditional probability that an earthquake of random magnitude M at a random distance R will cause a PGA equal to, or greater than, an acceleration of engineering interest a_{min}.

For its definition, probabilistic seismic hazard can be expressed as a function of acceleration and time $(a;T)$(a;T). The distribution function of a seismic hazard is the following:

$$H(a;T) = 1 - F_A^{max}(a;T) \tag{3-6}$$

Where F_A^{max} represents the cumulative distribution function of the largest PGA expected to occur during a specified time interval T.

For this purpose, the Boore attenuation equation (Boore and Joyner, 1982) was used as it can be seen in equation (3-7):

$$\ln(a) = c_1 + c_2 M + c_3 R + c_4 \ln R + \varepsilon \tag{3-7}$$

Where,

- c_1, c_2, c_3 and c_4 = empirical constants
- M = the earthquake Richter magnitude
- R = the earthquake distance
- ε = a random error, which has been observed to have a normal (Gaussian) distribution.

3.6.4 Relationship between Intensity and PGA

When historical and instrumental data are used together in a seismic hazard assessment, a relationship between macroseismic effects and ground motion needs to be specified. A common and simple assumption is that the logarithm of peak horizontal ground acceleration correlates with intensity (Marin et al., 2004). In this study PGA is converted into intensity according to Ambraseys (1974) as is shown in the following equation:

$$\log(y) = b_0 + b_1 I \tag{3-8}$$

Where,

- b_0= 8.755
- b_1= 1.2064
- y = PGA value
- I = Intensity

By integrating uncertainties in earthquake location, earthquake magnitude and attenuation equation into probability that the PGA will be exceeded at the specified site during the specified time interval (T), the ultimate result of the PSHA was then obtained: *a Seismic Hazard Curve.*

The *Seismic Hazard Curve* indicates the annual probability of exceeding a given PGA at least once during a specific time interval (T) and it is represented by equation (**3-6**).

3.7 Seismic Vulnerability Assessment

The last factor was the seismic vulnerability that described how the exposed assets, in this case the buildings, were going to be affected by the seismic hazard through quantifying the amount of expected damage to the various type of buildings.

3.7.1 Distribution of Damage

The expected damage to a building resulting from an earthquake during a time interval (T) of one year is called the *Expected Annual Damage (EAD).*

Seismic vulnerability can be expressed as the following:

The probability of exceedance of a certain level of damage *d*, at least once within the specified time interval. It is denote by $\mathrm{p_D(d;T)}$.

According to the total probability theorem, the probability $p_D(d|T)$ can be expressed as:

$$p_D(d;T) = \int_{d}^{d_{max}} \int_{i_{min}}^{i_{max}} \int_{a_{min}}^{a_{max}} f_D(\tilde{d}|i) f_I(i|a) f_A^{max}(a;T) da\, di\, d\tilde{d} \tag{3-9}$$

Where,

- $f_I(i|a)$ and $f_D(d|i)$ = conditional probability density functions (PDFs) respectively
- MM intensity = I

- PGA = a
- Damage = D

By Definition,

$$f_A^{max}(a;T) = \frac{d}{da}[f_A^{max}(a;T)]$$

(3-10)

From equation (**3-6**),

$$f_A^{max}(a;T) = -\frac{d}{da}[H(a;T)]$$

(3-11)

The innermost integration is over the PGA, a, for the chosen time period T where a_{min} is the minimum value of PGA of engineering interest (0.05g), and a_{max} is the maximum possible PGA at the site. Associated with each value of ground acceleration is the distribution of MM intensity, $f_I(i|a)$, and therefore the second innermost integration from i_{min} to i_{max} is over the MM intensity, where i_{min} is the minimum value of intensity which is capable of generating damage (say i = IV) and i_{max} is the maximum possible intensity, (i = XII). Since relations between PGA and damage are not as commonly known or used as the relations between MM intensity and damage, use is made of conditional PDFs $f_I(i|a)$ and $f_D(d|i)$. The outermost integration from d to d_{max} is over the damage where the maximum value of damage, d_{max}, is 100%, and corresponds to complete destruction.

Equation (3-9) can then be rewritten by replacing the corresponding values of each limit of each integration as shown in equation (3-12). This is the general formula that describes the expected damage to the structure under seismic forces, within a specified time interval (T).

$$\boxed{E[(D;T)] = \int_0^{d_{max}} \int_{i_{min}}^{i_{max}} \int_{a_{min}}^{a_{max}} d f_D(\tilde{d}|i) f_I(i|a) f_A^{max}(a;T) da\, di\, d\tilde{d}}$$

(3-12)

3.7.2 Mean Damage Factor

In order to estimate the distribution and the expected value of damage to the structure under seismically induced forces, the conditional distributions $f_I(i|a)$, $f_D(d|i)$ and the PDF of seismic hazard, $f_A^{max}(a;T)$, must be specified.

By definition of the operator of expectancy $[E]$, equation (3-12) can be rewritten in the form:

$$E[(D;T)] = \int_{i_{min}}^{i_{max}} \int_{a_{min}}^{a_{max}} E[D|i] f_I(i|a) f_A^{max}(a;T) da\, di$$

(3-13)

Where the function $E[D|i]$ is:

$$E[D|i] = \int_0^{d_{max}} d\, f_D(d|i) dd$$

(3-14)

The function $E[D|i]$ denotes the *Mean Damage Factor* for a given MM intensity (i) as shown in equation (**3-14**).

When the previous function $E[D|i]$ shown in equation (3-14), is put together with the intensity (*i)*, the *Vulnerability Curve* can be obtained as seen in Figure 3-3.

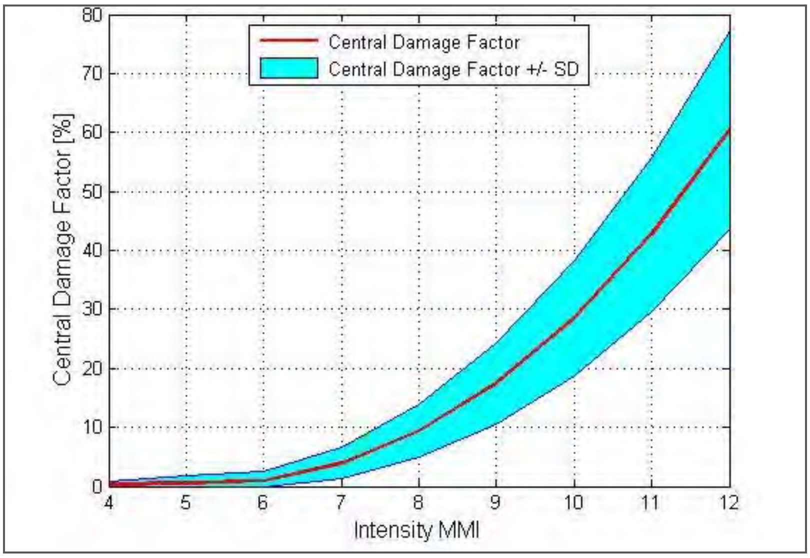

Figure 3-3 Example of a Vulnerability Curve

For these vulnerability curves the conditional PDFs $[f_D(d|i)]$ are given in the form of the *Damage Probability Matrices* **(***DPM)* (Whitman et al., 1973).

3.7.3 Damage Probability Matrices (DPM)

The concept of a DPM is that a given structural typology will have a particular probability of being in a given damage state (*j)* for a given earthquake intensity (*i)*.

Damage Probability Matrices based on expert judgment and opinion were first introduced in ATC-13 (1985). It provided low, best and high estimates of the damage factor (the ratio of the loss to replacement cost, expressed as a percentage) for MMI from VI to XII for 36 different building classes.

A typical DPM is presented below in Table 3-1.

Table 3-1 A typical damage probability matrix

Damage state	Damage factor range (per cent)	Central damage factor (per cent)	Probability of damage (per cent) by MM intensity and damage state				
			VI	VII	VIII	IX	X
1	0	0,0	95,0	49,0	30	14	3
2	0-1	0,5	3,0	38,0	40	30	10
3	1-10	5,0	1,5	8,0	16	24	30
4	10-30	20,0	0,4	2,0	8	16	26
5	30-60	45,0	0,1	1,5	3	10	18
6	60-100	80,0		1,0	2	4	10
7	100	100,0		0,5	1	2	3

1- None: no damage
2- Slight: limited localised minor damage not requiring repair
3- Light: significant localised damage of some components generally not requiring repair
4- Moderate: significant localised damage of many components warranting repair
5- Heavy: extensive damage requiring major repairs
6- Major: major widespread damage that may result in the facility being razed
7- Destroyed: total destruction of the majority of the facility

The extent of damage, from none to total, is divided into damage states. Each damage state is described both in words and by a range of damage factors, where damage factor denotes the ratio of the value of physical damage or rand loss due to the earthquake to the replacement value (ATC-13, 1985).

As shown in Table 3-2, for each damage state there are associated *Central Damage Factors* (CDF), defined as:

Table 3-2 ATC-13 Central Damage Factors

Central Damage Factors (CDF)		
CDF_1	0%	No Damage
CDF_2	0,5%	Slight Damage
CDF_3	5%	Light Damage
CDF_4	20%	Moderate Damage
CDF_5	45%	Heavy Damage
CDF_6	80%	Major Damage
CDF_7	100%	Total Destruction

The vulnerability curve for a specified kind of structure can then be calculated from the equation (3-14), where integration is replaced by simple summation as shown in equation (3-12):

$$E[D|i] = \sum_{j=1}^{7} CDF_j DPM_{ij}$$

(3-15)

Knowledge of the DPMs, and of the PDFs, $f_D(d|i)$, $f_I(i|a)$ and $f_A^{max}(a;T)$, makes it possible to calculate the distribution of damage (equation (3-7)) and expected damage during the specified time interval (T) (equation (3-12)), both of which are obtained by numerical integration.

3.7.4 Building Classes of the Area

The vulnerability was assessed for 12 typical building classes used in SA. Whitman's damage probability matrices were used to represent how vulnerable these structures are to damage.
Buildings can be classified in different classes according to their structures. A building class is the basic factor of the amount of damage possibly experienced in a seismic event.

The Applied Technology Council report (ATC-13, 1985) made mention of 36 classes of building structures.

Later in 1992, the European Macroseismic Scale EMS was introduced. An update of the scale was presented in 1998 as EMS-98 which is the basis for evaluation of seismic intensity in European countries (EMS, 1998).

The Earthquake Engineering Research Institute (EERI) presented a scale in 1994 where building classes where provided (EERI, 2004).

A study modifying the EMS-1998 to make the scale more internationally applicable, was presented (Foulser-Piggo and Spence, 2013). The study is known as the International Macroseismic Scale (IMS) and was funded by the Willis Research Network and supported by the Global Earthquake Model (GEM) and the authors of EMS-98. One of the main objectives of the study was to identify building types that are not currently represented in EMS-98 for extension of EMS-98 for international application.

In South Africa, discussions with civil engineers, building-science academics and other practitioners proposed that of these 36 classes, 12 could be identified as being relevant to the local insurance industry. Kijko and Retief (2001) list these 12 classes as well as their assumed distribution.

Davies and Kijko (2003) also mentioned these 12 building classes on their study of seismic risk assessment. Assumptions were made of the distributions of these building classes in some South African metropoles, cities and towns.

Pule et al. (2006) derived a graphical representation of the 12 building classes, showing their specific engineering type descriptions used in earthquake resistant building of structures, which the Council for Geosciences uses for its seismic risk assessments. His report was based on the building types from the European Macro seismic Scale EMS (1998) and EERI (2004) , with the 12 selected building classes obtained from the (already mentioned) publication by the Applied Technology Council ATC–13 (ATC-13, 1985).

The result of this report was a correlation between building classes provided in the two scales, EMS (1998) and (EERI, 2004), with relevant classes from ATC-13. Some discrepancies in the descriptions of the buildings were noted.

A summary of the results of such correlations is provided in Table 3-3 below.

The eThekwini Municipality area has been classed according to these 12 building classes by districts as it can be seen later on Chapter 4 in Figure 4-26.

Table 3-3 Building Classes Correlation between ATC-13 with EMS–1998 and EERI–2004

<table>
<tr><th>BUILDING CLASS</th><th>DESCRIPTION
ATC-13</th><th>TYPE OF STRUCTURE
EMS–1998 AND
EERI–2004</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Wood Frame, Low Rise</td><td>Timber Structure</td></tr>
<tr><td>Wood Frame Buildings</td></tr>
<tr><td>2</td><td>Light Metal, Low Rise</td><td>Light Metal Buildings</td></tr>
<tr><td>3</td><td rowspan="3">Unreinforced Masonry Bearing Wall, Low Rise.
• Load Bearing Frame, Low Rise.
• Load Bearing, Medium Rise.</td><td rowspan="3">Unreinforced Masonry</td></tr>
<tr><td>4</td></tr>
<tr><td>5</td></tr>
<tr><td>6</td><td rowspan="2">Reinforced Concrete Shear Wall with Moment Resisting Frame, Medium Rise and High Rise</td><td>Reinforced Concrete Frame</td></tr>
<tr><td>7</td><td>Reinforced Buildings with Frame</td></tr>
<tr><td>8</td><td rowspan="2">Reinforced Concrete Shear Wall without Moment Resisting Frame, Medium Rise and High Rise</td><td rowspan="2">Reinforced Concrete Walls</td></tr>
<tr><td>9</td></tr>
<tr><td rowspan="2">10</td><td rowspan="2">Braced Steel Frame, Low Rise</td><td>Steel Frame</td></tr>
<tr><td>Steel Frame Buildings</td></tr>
<tr><td>11</td><td>Precast Concrete, Low Rise</td><td>Precast Concrete buildings</td></tr>
<tr><td>12</td><td>Long Span, Low Rise</td><td>Long Span Buildings</td></tr>
</table>

3.8 Seismic Risk

Finally the risk was calculated by combining the seismic hazard curve with the buildings vulnerability curves to provide the annual probabilities of exceeding given values of damage, or equivalently the seismic risk curves.

The results were expressed in terms of expected percentage damage to buildings for each building class and its uncertainty interval.

The HRD program was also used to provide the risk analysis.

CHAPTER 4:RESULTS AND ANALYSIS

4.1 Introduction

The results of applying the methodology described in Chapter 3 to the data are presented in this chapter. These results include: the seismic hazard curve for the eThekwini Municipality area, the vulnerability curves and the seismic risk curves for the 12 different building classes and the seismic risk curves for the 12 building classes. These results are then analysed.

4.2 Probabilistic Seismic Hazard Assessment Results

For the determination of m_{max}, the seismic catalogue used was divided into 9 sub-catalogues (Kijko, 2014). Table 4-1 shows the different subdivisions made to the catalogue with their correspondent time period, the percentage of magnitude level of completeness and the percentage standard error of the magnitude determination for the percentage of seismic events within each sub-catalogue.

Table 4-1 Completeness Levels for the Catalogue

Sub-Catalogue	Beginning of Sub-Catalogue	End of Sub-Catalogue	% Magnitude Level of Completeness of Sub-Catalogue	% Standard Error of Magnitude Determination for % Earthquakes Within Sub-Catalogue
1	01-01-1806	31-12-1905	5.9	0.3
2	01-01-1906	31-12-1909	5.3	0.2
3	01-01-1910	31-12-1949	4.9	0.2
4	01-01-1950	31-12-1970	4.6	0.2
5	01-01-1971	31-12-1980	4.0	0.1
6	01-01-1981	31-12-1990	3.8	0.1
7	01-01-1991	31-12-1995	3.5	0.1
8	01-01-1996	31-12-2002	3.5	0.1

9	01-01-2003	31-01-2013	3.0	0.1

Table 4-2 below provides the summary of the calculated parameters b-value of Gutenberg-Richter, the mean activity rate $\lambda_{4.0}$ and the estimated regional maximum possible seismic event magnitude.

Table 4-2 Estimated area-characteristic seismic hazard parameters for the ISC sub-catalogues

The mean values of the area-characteristic seismic hazard parameters for the eThekwini Municipality area	
b	1.14
$\lambda_{4.0}$	0.97 (event/year)
$\hat{m}_{\max}$	6.43

This then explains the model parameters, which in conjunction with the steps explained in section 3.6, resulted in the *Seismic Hazard Curve*, defined as the annual probability of exceeding a specified ground motion parameter at least once.

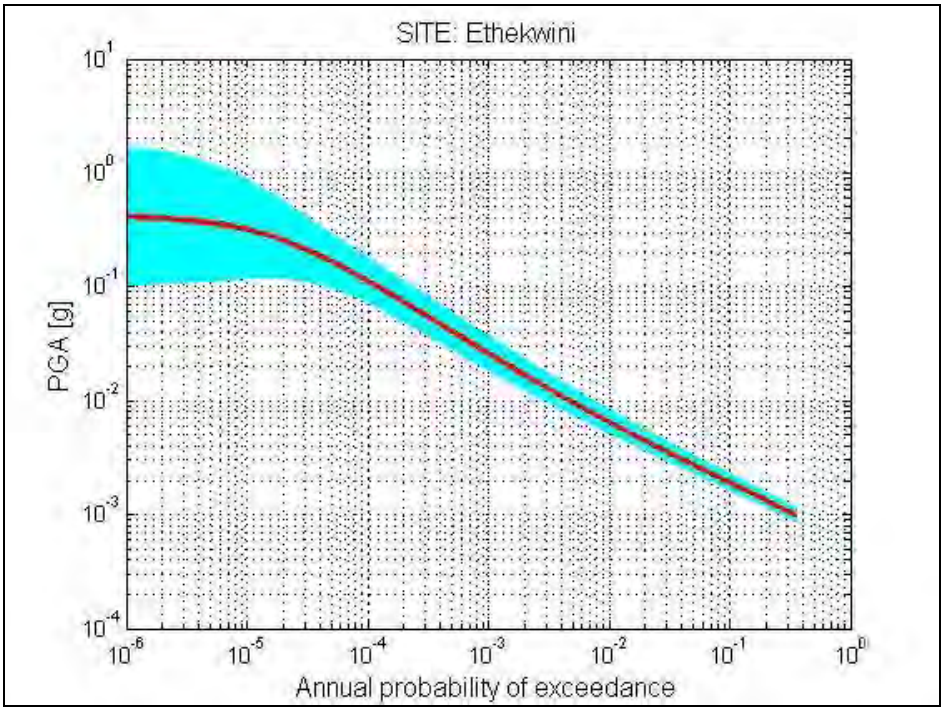

Figure 4-1 Seismic Hazard Curve for eThekwini Municipality area

The Annual Seismic Hazard Curve for the eThekwini Municipality area (T = 1 year) is indicated in Figure 4-1.

Figure 4-2 shows the plot of the return period against the PGA.

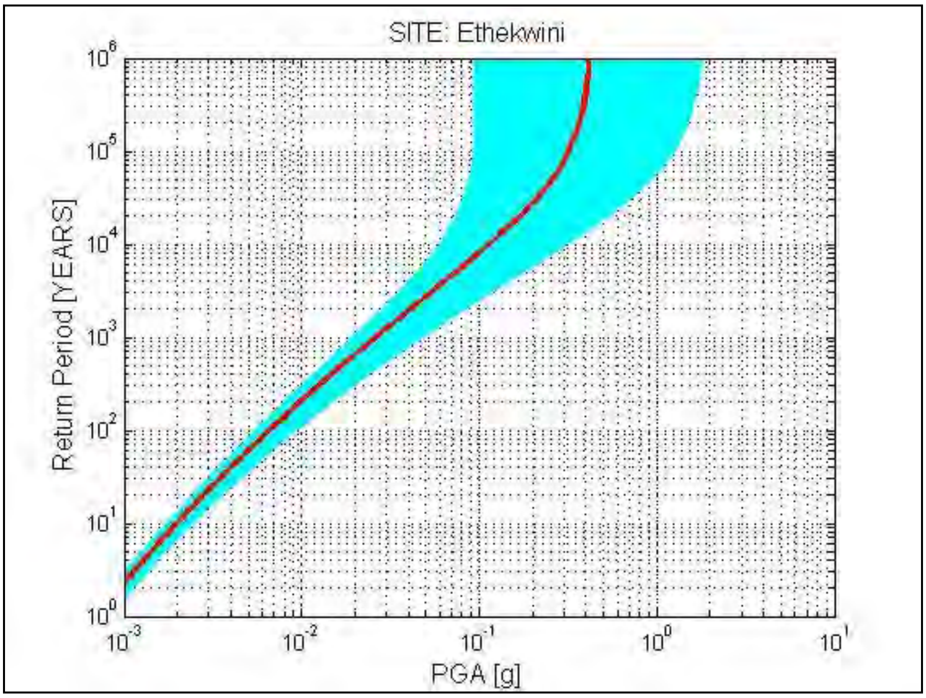

Figure 4-2 Return Period of Specified Values of PGA

Figure 4-3 shows the plot of the annual probability of exceedance against the PGA with a set of quantile curves for values of 5%, 15%, 50%, mean, 85% and 95%.

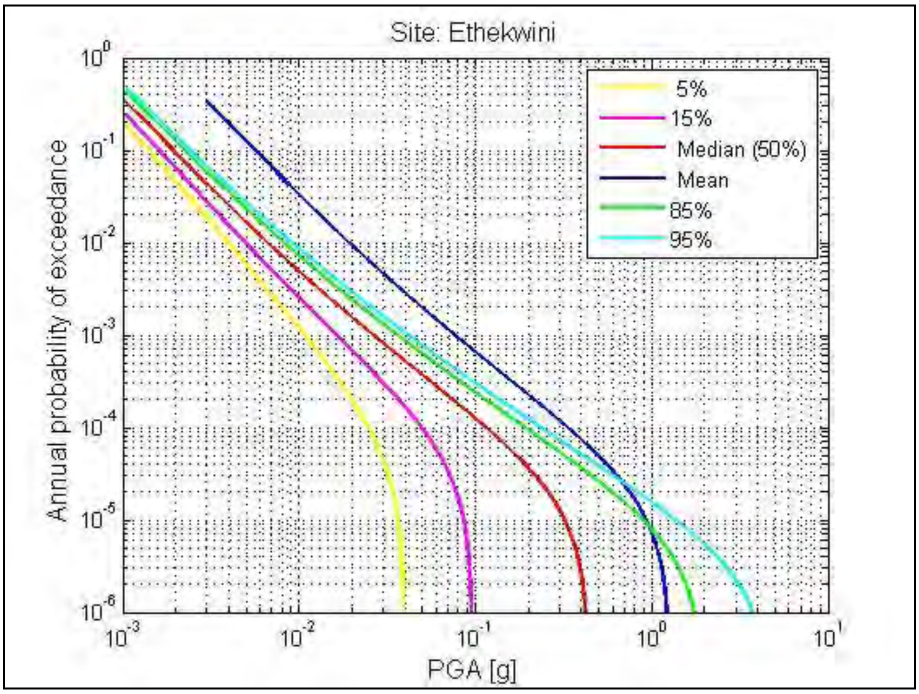

Figure 4-3 Annual Probability of Exceedance Plus Quantiles

Figure 4-4 shows the probability of exceeding a specified ground motion parameter (PGA) at least once for 3 different time intervals: 50 years, 100 years and 1000 years.

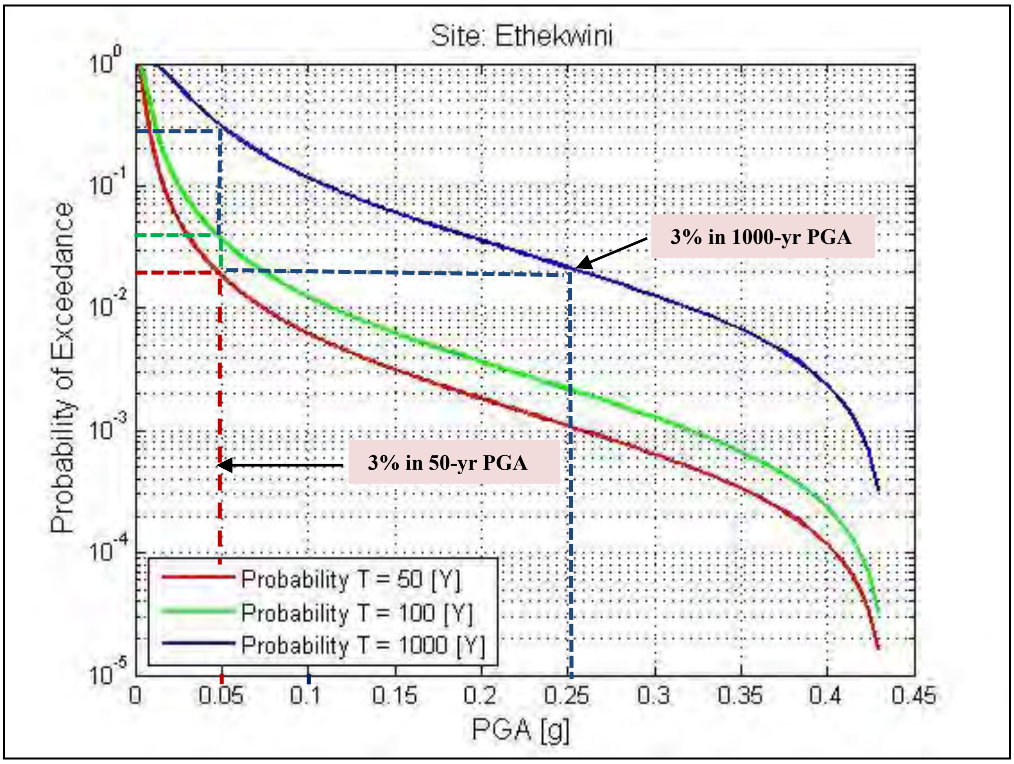

Figure 4-4 Seismic Hazard Curve for 3 time intervals (50, 100 and 1000 years)

This seismic hazard curves shown in Figure 4-4 can be interpreted as the probability of exceeding a specified value of PGA at least once for 3 different time intervals: 50 years, 100 years and 1000 years; over the eThekwini area.

The red curve indicates the 50 year time interval, the green curve indicates the 100 year time interval and the blue curve indicates the 1000 year time interval. For example, a 0.05g earthquake PGA has a 3% chance of being exceeded in 50 years, a 7% chance of being exceeded in 100 years and a 43% chance of being exceeded in a 1000 years.

This can be compared to the earthquake PGA that has a 3% chance of being exceeded in 1000 years, which has a value of around 0.26g. In other words, there is a 97% chance that the shaking will not exceed 0.26g.

Comparing the results of the seismic hazard obtained in this study with the seismic hazard map showed earlier in Chapter 2 for South Africa (Figure 2-5), it can be seen that there is a variation of the values that both graphs are showing. The first map indicates a PGA value of around 0.05g for a 10% probability of being exceed for the eThekwini area, in contrast to a 0.05 PGA value for a 3% probability of being exceed.

Structures are designed according to accelerations for specific return periods. A return period of 475 years is usually considered for the design of residential structures in South Africa. Figure 4-2 indicates a PGA value of 0.41 g for such a return period for the eThekwini area.

Also, the condition of the site where the structure is or will be located is essential. The response that a structure with a given natural frequency and ground type will have to a ground acceleration produced by an earthquake needs to be calculated. Design codes applies design response spectra to determine such a response. The response results are statistically manipulated and smoothed to produce *Elastic Response Spectra*. Response spectra are constructed for a specific damping value.

The SANS describes four different ground types with their corresponding parameters as shown in Table 4-3.

Table 4-3 Ground Types SANS 10160-4 (2009)

Ground Type	Description of stratigraphic profile	Parameters		
		$v_{s\,30}$ m/s	N_{SPT} Blows/30 cm	C_u kPa
1	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface	>800	-	-
2	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of m in thickness, characterised by a gradual increase of mechanical properties with depth	360 – 800	>50	>250
3	Deep deposits of dense or medium dense sand, gravel or stiff clay with thickness from several tens to many hundreds of m	180 – 360	15-50	70 – 250
4	Deposits of loose-to-medium cohesion-less soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil	<180	<15	<70

Where

$v_{s\,30}$ is the average value of propagation of S-waves in the upper 30 m of the soil profile at shear strains of 10^{-5} or less

N_{SPT} is the Standard Penetration Test blow-count

C_u is the un-drained shear strength of soil (kPa)

The SANS 10160-4 code specifies that when the site conditions are not fully known or if the site investigations do not enable any profiles to be used, an *Elastic Response Spectrum* should be used and the most unfavorable (the curve representing the largest response for a given natural frequency) of the four curves can be considered. The normalized design response elastic spectra shown in Figure 4-5, is created for each ground type for 5% damping and a behavior factor q=1 as published in SANS 10160-4 (2009).

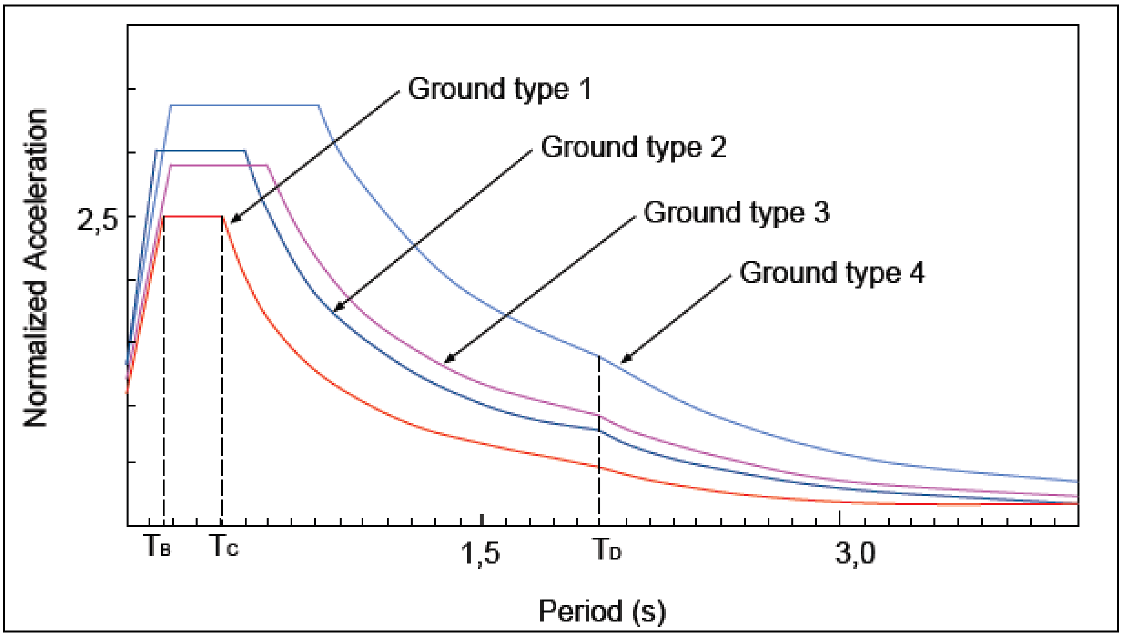

Figure 4-5 Normalized Design Response Elastic Spectrum SANS 10160-4 (2009)

Using a hazard curve, one could determine the annual probability of occurrence of each of these ground motions. Then one could decide whether that corresponding probability is acceptable. If one of the probabilities is unacceptably high, the design would have to be revised.

The South African Bureau of Standards, SABS 0160 code, defines two zones in the country for which seismic loading needs to be considered in the design of building structures. Zone 1 is for areas of seismic activity of natural origin and Zone 2 is for areas of seismic activity due to mining related activities. For Zone 1, a PGA value of 0.1g is defined for a 10% probability of being exceeded in 50 years. Structures located in Zone 2 are only required to comply with certain layout requirements for low rise buildings, and with provisions for non-structural components.

SABS 0160 was first published in 1989, with some revisions in 1993. Ever since the publication of the Code, designers in the Western Cape have considered the provisions to be unrealistic and too stringent. It has been suggested that the South African loading code (seismic provisions) needs to be re-evaluated and revised. For example, the seismic hazard map published by the South African

Council for Geoscience in 2003, shows peak ground acceleration values of approximately 0.2g with a 10% probability of being exceeded in 50 years for Zone 1.

Figure 4-6 shows the seismic hazard zones of South Africa according to the SANS 10160-4 (2009) overlain with the locations of earthquakes that occurred in and around South Africa from 1620 to 1970 (Van der Kolf, 2014).
When comparing the values shown in the seismic map, it is evident that the values of PGA does not correspond with the actual values and readjustments are necessary.

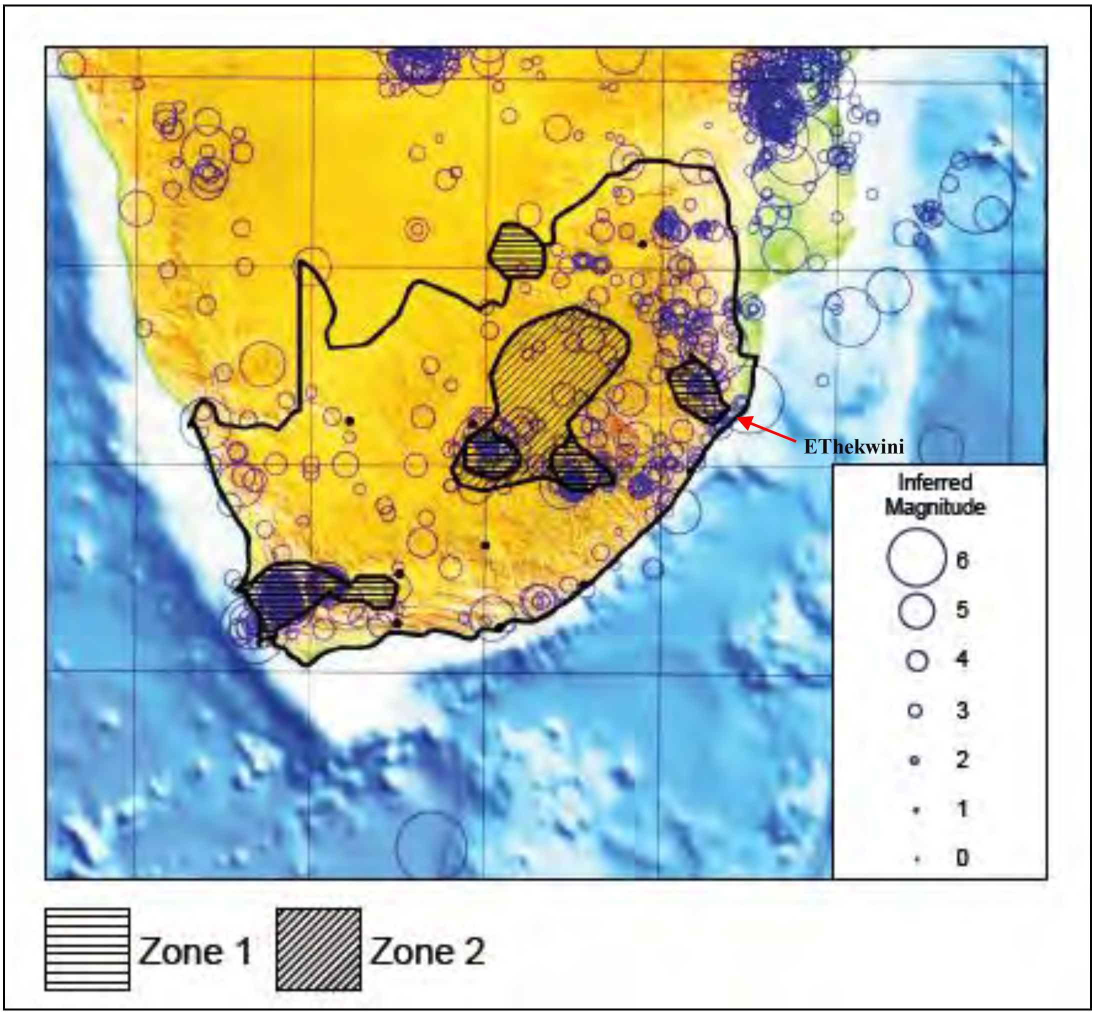

Figure 4-6 Map of Zones for South Africa SANS 10160-4:2009 overlaid with map of inferred magnitudes of known earthquakes from 1620 to 1970 (from Van der Kolf (2014))

The seismic hazard curve is useful in different fields. For example, in seismic design of structures such as design criteria for dams, it is essential to know the probability of exceeding a given ground motion parameter at the dam site during a specified interval of time.

A Maximum Credible Earthquake (MCE) is the largest probable earthquake magnitude. The most severe ground motion affecting a dam site due to an MCE scenario is known as the MCE ground motion.

A dam should be designed or analysed according to a maximum level of ground motion affecting a dam site due to a seismic event. The ground motions at a dam are typically considered for a long return period such as 10,000 years.

Where there is not a great risk to human life, a lower return period (depending on the consequences of dam failure) could be used (ICOLD, 2010). According to the seismic hazard figures obtained in this study, one could consider that the seismic hazard for the eThekwini municipality area is low. Decreasing probability of exceedance implies higher levels of safety.

PSHA can account for any uncertainties provided they are quantifiable. The blue curves shown in Figure 4-1, Figure 4-2 and some of the following figures, represent the uncertainty interval with a log-normal distribution (that is, $\ln(PGA)$ has a normal or Gaussian distribution). The uncertainty interval reveals the standard deviation of $\ln(PGA)$ and the probability that the values will fall within a certain value of the median predicted PGA.

4.3 Seismic Vulnerability Assessment Results

The result of the seismic vulnerability assessment for the eThekwini Municipality area explained in section 3.4.2 is shown in Figure 4-8. The seismic vulnerability curves describe the amount of damage to each building class by the seismic hazard.

For example, as shown in Figure 4-7, a high rise building with reinforced concrete shear wall with moment resisting frame, which is building type number 7, and which experiences an earthquake with an intensity of 9 MM would suffer a 17% damage factor.

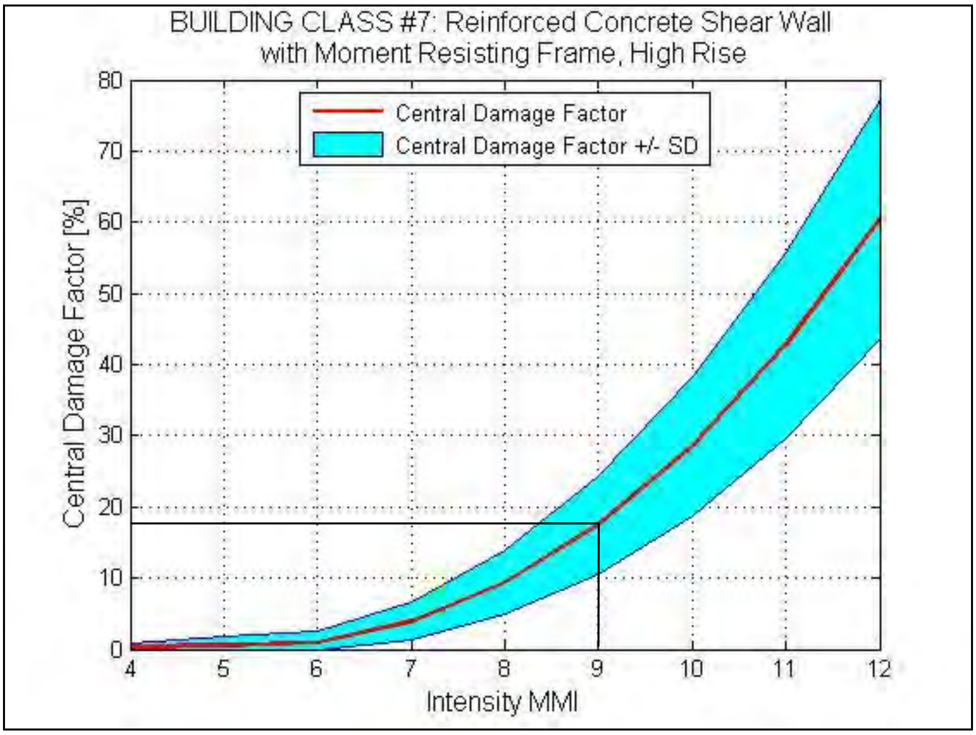

Figure 4-7 Seismic Vulnerability Curve for Building Type #7

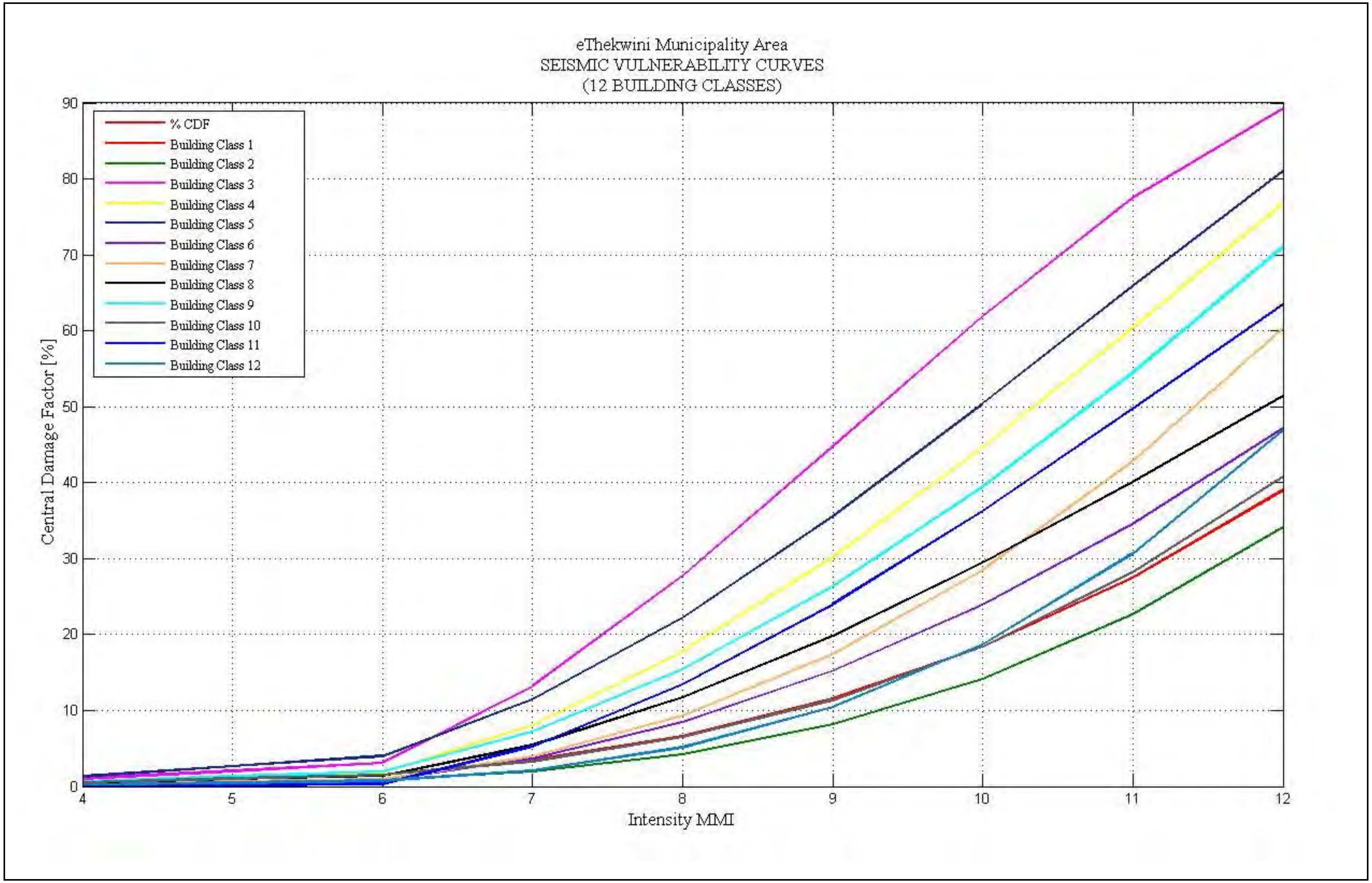

Figure 4-8 Vulnerability Curves for the 12 Buildings Classes

Figure 4-8 illustrates the level of vulnerability of each building class to a seismic event.

Referring to Figure 4-8, an event of intensity 6 would need to occur for any building class to reach a CDF of 5% (equivalent to light damage). The first building class to reach such a level would be building class 5.

Should the intensity of an event rise from 6 to 7, building class 3 (Unreinforced Masonry Bearing Wall, Low Rise) would become more vulnerable than class 5 (Unreinforced Masonry Load Bearing, Medium Rise). A similar cross-over of damage would occur with building class 7 (Reinforced Concrete Shear Wall with Moment Resisting Frame, High Rise) and building class 8 (Reinforced Concrete Shear Wall without Moment Resisting Frame, Medium Rise), becoming relatively more vulnerable when the intensity changes from 10 to 11.

Table 4-4 indicates the most and least vulnerable building classes for a “very strong” earthquake of MM intensity VII. However, one should keep in mind the level of uncertainty in the values (+/- Standard Deviation) as mentioned earlier.

Table 4-4 Level of Vulnerability of the Building Classes for an MMI VII Event

LEVEL OF VULNERABILITY	
LEAST VULNERABLE	MOST VULNERABLE
Building Class 12	Building Class 3
Building Class 2	Building Class 5
Building Class 10	Building Class 4

4.4 Probabilistic Seismic Risk Assessment Results

As mentioned in section 3.8, the seismic risk curves were generated by combining the seismic hazard curve with the vulnerability curves. The seismic risk curves show the annual probabilities of exceeding given values of damage, for each building class.

In the following set of figures (Figure 4-9 to Figure 4-20), the seismic risk curves are presented.

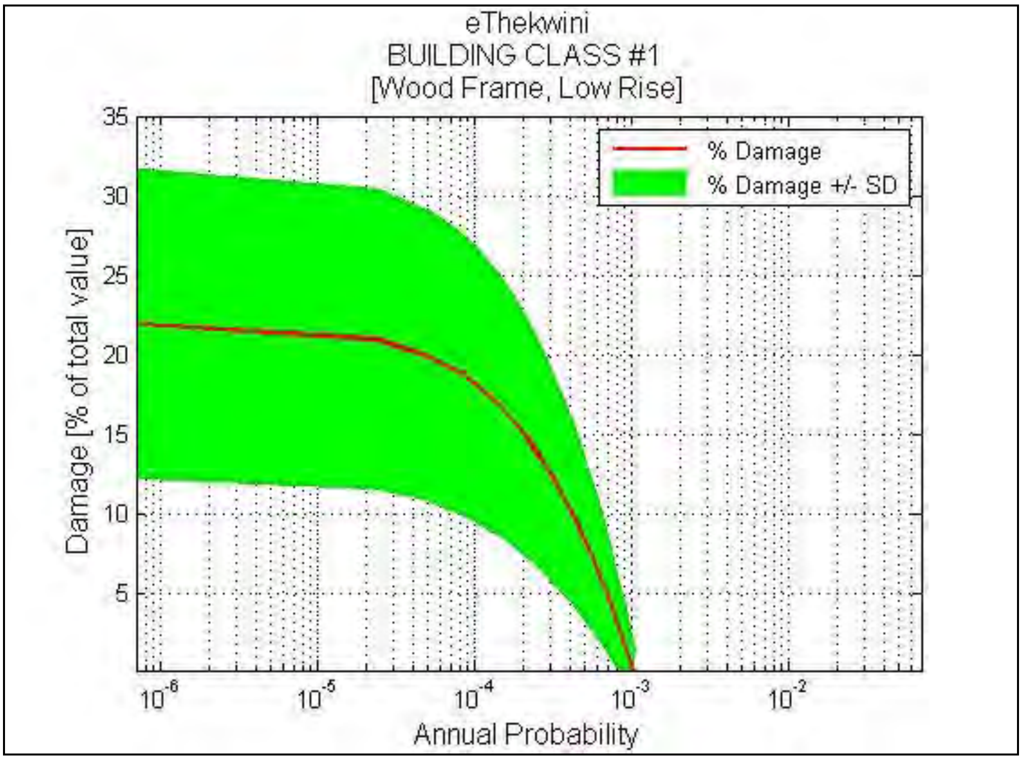

Figure 4-9 Seismic Risk Curve for Building Class #1

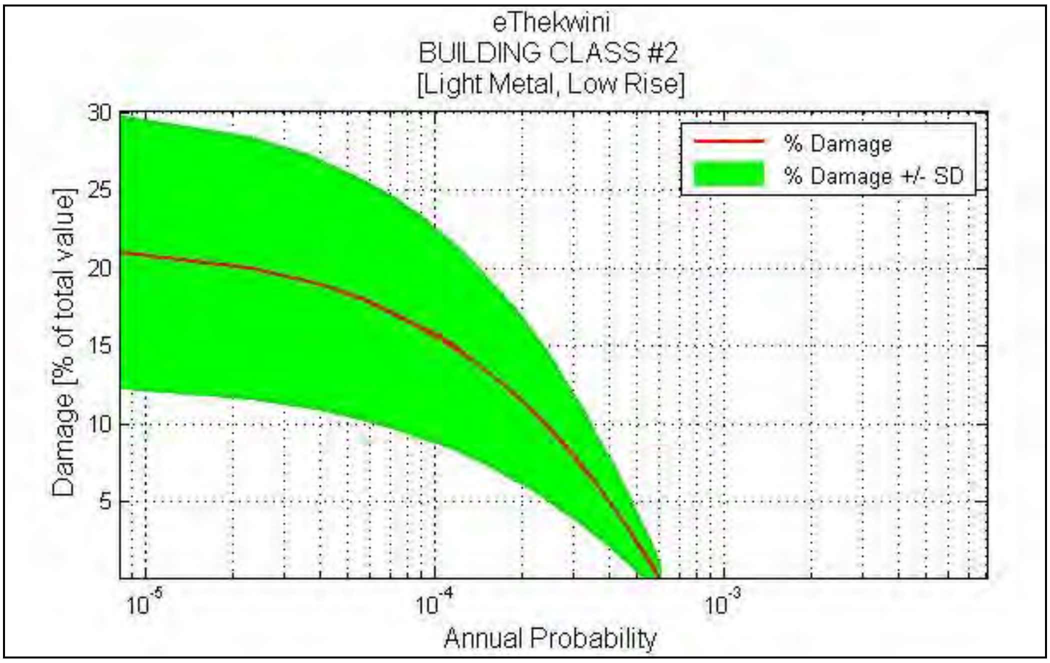

Figure 4-10 Seismic Risk Curve for Building Class #2

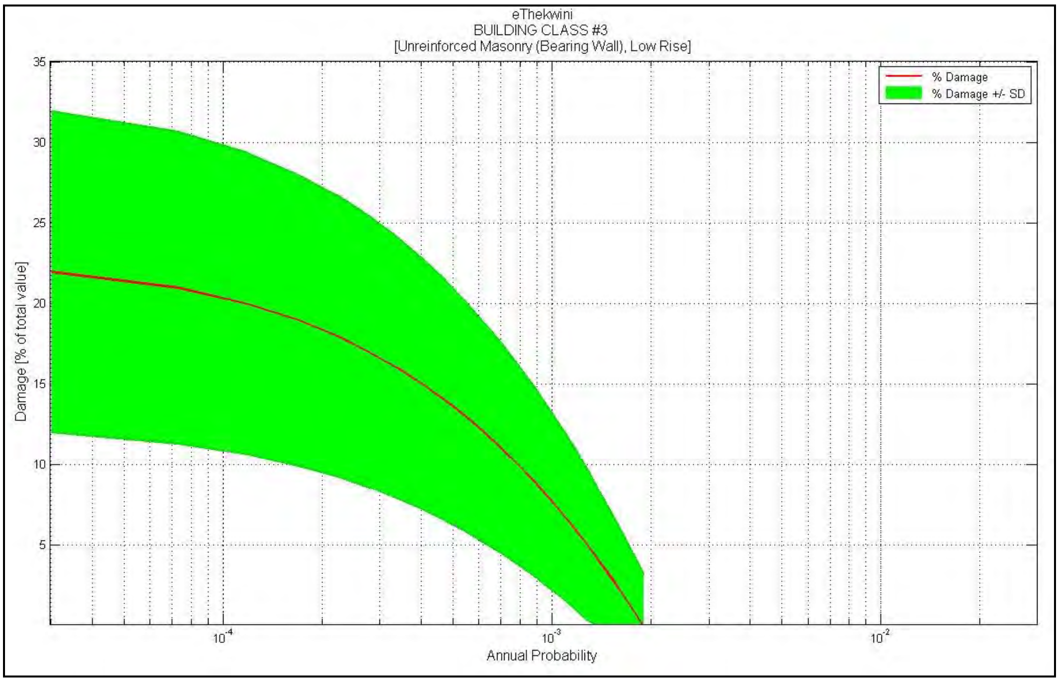

Figure 4-11 Seismic Risk Curve for Building Class #3

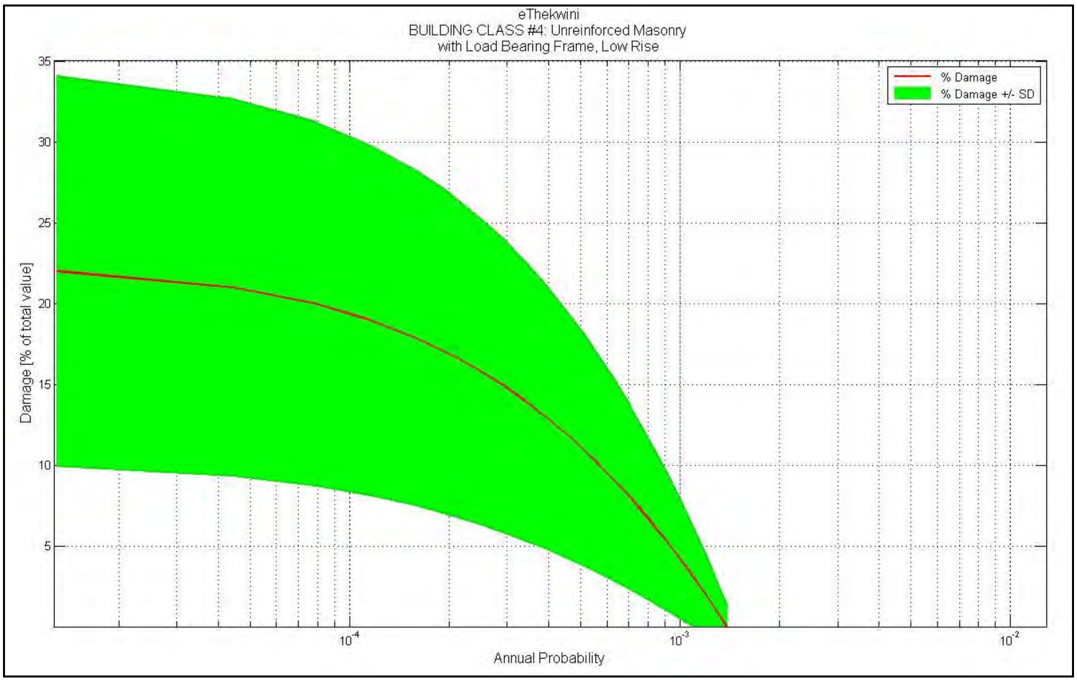

Figure 4-12 Seismic Risk Curve for Building Class #4

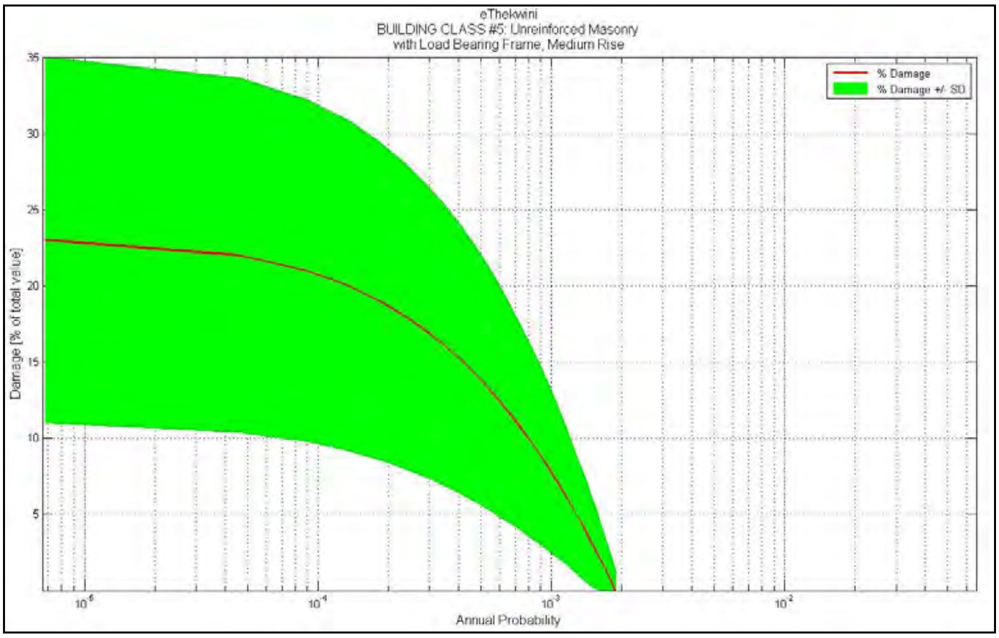

Figure 4-13 Seismic Risk Curve for Building Class #5

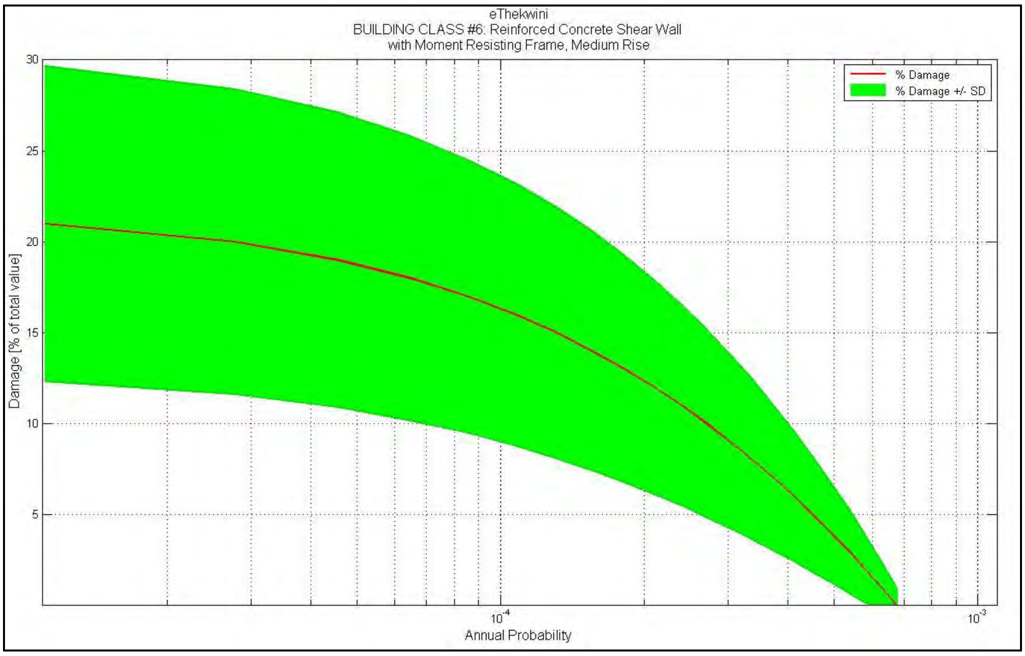

Figure 4-14 Seismic Risk Curve for Building Class #6

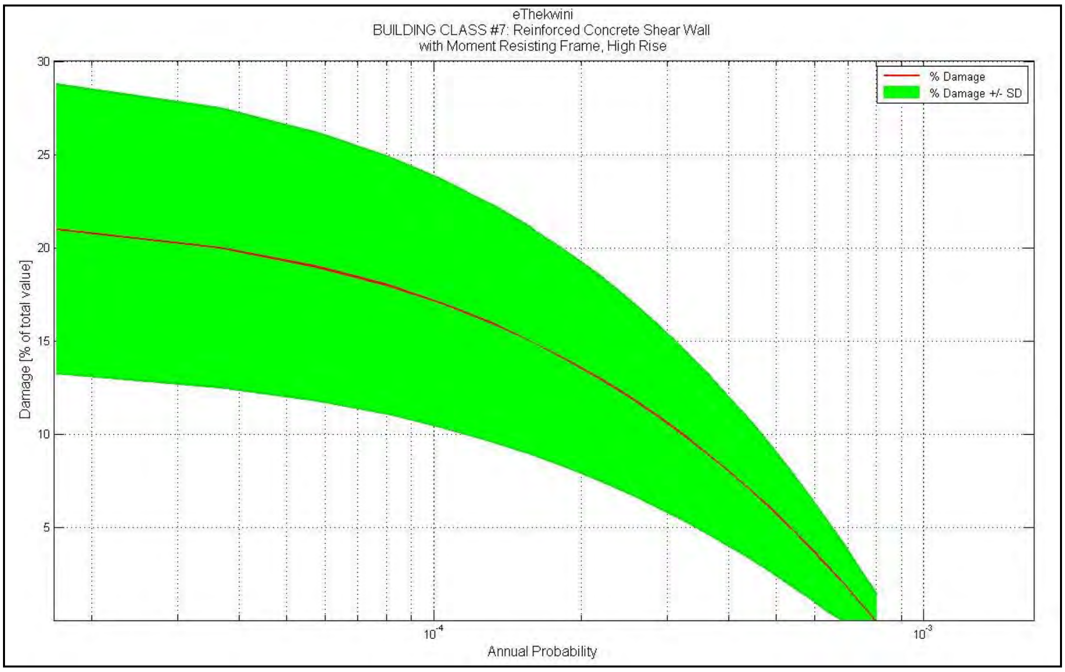

Figure 4-15 Seismic Risk Curve for Building Class #7

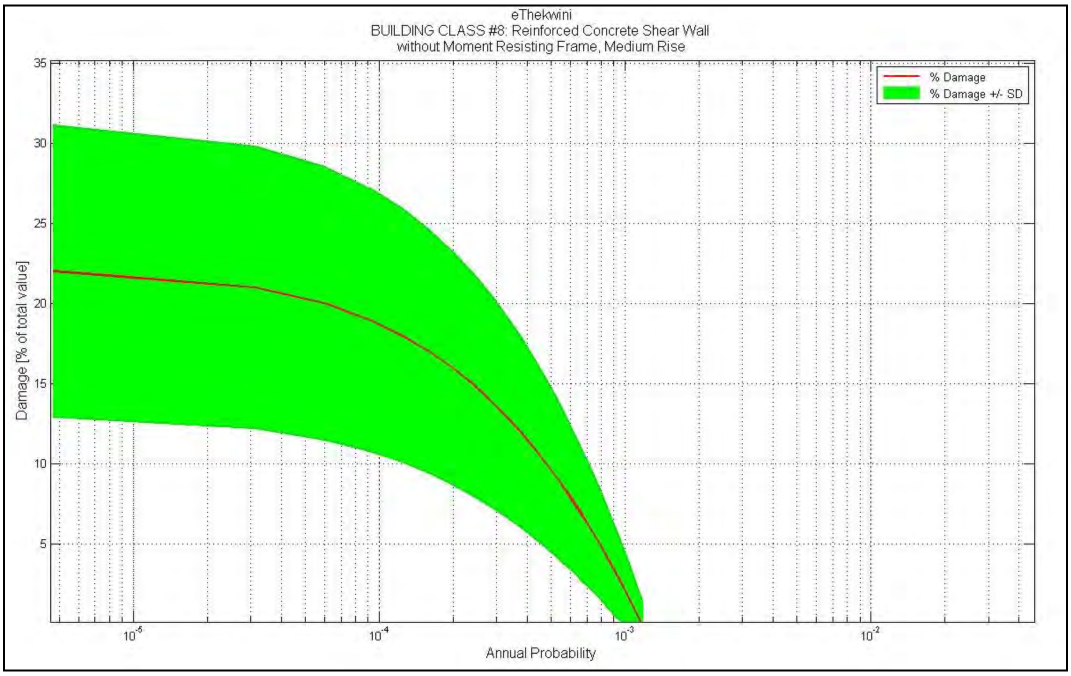

Figure 4-16 Seismic Risk Curve for Building Class #8

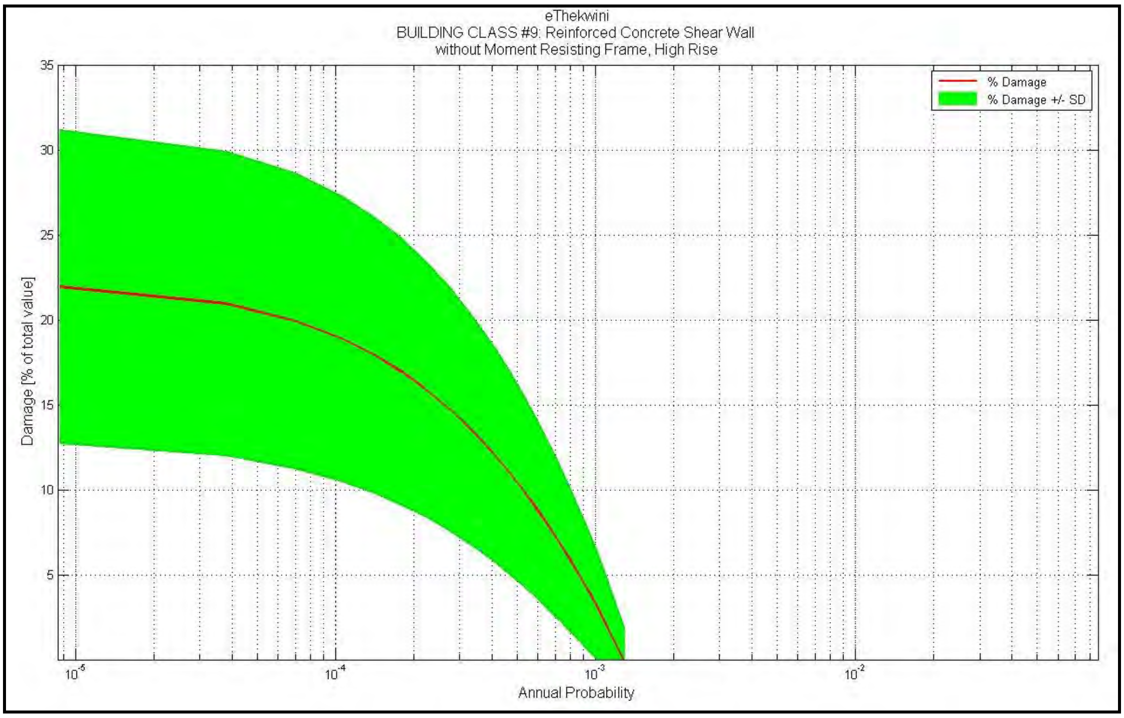

Figure 4-17 Seismic Risk Curve for Building Class #9

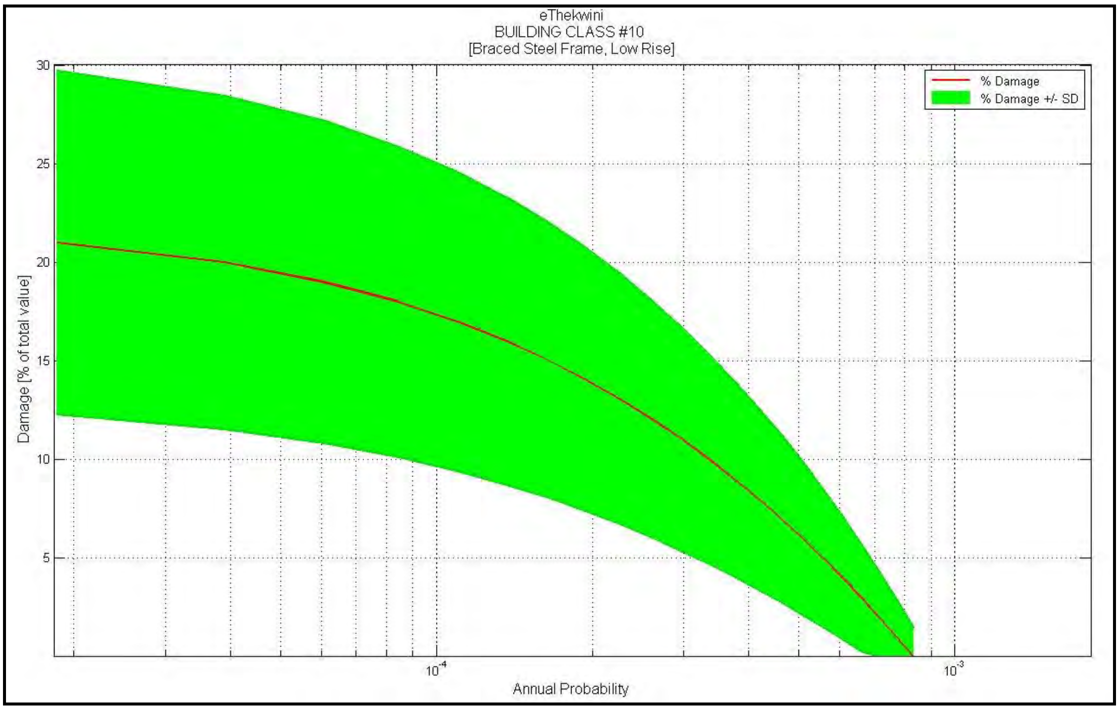

Figure 4-18 Seismic Risk Curve for Building Class #10

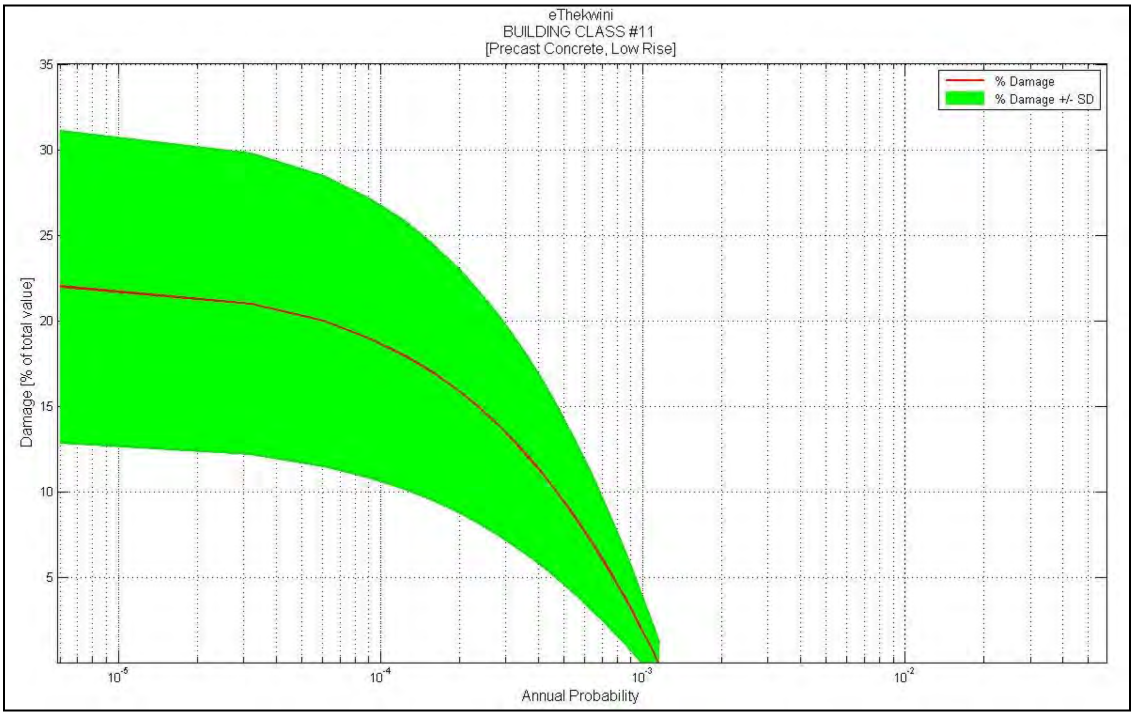

Figure 4-19 Seismic Risk Curve for Building Class #11

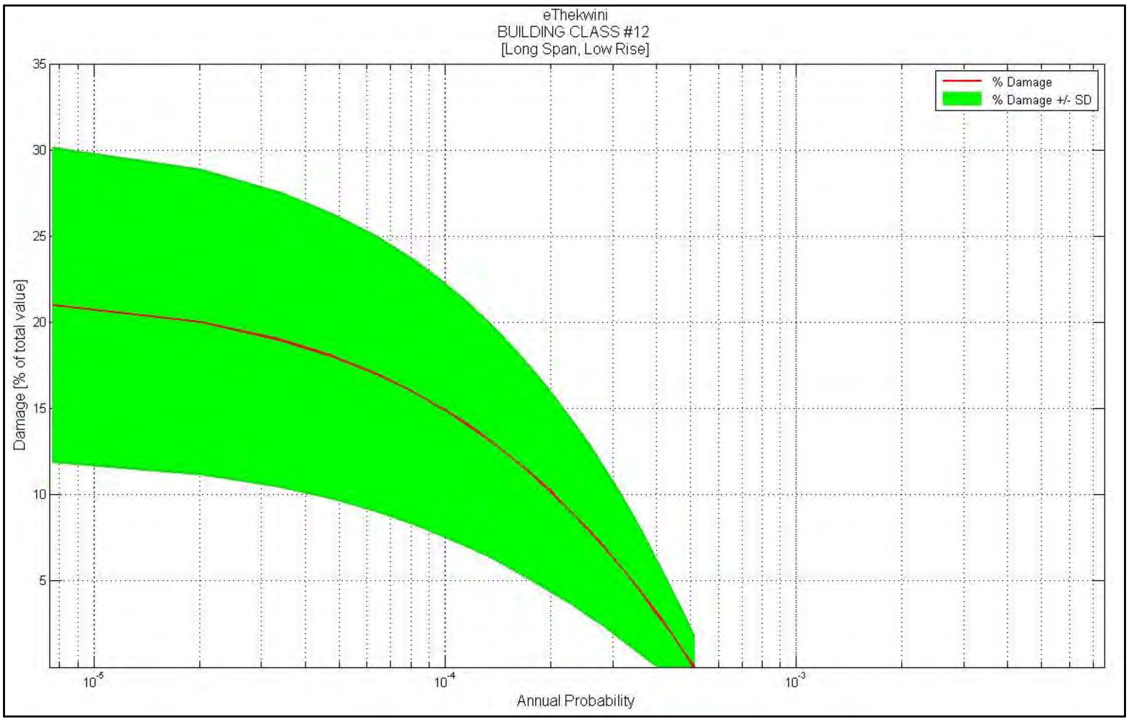

Figure 4-20 Seismic Risk Curve for Building Class #12

To have a better understanding of the previous information, all the seismic risk curves were incorporated into one graph, as appears in Figure 4-21.

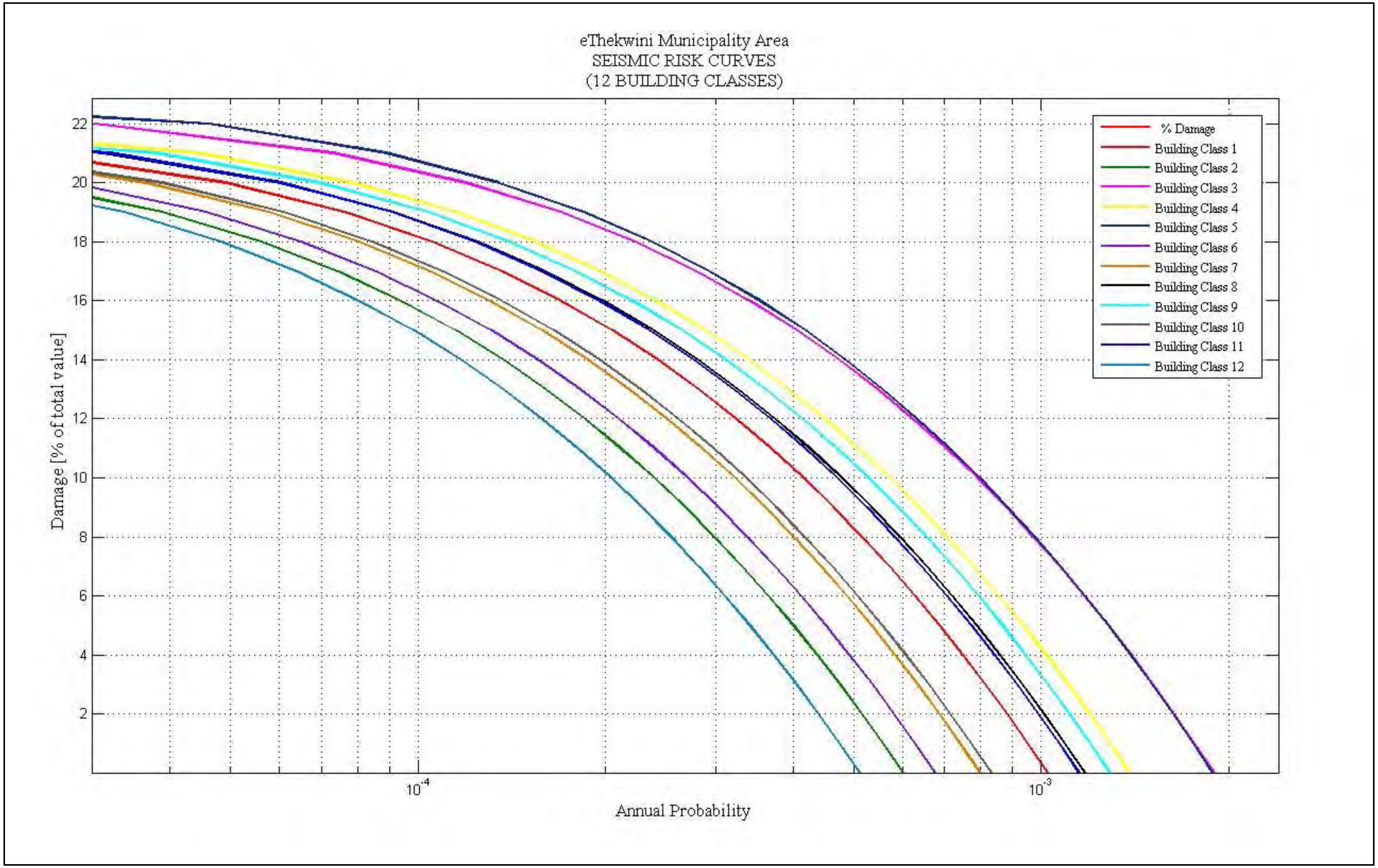

Figure 4-21 Seismic Risk Curves for the eThekwini Municipality Area

Referring to Figure 4-21, building class 8 (Reinforced Concrete Shear Wall without Moment Resisting Frame, Medium Rise) and building class 11 (Precast Concrete, Low Rise) follow similar patterns of damage values. The exception is when damage varies from damage state 3 to damage state 4 (see Table 3-1). In this case the annual expected damage probability increases for building class 8.

Building class 3 (Unreinforced Masory Bearing Wall, Low Rise) and building class 5 (Unreinforced Masonry Load Bearing Frame, Medium Rise) also show similar damage values. However, when damage varies from damage state 3 to damage state 4, building class 5 shows a higher annual expected damage probability.

The results of the annual expected damage for the different classes of buildings are presented in Table 4-5.

Table 4-5 Annual Expected Damage for the Building Classes

BUILDING CLASS NUMBER	ANNUAL EXPECTED DAMAGE (%)
1	0.009
2	0.005
3	0.017
4	0.012
5	0.017
6	0.005
7	0.007
8	0.010
9	0.011
10	0.007
11	0.010
12	0.004

Figure 4-22 shows graphically the results of the annual expected damage for the different classes of buildings that were indicated in Table 4-5.

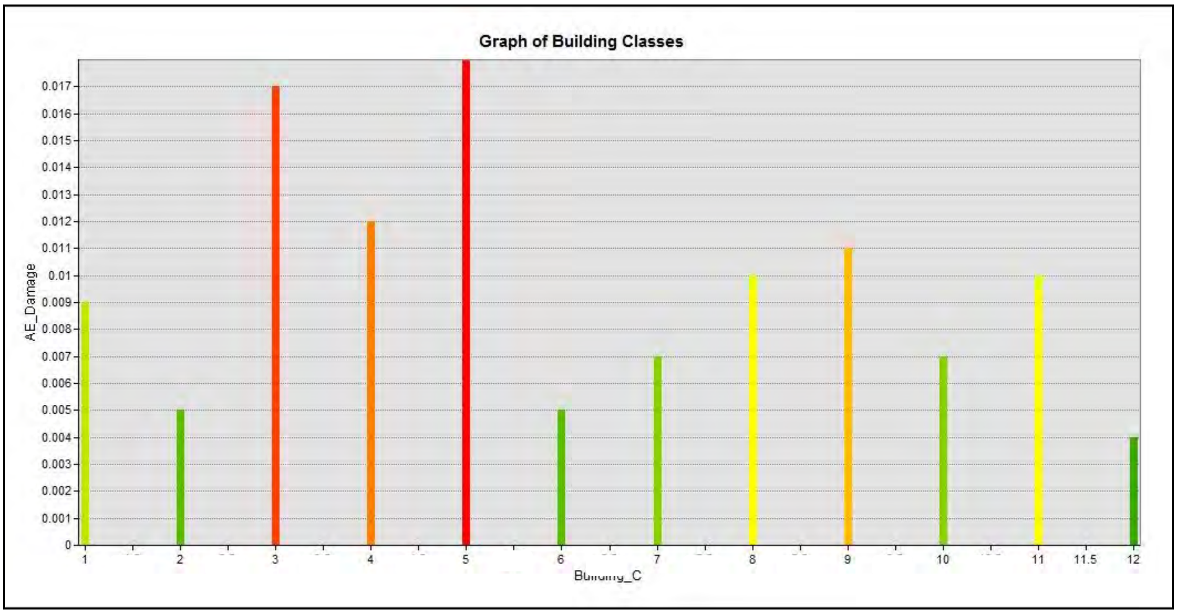

Figure 4-22 Graph of Annual Expected Damage for Building Classes

4.4.1 Discussion of Results

The eThekwini Municipality area has diverse land uses. These include urban settlements formal and informal, peri-urban settlement, institutional, recreational, commercial, industrial, under construction, agriculture, forestry, the harbour, sugar cane fields, beach, water bodies, as well as undeveloped land. Figure 4-24 shows the different land uses present in the area.

A number of high rise buildings are present on the area mostly used for commercial purposes. Figure 4-23, shows some examples of this type of buildings ordered by official height. These include buildings of built, under-construction and proposed status.

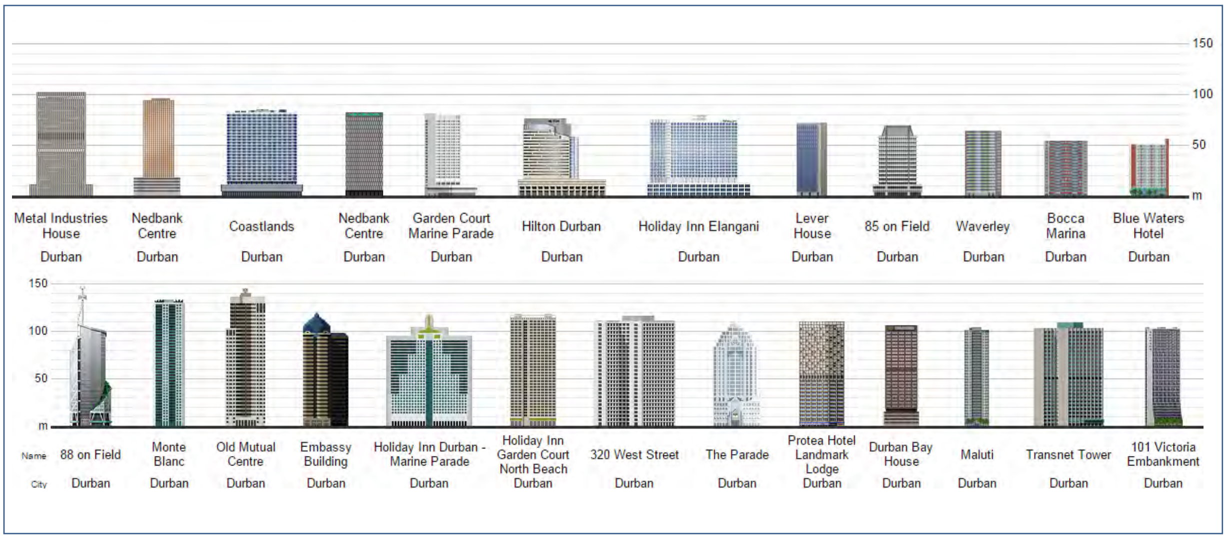

Figure 4-23 High Rise Buildings eThekwini Municipality (Source: http://skyscraperpage.com)

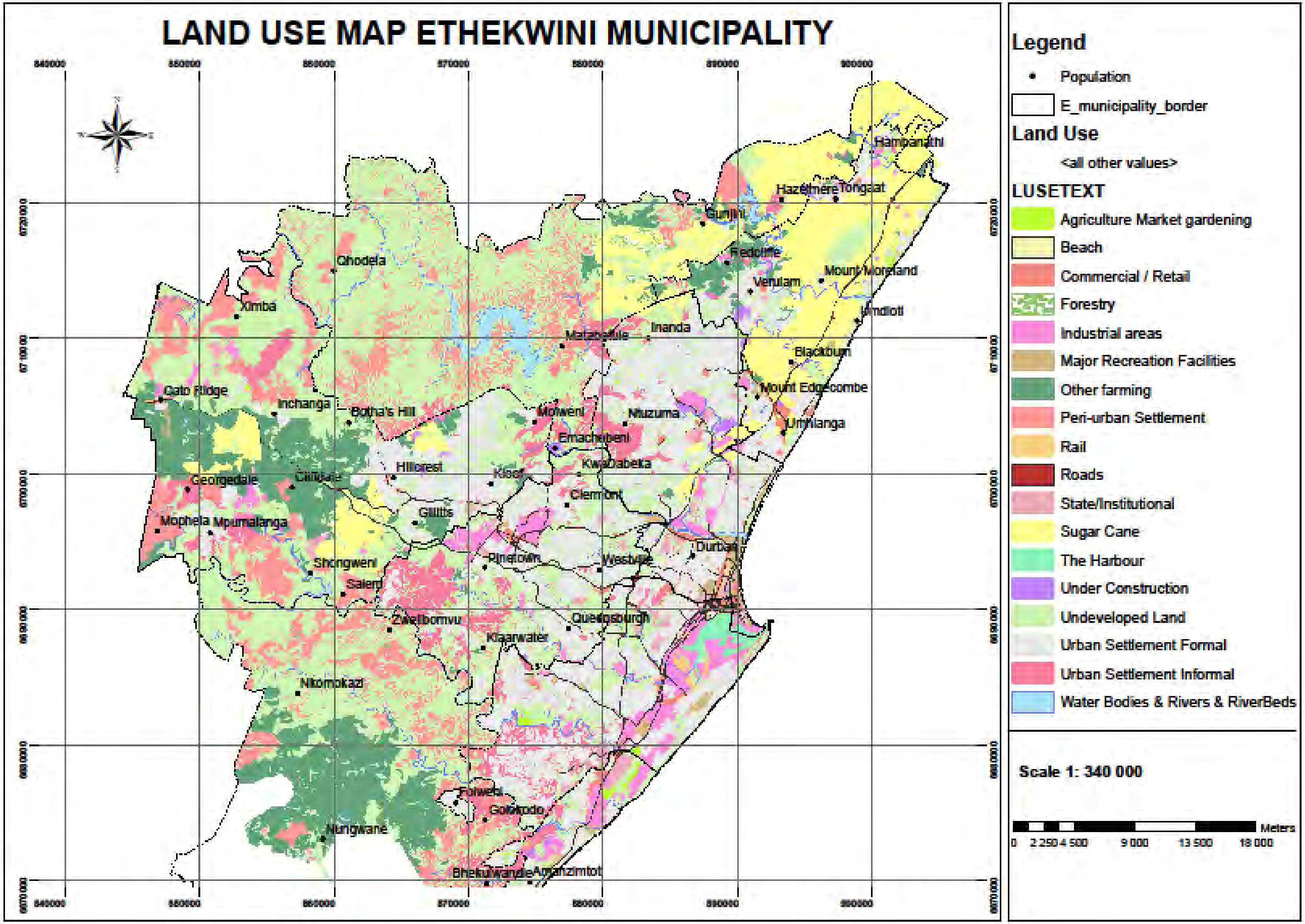

Figure 4-24 Land Use Map eThekwini Municipality

Building classes with the highest damage percentage were 3, 4 and 5 (being the highest out of all) which are all Unreinforced Masonry (URM) Structures Type.

URM is a brittle material with low tensile strength. This causes URM buildings to typically perform poorly under lateral excitation. URM is therefore considered to be the most vulnerable type of structure when subjected to earthquake excitation (Bruneau, 1994) (Tomazevic, 1999).

Bruneau (1994) reported that URM buildings suffer considerable damage in low to moderate seismic events. This can be attributed to the low tensile and shear strength of masonry as well as the large reduction in strength once cracking has initiated.

In South Africa, URM structures are commonly used. Their advantages including low cost, good thermal insulation, durability and good compressive strength, all of which make it a popular building material in residential areas.

South African structural design codes make provisions for the use of URM in seismic regions by including mandatory design requirements in the seismic loading code, SANS 10160-4 (2009). However, many of these buildings were constructed before the implementation of SABS 10160.

Nevertheless research shows that URM can withstand moderate seismic events if proper design procedures are followed (Tomazevic, 1999).

A seismic analysis done in South Africa on the vulnerability of a typical South African unreinforced masonry structure concluded that a typical URM building had a high probability of failing during a 0.15g earthquake excitation or being damaged to such an extent that the structure would be unsafe for use. However, such a level of damage could be avoided with a good conceptual layout of the building's performance (Van der Kolf, 2014).

In contrast, the building classes with the lowest annual expected damage percentage were class 12 and 2 (Long Span Buildings and Light Metal Buildings).

Long Span structures are usually used for activities where visibility is important and where large audiences are accommodated (auditoriums and covered stadiums), where flexibility is important (exhibition halls and certain types of manufacturing facilities), and where large movable objects are housed (aircraft hangars). Bridges are also a common type of long-span structure. These structures tend to perform well under seismic stress, since it is crucial that these structures are designed to withstand seismic events.

Light Metal Low Rise structures usually tend to perform well in earthquakes because these buildings are lightweight and constructed of steel members. Failures do not typically occur (FEMA, 1988).

Local authorities can use risk analysis instruments as a decision-making support mechanism during planning and development procedures. It is important to enable planners to undertake such analyses.

4.4.2 Spatial Analysis of Results

The eThekwini municipality is divided into 117 districts, where assumptions were made regarding the different building classes in order to produce two maps that shows how the results obtained could be represented in a spatial context.

Every district has a mixture of land uses, which makes it difficult to select just one building class. By overlapping the land use layer with four aerial photographs that fully cover the area in the software ArcGIS, an analysis was made in order to select the predominant building class for every district.

In the cases where formal and informal urban settlements or peri-urban settlement are mixed with agriculture, forestry or undeveloped land, the priority was given to the settlements.

The following map, Figure 4-25, indicates the distribution of building classes per districts of the municipality, together with the values of population for most of the districts.

A table containing the values of population for every district that was available according to the last Census recorded in 2011 (Statistics South Africa, 2011), is presented in Annex C.

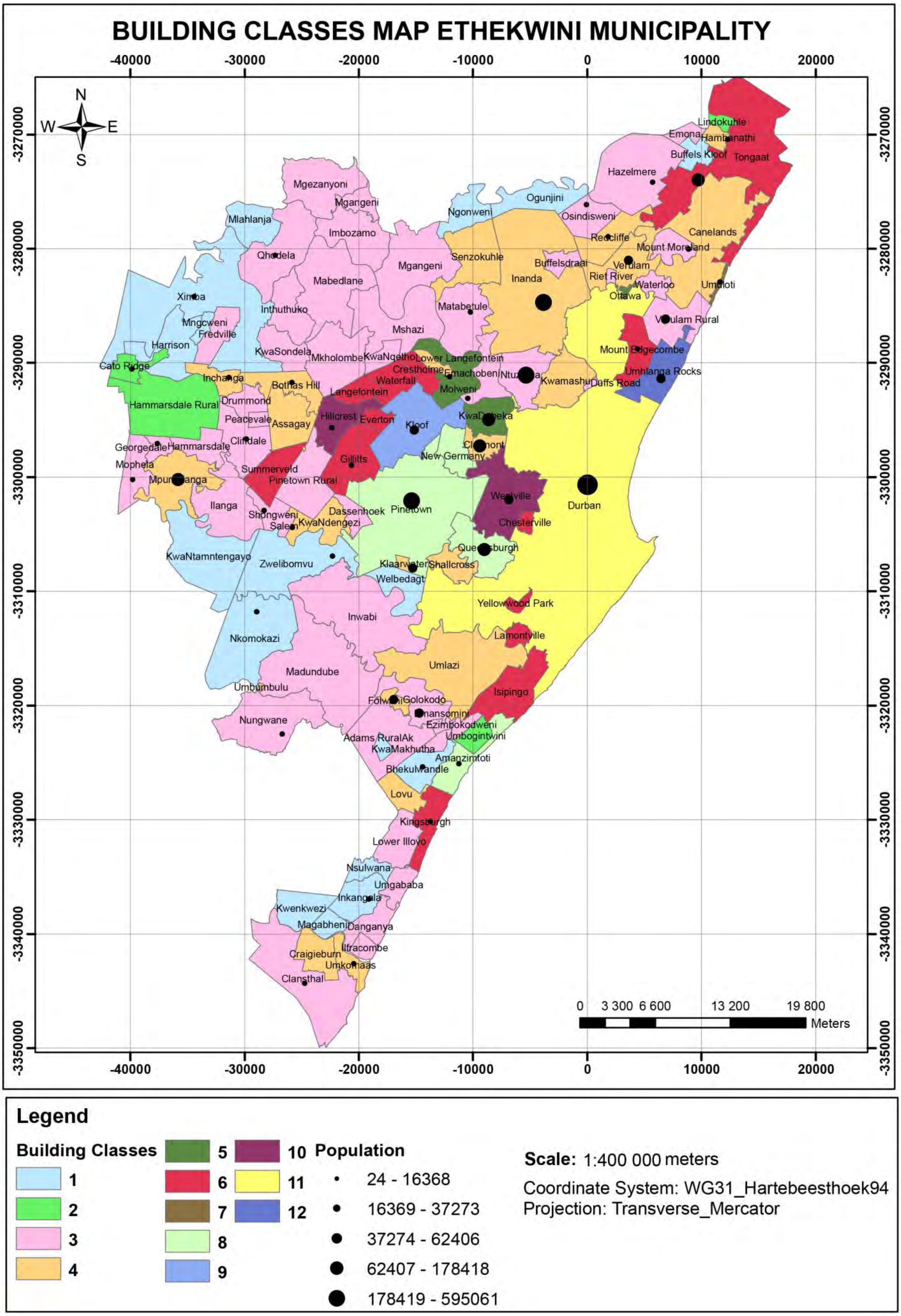

Figure 4-25 Map of Building Classes for the eThekwini Municipality Area

Figure 4-26 indicates the annual expected damage according to the different building classes. A colour code that goes from green (lowest) to red (highest), represents the risk that each district is facing.

A table containing the values of building classes and annual expected damage with their corresponding district is presented in Annex D.

The spatial analysis shows predominance of the building classes 3 and 4 (Unreinforced Masonry (URM) Structures Type), which are the classes with the highest percentages of damage after building class 5.

It should be noted that these assumptions may have low reliability. The purpose of these assumptions is to illustrate the results spatially. Specific assessments should be made in order to improve accuracy.

As it is shown in Table 4-6, 46 out of 117 districts in which the eThekwini Municipality area has been divided, has structures classified as building class 3 (Unreinforced Masonry Bearing Wall, Low Rise).

Table 4-6 Total Number of Districts per Building Class

BUILDING CLASS	NUMBER OF DISTRICTS
1	18
2	4
3	46
4	23
5	3
6	13
7	1
8	4
9	1
10	2
11	1
12	1
TOTAL	**117**

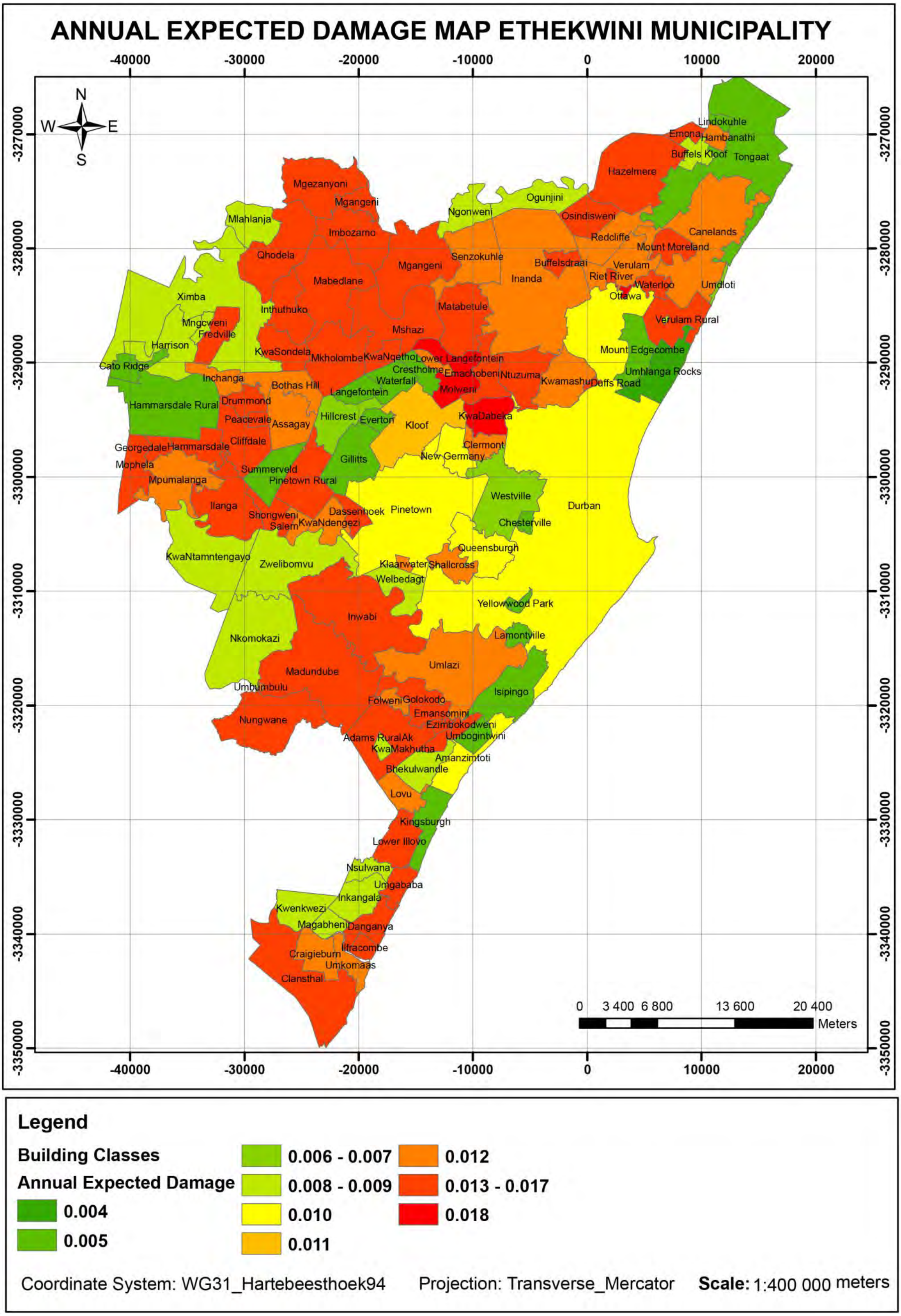

Figure 4-26 Map of Annual Expected Damage for 12 Building Classes Typical of the eThekwini Municipality Area

From Table 4-6, the following pie chart can be obtained. Figure 4-27 indicates the distribution of the building classes in the districts of the eThekwini Municipality. For example, building class 3 predominates in 39% of the districts, and building class 12 in 1% of the districts.

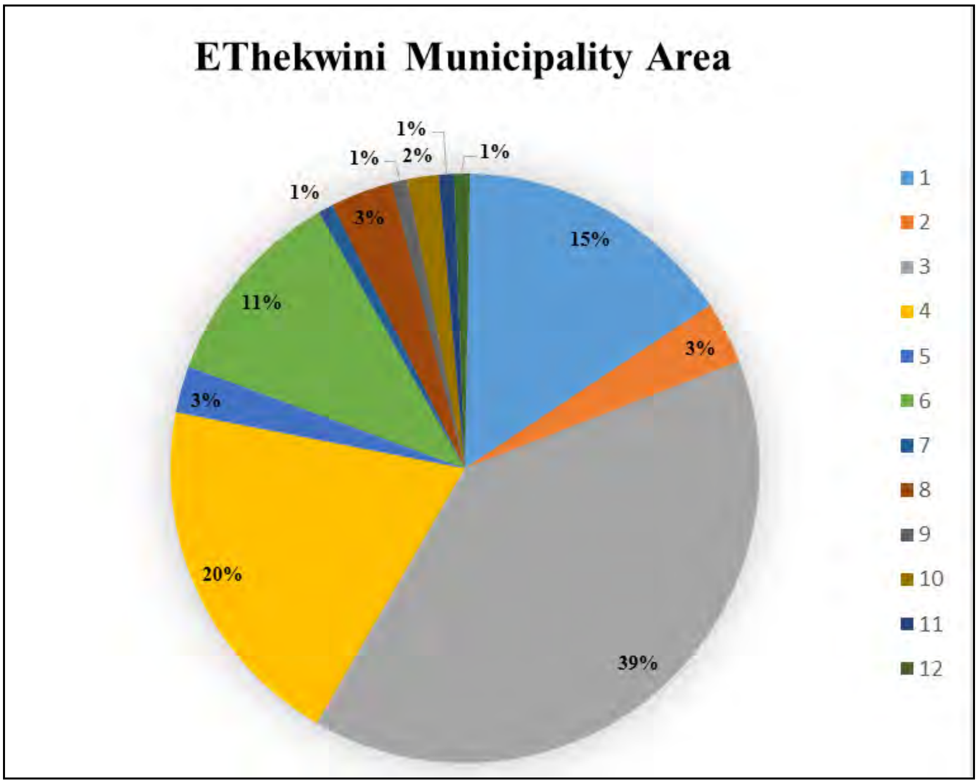

Figure 4-27 Building Classes Pie Chart

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

This study sought to answer the following specific question:

What is the probability that buildings will be damaged due to earthquakes in the eThekwini Municipality area?

The answer to that question involved exploring seismic risk in the eThekwini Municipality according to buildings classes in South Africa.

The major data issues identified in this research were the lack of practical availability of detail building information for the area and the non-existence of building information in digital format. Collation of such digital data for the study area was beyond the scope of this project.

Another limitation on this research was earthquake data. More seismic stations need to be installed in the area to provide such data.

As noted in Chapter 2, most of the seismic risk assessment methodologies require detailed building information data. The methodology chosen to carry out this research was ideal for areas that does not have this kind of information.

A probabilistic seismic hazard assessment and a seismic vulnerability assessment were performed to calculate a probabilistic seismic risk assessment.

In order to perform a probabilistic seismic hazard assessment, use was made of the classical Ambraseys (1974) relationship between PGA and intensity I. Assumptions were made to choose this relation from the several that exist. It will be important to make a comparison between the different relations that can be used and analyse the results.

The seismic hazard assessment was expressed in the form of a seismic hazard curve. This showed the annual probability of exceeding a specified ground motion parameter at least once for the area. This graph can be used to support decisions on whether the design of a structure is acceptable or not in terms of earthquake safety.

This research also provided quantification of the amount of annual damage associated with seismic activity in the eThekwini Municipality area. The expected damage for twelve building classes is shown in Chapter 4.

The extent of damage that a building can reasonably be expected to sustain during a seismic event can then be deduced.

The building classes that were found to potentially suffer the highest proportion of damage were Unreinforced Masonry (URM) Structures (Building Classes 3, 4 and 5). In the studies done by Pule (2014) and Van der Kolf (2014), it was established as well that unreinforced masonry buildings are usually more vulnerable to seismic damage. In South Africa, URM structures are commonly used and it should be a concern when appropriate design procedures are not followed for such structures.

Another challenge faced by this study was the assessment of seismic hazard when seismic source zones are not defined. Instead, to account for the local tectonic hazards in the area, seismic source zones should be defined (Singh et al., 2014).

This research found that for a “severe” earthquake of MM Intensity VIII, for which severe damage to buildings is expected, there is a very low annual probability of occurrence of $1.90e^{-6}$ with a return period of 527 000 years. However, for a “very strong” earthquake of MM Intensity VII, there is an annual probability of occurrence of $5.85e^{-5}$ with a return period of 17 100 years, in which up to 80% of all structures could experience light damage. Three earthquakes of MM intensity VII have been recorded between the 20th and 21st Century in South Africa.

It is important to collected detail building type data for the eThekwini Municipality area in a digital format and make it available for seismic risk research.

Also, it is important to develop building vulnerability curves. This would improve the reliability of the calculations and improve the confidence of the predicted damage. It will improve the accuracy of damage assessments in earthquakes events such as the event on the 5th of August of 2014 in Orkney, where there was extensive damage to buildings in Orkney and the surrounding areas.

Due to the location of the area of study, tsunami risk should also be taken into consideration for risk assessments.

Although the risk assessment showed an annual expected damage of 1.7% to buildings of Class 5 as the highest out of all the building classes, one should also bear in mind that historically there have indeed been potentially destructing earthquakes in the region. Also the seismic catalogue is very incomplete and the method followed in this study might not provide an accurate perception of the risk.

The results of this project could be used with an assessment of the total estate and commercial value of eThekwini to calculate the expected financial loss of the entire area. Such results could then be used by government to guide investors and stakeholders of the level of risk.

Risk analysis is an essential decision-making support mechanism during planning and development procedures. It is important for local authorities to undertake such analyses.

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APPENDICES

APPENDIX A: MODIFIED MERCALLI INTENSITY SCALE (MMI)

Source: Adapted from Sieberg's Mercalli-Cancani scale (Sieberg, A., 1923, "Erdbebenkunde", Jena, Ficher, August), modified and condensed; Quoted from Wood, H.O., and Neumann, F., 1931. "Modified Mercalli Intensity Scale of 1931", Bulletin of the Seismological Society of America, Vol. 21, No. 4, pp. 277-283.

MMI	INTENSITIES AND FULL DESCRIPTIONS
I	• Not felt - or, except rarely under especially favourable circumstances. Under certain conditions, at and outside the boundary of the area in which a great shock is felt. • Sometimes birds, animals, reported uneasy or disturbed; • sometimes dizziness or nausea experienced; • Sometimes trees, structures, liquids, bodies of water, may sway doors may swing, very slowly.
II	• Felt indoors by few, especially on upper floors, or by sensitive, or nervous Persons. Also, as in grade I, but often more noticeable. • Sometimes hanging objects may swing, especially when delicately suspended; • Sometimes trees, structures, liquids, bodies of water, may sway, doors may swing, very slowly; • Sometimes birds, animals, reported uneasy or disturbed; • Sometimes dizziness or nausea experienced.
III	• Felt indoors by several, motion usually rapid vibration. • Sometimes not recognized to be an earthquake at first. • Duration estimated in some cases. • Vibration like that due to passing of light or lightly loaded trucks, or • Heavy trucks some distance away. • Hanging objects may swing slightly. • Movement may be appreciable on upper levels of tall structures. • Rocks standing motor cars slightly.
IV	• Felt indoors by many, outdoors by few. • Awakening a few, especially light sleepers. • Vibration like that due to passing of heavy or heavily loaded trucks.

	• Sensations like heavy body striking building, or falling of heavy objects inside. • Rattling of dishes, windows, doors; glassware and crockery clink and clash. • Creaking of walls, frame, especially in the upper range of this grade. • Hanging objects swing in numerous instances. • Slightly disturbs liquids in open vessels. • Rocks standing motor cars slightly.
V	• Felt indoors by practically all, outdoors by many or most: outdoors direction estimated. • Awakens many, or most. • Frightens few – slight excitement, a few ran outdoors. • Buildings tremble throughout. • Breaks dishes, glassware, to some extent. • Cracks windows – in some cases, but not generally. • Overturns small or unstable objects, in many instances, with occasional fall. • Hanging objects, doors, swing generally or considerably. • Knocks pictures against walls, or swings them out of place. • Opens or closes, doors, shutters, abruptly. • Pendulum clocks stop, start, or run fast, or slow. • Moves small objects, furnishings, the latter to slight extent. • Spills liquids in small amounts from well filled open containers. • Trees, bushes shaken slightly.
VI	• Felt by all, indoors and outdoors. • Frightens many, excitement general, some alarm, many ran outdoors. Awakens all. • Persons made to move unsteadily. • Trees, bushes, shaken slightly to moderately. • Liquid set in strong motion. • Small bells rung –church, chapel, school etc. • Damage slight in poorly built buildings. • Fall of plaster in small amount. • Cracks plaster somewhat, especially fine cracks in chimneys in some instances. • Breaks dishes, glassware, in considerably quantity, also some windows. • Fall of ornaments, books, pictures. • Overturns furniture in many instances. • Moves furnishings of moderately heavy kind.

VII	• Frightens all – general alarm, all run outdoors. • Some or many find it difficult to stand. • Noticed by persons driving motor cars. • Trees and bushes shaken moderately to strongly. • Waves on ponds, lakes, and running water. • Water turbid from stirred up mud. • Caving in of sand or gravel stream banks to some extent. • Rings large church bells, etc. • Suspended objects made to quiver. • Damage negligible in buildings of good design and construction, slight to moderate in well-built ordinary buildings, considerable in poorly built or badly designed buildings, abode houses, old walls (especially where laid up without mortar), spires, etc. • Cracked chimneys to a considerable extent, walls to some extent. • Fall of plaster in considerable to large amount, also some stucco. • Breaks numerous windows, furniture to some extent. • Shakes down loosened brickwork and tiles. • Breaks weak chimneys at the roof-line (sometimes damaging roofs). Fall of cornices from towers and high buildings. • Dislodged bricks and stones. • Overturns heavy furniture, with damage from breaking. • Damage to concrete irrigation ditches considerable.
VIII	• General fright – alarm approaches panic. • Disturbs persons driving motor cars. • Trees shaken strongly – branches, trunks, broken, especially palm trees. • Ejected sand and mud in small amounts. • Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters. • Damage slight in structures (brick) especially built to withstand earthquakes. • Considerable in ordinary substantial buildings, partial collapse: racks, tumbles down, wooden houses in some cases; throws out panel walls in frame structures, breaks off decayed piling. Walls topple. • Cracks and breaks solid stone walls seriously. • Wet ground to some extent, also ground on steep slopes. • Twisting and fall of chimneys, columns, monuments, also factory stacks and

	towers. • Moves conspicuously and overturns very heavy furniture.
IX	• General panic. • Ground cracks conspicuously. • Damage considerable in (masonry) structure built especially to withstand earthquakes. • Throws out plumb some wood-frame houses built especially to withstand earthquakes. • Great in substantial (masonry) buildings, some collapse in large parts; or wholly shifts frame buildings off foundations, rack frames; serious to reservoirs; underground pipes sometimes broken.
X	• Cracked ground, especially when loose and wet, up to a width of several inches; fissures up to a yard in width run parallel to canal and stream banks. • Landslides considerable from river banks and steep coasts. • Sand and mud shifts horizontally on beaches and flat land. • Changed level of water in wells. • Throws water on banks of canals, lakes, rivers, etc. • Serious damage to dams, dikes, embankments. • Damage severe to well-built wooden structures and bridges, some destroyed. • Causing dangerous cracks to develop in excellent brick work. • Destroys most masonry and frame structures and their foundations. • Bends railroad rails slightly. • Tears apart, or crushes endwise pipe lines buried in earth. • Open cracks and broad wavy folds in cement pavements and asphalt road surfaces.
XI	• Disturbances in ground many and widespread, varying with ground material. • Broad and fissures, earth slumps, and land slips in soft, wet ground. • Ejected water in large amounts charged with sand and mud. • Causes sea-waves (“tidal” waves) of significant magnitude. • Damage severe to wood-frame structures, especially near shock centres. • Damage great to dams, dikes, embankments, often for long distances. • Few, if any (masonry), structures remained standing. • Destroys large well-built bridges by wrecking or supporting piers or pillars. • Affects yielding wooden bridges less. • Bends railroad rails greatly and thrusts them endwise.

	• Forces pipe lines buried in earth completely out of service.
XII	• Damage total – practically all works of construction greatly damaged or destroyed. • Disturbances in ground great and varied, numerous shearing cracks. Landslides, falls of rock of significant character, slumping of river banks, etc. numerous and extensive. • Wrenches loose, tears off, large rock masses. • Fault slips in firm rock develops, with notable horizontal and vertical offset displacements. • Water channels, surface and underground, disturbed and modified greatly. • Dams lakes, produces waterfalls, deflects rivers, etc. • Waves seen on ground surfaces (actually seen in some cases). • Distorts line of sight and level. • Throws objects upward into the air.

APPENDIX B: OUTPUT FILES FOR PSRA

The results of the seismic risk assessment using the HRS program are provided in this Appendix.

```
=========================================================================
 File       : Probabilistic Seismic Risk Assessment for EThekwini
 Created on : 06-Mar-2015 15:06:53
=========================================================================

 SEISMIC HAZARD AND RISK ASSESSMENT FOR SPECIFIED SITE

 HAZARD calculation is based on LARGEST PGA-s recorded at the site
 HAZARD IS EXPRESSED IN TERMS OF PGA and ACCELERATION RESPONSE SPECTRA

 SITE specific seismic hazard parameters are estimated by
 the maximum likelihood procedure. Maximum of likelihood function
 is calculated by solution of system of two equations similar to that
 derived by A.Kijko & M.Dessokey (1987), Bull.Seis.Soc.Am, vol.77,
No.4.


 Current version of the code takes into account:

    - uncertainty in seismic event epicenter location,
    - uncertainty in determination of seismic event magnitude,
    - uncertainty of PGA attenuation equation.


 The methodology applied is described in :


  "PARAMETRIC-HISTORIC" PROCEDURE FOR PROBABILISTIC SEISMIC HAZARD
ANALYSIS

   PART I  : Assessment of the maximum regional magnitude Mmax,
   (Pure App. Geophys. vol. 152, p.413-442, 1998)

   PART II : Assessment of seismic hazard at specified site.
   (Pure App. Geophys. vol. 154, p.1-22, 1999)


PROGRAM ACCEPTS 2 TYPES OF INPUT DATA:


   (1) Seismic event catalogues containing information on the strongest
       events occurred in the vicinity of the site. It is assumed that
       for each seismic event, the following parameters are known:
       - origin time,
       - size of seismic event (in terms of magnitude or focal
intensity),
       - spatial location (Latitude, Longitude, Depth).

   (2) Seismic zones in the vicinity of the site. Each seismic zone
       is described by 7 parameters: its Latitude, Longitude, mean EQ-e
depth,
```

```
       Mean Activity Rate LAMBDA, b-value of the frequency-magnitude
       Gutenberg-Richter relation, minimum magnitude Mmin,
       and the maximum, zone-characteristic EQ-e magnitude Mmax.


Calculation of SEISMIC RISK based on calculated seismic hazard
parameters.
Current version of the code calculates and plots Seismic Risk in terms
of:

    - CENTRAL DAMAGE FACTOR for 12 of 25 CLASSES,
    - PROBABILITY OF EXCEEDANCE OF DAMAGE for 12 of 25 CLASSES,
    - MEAN OF CENTRAL DAMAGE FACTOR.
    - PROBABILITY OF EXCEEDANCE OF MEAN DAMAGE.

=======================================================================


 PROGRAM NAME     : HRS (H = Hazard; R = Risk; S = Site)
 WRITTEN          : 15 AUG 1999 by A.K.
 REVISED          : 02 APR 2005
                  : 30 MAY 2005
                  : 19 AUG 2005
                  : 01 JAN 2006
                  : 05 JAN 2006
                  : 20 AUG 2006
                  : 15 NOV 2010
                  : 23 NOV 2010
 VERSION          : 3.04

=======================================================================

 For more information, contact A. Kijko
 University of Pretoria
 Mineral Sciences Building Room 4-30 Pretoria 0002, South Africa.

 Phone  :  +(27) (0) 12 420-3613
 Fax    :  +(27) (0) 12 362-5219
 E-mail :  andrzej.kijko@up.ac.za

=======================================================================

  SEISMIC HAZARD ASSESSMENT BY PARAMETRIC-HISTORIC PROCEDURE
 ============================================================


 NAME OF THE SITE    : EThekwini
 NAME OF THE DATABASE: cat.txt

 DATABASE STARTS (Y-M-D)         =  1902  5 28
 DATABASE ENDS   (Y-M-D)         =  2006  3 31
 TIME SPAN OF THE DATABASE       = 103.84 [Y]
 NUMBER OF EQ-s in THE DATABASE = 9896
 LARGEST EQ IN THE DATABASE     = 7.2

 FILE NAME WITH ATTENUATION COEFFICIENTS c1,...,c5: att.txt

                 ATTENUATION COEFFICIENTS
```

==============================

Freq. (Hz)	c1	c2	c3	c4	c5
0.5	-10.798	1.614	0.0042	-1.250	0.244
1.0	-9.213	1.531	0.0040	-1.237	0.179
2.0	-7.280	1.393	0.0032	-1.228	0.169
3.0	-5.927	1.276	0.0028	-1.259	0.168
5.0	-4.380	1.123	0.0021	-1.283	0.167
7.9	-3.453	1.042	0.0006	-1.279	0.177
10.0	-3.123	1.039	0.0002	-1.324	0.204
13.0	-2.749	0.983	-0.0011	-1.283	0.184
20.0	-2.346	0.968	-0.0033	-1.289	0.200
99.9	-2.682	0.980	0.0006	-1.522	0.187

PGA is converted into MM Intensity according to Ambraseys (1974)

RANGE OF OBSERVATIONS TO BE USED IN CALCULATIONS SPECIFIED AS : MEDIUM

PROVISION FOR INDUCED SEISMICITY : NOT REQUIRED
===

Benders correction of mean acativity rate LAMBDA is NOT taken into account
[For details see paper by B.Bender, BSSA, vol.74, pp.1451-1462, 1984]

SITE SPECIFIC DATA
========================

NAME OF THE SITE-SPECIFIC INPUT FILE: ssp.txt

```
SITE COORDINATES (LATITUDE)                = -29.860 [DEG]
SITE COORDINATES (LONGITUDE)               =  31.010 [DEG]

b-VALUE OF THE GUTENBERG-RICHTER           = 0.96  SD = 0.10
MODEL UNCERTAINTY OF THE b-VALUE           = 25  [per cent]
MODEL UNCERTAINTY OF SITE-SPECIFIC LAMBDA = 97  [per cent]
UNCERTAINTY OF EQ-e EPICENTER LOCATION     = 10  [KM]
STANDARD ERROR OF EQ-e MAG DETERMINATION   = 0.20
MAXIMUM REGIONAL MAGNITUDE Mmax            = 6.42  SD = 0.10
MAXIMUM EPICENTRAL DISTANCE                = 300.0 [KM]
EPI. DISTANCE OF THE FLOATING EQ-e         = 25.0  [KM]
DEPTH OF THE FLOATING EQ-e                 = 2.5  [KM]
SD(HYP. DISTANCE OF THE FLOATING EQ-e)     = 25.0   [KM]
LARGEST PGA-s ARE SELECTED FROM TIME INT. = 1.00  [Y]
```

MIN PGA = 0.0010 [g]

MAX PGA = 0.4342 [g] (MAG = 6.4, EPI.DIS. = 25.0, DEPTH = 2.5 [KM])

MAX OBS.PGA #1 = 0.01 [g] (Y-M-D = 1932 12 31; EPI.DIS. = 225.8; MAG = 6.3)
MAX OBS.PGA #2 = 0.01 [g] (Y-M-D = 1919 10 31; EPI.DIS. = 321.4; MAG = 6.5)

NUMBER OF EQ-s USED IN CALCULATIONS = 11

ALL CALCULATIONS ARE PERFORMED FOR MEAN VALUE OF ln[PGA]

RESULTS

=============

GAMMA = 2.26 +- 0.23 (BETA = 2.21 +- 0.22, b = 0.96 +- 0.10)
LAMBDA = 0.916 +- 0.463 (for Min(PGA) = 0.0010 [g])

Max PGA [MEDIAN VALUE] = 0.434 [g]
Max PGA [QUANTILE 84 percent] = 1.869 [g]

SEISMIC HAZARD CHARACTERISTICS (in terms of PGA [g])

==

PGA[g]	Lambda	RP[Y]	Prob(T = 1	50	100	1000)
0.001	9.1564e-01	1.09e+00	0.48337	0.98211	0.99133	0.99924
0.005	3.4706e-02	2.88e+01	0.03357	0.64257	0.78598	0.97617
0.010	1.0152e-02	9.85e+01	0.01005	0.33962	0.50964	0.91827
0.015	5.1416e-03	1.94e+02	0.00512	0.20566	0.34254	0.84667
0.020	3.2196e-03	3.11e+02	0.00321	0.13920	0.24515	0.77262
0.025	2.2552e-03	4.43e+02	0.00225	0.10163	0.18496	0.70179
0.030	1.6925e-03	5.91e+02	0.00169	0.07820	0.14534	0.63667
0.035	1.3307e-03	7.51e+02	0.00133	0.06250	0.11784	0.57804
0.040	1.0818e-03	9.24e+02	0.00108	0.05139	0.09790	0.52581
0.045	9.0187e-04	1.11e+03	0.00090	0.04320	0.08292	0.47952
0.050	7.6664e-04	1.30e+03	0.00077	0.03696	0.07135	0.43854
0.055	6.6190e-04	1.51e+03	0.00066	0.03206	0.06219	0.40223
0.060	5.7876e-04	1.73e+03	0.00058	0.02815	0.05480	0.37000
0.065	5.1140e-04	1.96e+03	0.00051	0.02495	0.04872	0.34131
0.070	4.5588e-04	2.19e+03	0.00046	0.02230	0.04366	0.31570
0.075	4.0946e-04	2.44e+03	0.00041	0.02007	0.03938	0.29274
0.080	3.7015e-04	2.70e+03	0.00037	0.01818	0.03573	0.27210
0.085	3.3650e-04	2.97e+03	0.00034	0.01655	0.03259	0.25348
0.090	3.0741e-04	3.25e+03	0.00031	0.01514	0.02985	0.23663
0.095	2.8204e-04	3.55e+03	0.00028	0.01391	0.02745	0.22132
0.100	2.5976e-04	3.85e+03	0.00026	0.01283	0.02534	0.20737
0.105	2.4006e-04	4.17e+03	0.00024	0.01186	0.02346	0.19462
0.110	2.2252e-04	4.49e+03	0.00022	0.01101	0.02178	0.18294
0.115	2.0683e-04	4.83e+03	0.00021	0.01024	0.02028	0.17220
0.120	1.9271e-04	5.19e+03	0.00019	0.00955	0.01892	0.16231
0.125	1.7996e-04	5.56e+03	0.00018	0.00892	0.01769	0.15317
0.130	1.6838e-04	5.94e+03	0.00017	0.00835	0.01657	0.14470
0.135	1.5784e-04	6.34e+03	0.00016	0.00783	0.01555	0.13685
0.140	1.4820e-04	6.75e+03	0.00015	0.00736	0.01461	0.12954
0.145	1.3935e-04	7.18e+03	0.00014	0.00692	0.01375	0.12273
0.150	1.3121e-04	7.62e+03	0.00013	0.00652	0.01296	0.11638
0.155	1.2370e-04	8.08e+03	0.00012	0.00615	0.01222	0.11043
0.160	1.1675e-04	8.57e+03	0.00012	0.00580	0.01154	0.10486
0.165	1.1030e-04	9.07e+03	0.00011	0.00549	0.01091	0.09962
0.170	1.0430e-04	9.59e+03	0.00010	0.00519	0.01033	0.09470
0.175	9.8707e-05	1.01e+04	0.00010	0.00491	0.00978	0.09007
0.180	9.3484e-05	1.07e+04	0.00009	0.00465	0.00926	0.08570
0.185	8.8596e-05	1.13e+04	0.00009	0.00441	0.00878	0.08158
0.190	8.4012e-05	1.19e+04	0.00008	0.00418	0.00833	0.07767
0.195	7.9707e-05	1.25e+04	0.00008	0.00397	0.00791	0.07398

0.200	7.5655e-05	1.32e+04	0.00008	0.00377	0.00751	0.07048
0.205	7.1837e-05	1.39e+04	0.00007	0.00358	0.00713	0.06715
0.210	6.8234e-05	1.47e+04	0.00007	0.00340	0.00678	0.06399
0.215	6.4828e-05	1.54e+04	0.00006	0.00323	0.00644	0.06099
0.220	6.1604e-05	1.62e+04	0.00006	0.00307	0.00612	0.05813
0.225	5.8549e-05	1.71e+04	0.00006	0.00292	0.00582	0.05540
0.230	5.5649e-05	1.80e+04	0.00006	0.00277	0.00554	0.05280
0.235	5.2895e-05	1.89e+04	0.00005	0.00264	0.00526	0.05031
0.240	5.0275e-05	1.99e+04	0.00005	0.00251	0.00500	0.04794
0.245	4.7780e-05	2.09e+04	0.00005	0.00238	0.00476	0.04566
0.250	4.5403e-05	2.20e+04	0.00005	0.00227	0.00452	0.04349
0.255	4.3134e-05	2.32e+04	0.00004	0.00215	0.00430	0.04140
0.260	4.0967e-05	2.44e+04	0.00004	0.00204	0.00408	0.03940
0.265	3.8896e-05	2.57e+04	0.00004	0.00194	0.00387	0.03748
0.270	3.6914e-05	2.71e+04	0.00004	0.00184	0.00368	0.03564
0.275	3.5017e-05	2.86e+04	0.00004	0.00175	0.00349	0.03387
0.280	3.3198e-05	3.01e+04	0.00003	0.00166	0.00331	0.03216
0.285	3.1454e-05	3.18e+04	0.00003	0.00157	0.00314	0.03052
0.290	2.9779e-05	3.36e+04	0.00003	0.00149	0.00297	0.02894
0.295	2.8171e-05	3.55e+04	0.00003	0.00141	0.00281	0.02742
0.300	2.6625e-05	3.76e+04	0.00003	0.00133	0.00266	0.02595
0.305	2.5137e-05	3.98e+04	0.00003	0.00126	0.00251	0.02454
0.310	2.3706e-05	4.22e+04	0.00002	0.00118	0.00237	0.02317
0.315	2.2327e-05	4.48e+04	0.00002	0.00112	0.00223	0.02185
0.320	2.0998e-05	4.76e+04	0.00002	0.00105	0.00210	0.02058
0.325	1.9716e-05	5.07e+04	0.00002	0.00098	0.00197	0.01935
0.330	1.8479e-05	5.41e+04	0.00002	0.00092	0.00184	0.01815
0.335	1.7285e-05	5.79e+04	0.00002	0.00086	0.00173	0.01700
0.340	1.6132e-05	6.20e+04	0.00002	0.00081	0.00161	0.01588
0.345	1.5017e-05	6.66e+04	0.00002	0.00075	0.00150	0.01480
0.350	1.3939e-05	7.17e+04	0.00001	0.00070	0.00139	0.01375
0.355	1.2896e-05	7.75e+04	0.00001	0.00064	0.00129	0.01274
0.360	1.1887e-05	8.41e+04	0.00001	0.00059	0.00119	0.01175
0.365	1.0909e-05	9.17e+04	0.00001	0.00055	0.00109	0.01079
0.370	9.9615e-06	1.00e+05	0.00001	0.00050	0.00100	0.00987
0.375	9.0433e-06	1.11e+05	0.00001	0.00045	0.00090	0.00896
0.380	8.1529e-06	1.23e+05	0.00001	0.00041	0.00081	0.00809
0.385	7.2891e-06	1.37e+05	0.00001	0.00036	0.00073	0.00724
0.390	6.4507e-06	1.55e+05	0.00001	0.00032	0.00064	0.00641
0.395	5.6368e-06	1.77e+05	0.00001	0.00028	0.00056	0.00561
0.400	4.8461e-06	2.06e+05	0.00000	0.00024	0.00048	0.00482
0.405	4.0779e-06	2.45e+05	0.00000	0.00020	0.00041	0.00406
0.410	3.3312e-06	3.00e+05	0.00000	0.00017	0.00033	0.00332
0.415	2.6051e-06	3.84e+05	0.00000	0.00013	0.00026	0.00260
0.420	1.8988e-06	5.27e+05	0.00000	0.00009	0.00019	0.00190
0.425	1.2115e-06	8.25e+05	0.00000	0.00006	0.00012	0.00121

SEISMIC HAZARD CHARACTERISTICS (in terms of MMI)

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MM Intensity	PROB	Activity Rate [EQ/YEAR]	RP [YEARS]
4.0	3.21e-03	3.22e-03	3.11e+02
4.3	2.25e-03	2.26e-03	4.43e+02
4.5	1.69e-03	1.69e-03	5.91e+02
4.7	1.33e-03	1.33e-03	7.51e+02

4.9	1.08e-03	1.08e-03	9.24e+02
5.0	9.01e-04	9.02e-04	1.11e+03
5.1	7.66e-04	7.67e-04	1.30e+03
5.3	6.61e-04	6.62e-04	1.51e+03
5.4	5.78e-04	5.79e-04	1.73e+03
5.5	5.11e-04	5.11e-04	1.96e+03
5.5	4.56e-04	4.56e-04	2.19e+03
5.6	4.09e-04	4.09e-04	2.44e+03
5.7	3.70e-04	3.70e-04	2.70e+03
5.8	3.36e-04	3.36e-04	2.97e+03
5.9	3.07e-04	3.07e-04	3.25e+03
5.9	2.82e-04	2.82e-04	3.55e+03
6.0	2.60e-04	2.60e-04	3.85e+03
6.0	2.40e-04	2.40e-04	4.17e+03
6.1	2.22e-04	2.23e-04	4.49e+03
6.1	2.07e-04	2.07e-04	4.83e+03
6.2	1.93e-04	1.93e-04	5.19e+03
6.2	1.80e-04	1.80e-04	5.56e+03
6.3	1.68e-04	1.68e-04	5.94e+03
6.3	1.58e-04	1.58e-04	6.34e+03
6.4	1.48e-04	1.48e-04	6.75e+03
6.4	1.39e-04	1.39e-04	7.18e+03
6.5	1.31e-04	1.31e-04	7.62e+03
6.5	1.24e-04	1.24e-04	8.08e+03
6.5	1.17e-04	1.17e-04	8.57e+03
6.6	1.10e-04	1.10e-04	9.07e+03
6.6	1.04e-04	1.04e-04	9.59e+03
6.7	9.87e-05	9.87e-05	1.01e+04
6.7	9.35e-05	9.35e-05	1.07e+04
6.7	8.86e-05	8.86e-05	1.13e+04
6.8	8.40e-05	8.40e-05	1.19e+04
6.8	7.97e-05	7.97e-05	1.25e+04
6.8	7.56e-05	7.57e-05	1.32e+04
6.8	7.18e-05	7.18e-05	1.39e+04
6.9	6.82e-05	6.82e-05	1.47e+04
6.9	6.48e-05	6.48e-05	1.54e+04
6.9	6.16e-05	6.16e-05	1.62e+04
7.0	5.85e-05	5.85e-05	1.71e+04
7.0	5.56e-05	5.56e-05	1.80e+04
7.0	5.29e-05	5.29e-05	1.89e+04
7.0	5.03e-05	5.03e-05	1.99e+04
7.1	4.78e-05	4.78e-05	2.09e+04
7.1	4.54e-05	4.54e-05	2.20e+04
7.1	4.31e-05	4.31e-05	2.32e+04
7.1	4.10e-05	4.10e-05	2.44e+04
7.2	3.89e-05	3.89e-05	2.57e+04
7.2	3.69e-05	3.69e-05	2.71e+04
7.2	3.50e-05	3.50e-05	2.86e+04
7.2	3.32e-05	3.32e-05	3.01e+04
7.2	3.15e-05	3.15e-05	3.18e+04
7.3	2.98e-05	2.98e-05	3.36e+04
7.3	2.82e-05	2.82e-05	3.55e+04
7.3	2.66e-05	2.66e-05	3.76e+04
7.3	2.51e-05	2.51e-05	3.98e+04
7.3	2.37e-05	2.37e-05	4.22e+04
7.4	2.23e-05	2.23e-05	4.48e+04
7.4	2.10e-05	2.10e-05	4.76e+04
7.4	1.97e-05	1.97e-05	5.07e+04

7.4	1.85e-05	1.85e-05	5.41e+04
7.4	1.73e-05	1.73e-05	5.79e+04
7.5	1.61e-05	1.61e-05	6.20e+04
7.5	1.50e-05	1.50e-05	6.66e+04
7.5	1.39e-05	1.39e-05	7.17e+04
7.5	1.29e-05	1.29e-05	7.75e+04
7.5	1.19e-05	1.19e-05	8.41e+04
7.5	1.09e-05	1.09e-05	9.17e+04
7.6	9.96e-06	9.96e-06	1.00e+05
7.6	9.04e-06	9.04e-06	1.11e+05
7.6	8.15e-06	8.15e-06	1.23e+05
7.6	7.29e-06	7.29e-06	1.37e+05
7.6	6.45e-06	6.45e-06	1.55e+05
7.6	5.64e-06	5.64e-06	1.77e+05
7.6	4.85e-06	4.85e-06	2.06e+05
7.7	4.08e-06	4.08e-06	2.45e+05
7.7	3.33e-06	3.33e-06	3.00e+05
7.7	2.61e-06	2.61e-06	3.84e+05
7.7	1.90e-06	1.90e-06	5.27e+05
7.7	1.21e-06	1.21e-06	8.25e+05

=== ANNUAL EXPECTED DAMAGE - RESULTS ===

BUILDING CLASS #1
=============================

Annual Prob. [PERCENT]	Expected Damage [PERCENT]	+/- SD	
0.000	22.0	12.3	31.7
0.002	21.0	11.6	30.4
0.005	20.0	10.9	29.1
0.008	19.0	10.2	27.8
0.011	18.0	9.5	26.5
0.014	17.0	8.8	25.2
0.017	16.0	8.2	23.8
0.020	15.0	7.5	22.5
0.024	14.0	6.8	21.2
0.028	13.0	6.2	19.8
0.032	12.0	5.6	18.4
0.037	11.0	5.0	17.0
0.041	10.0	4.3	15.7
0.046	9.0	3.7	14.3
0.052	8.0	3.2	12.8
0.057	7.0	2.6	11.4
0.063	6.0	2.0	10.0
0.069	5.0	1.4	8.6
0.075	4.0	0.9	7.1
0.081	3.0	0.3	5.7
0.088	2.0	0.0	4.2
0.095	1.0	0.0	2.7
0.102	0.0	0.0	1.3

BUILDING CLASS #1   ANNUAL EXPECTED DAMAGE [PERCENT] = 0.0091659

BUILDING CLASS #2

Annual Prob. [PERCENT]	Expected Damage [PERCENT]	+/- SD	
0.001	21.0	12.3	29.7
0.002	20.0	11.7	28.3
0.004	19.0	11.0	27.0
0.006	18.0	10.4	25.6
0.007	17.0	9.7	24.3
0.009	16.0	9.1	22.9
0.011	15.0	8.4	21.6
0.014	14.0	7.8	20.2
0.016	13.0	7.2	18.8
0.019	12.0	6.5	17.5
0.021	11.0	5.9	16.1
0.024	10.0	5.3	14.7
0.027	9.0	4.7	13.3
0.030	8.0	4.0	12.0
0.033	7.0	3.4	10.6
0.036	6.0	2.8	9.2
0.040	5.0	2.2	7.8
0.044	4.0	1.6	6.4
0.048	3.0	1.0	5.0
0.052	2.0	0.4	3.6
0.056	1.0	0.0	2.2
0.060	0.0	0.0	0.8

BUILDING CLASS #2 ANNUAL EXPECTED DAMAGE [PERCENT] = 0.0052903

BUILDING CLASS #3

Annual Prob. [PERCENT]	Expected Damage [PERCENT]	+/- SD	
0.003	22.0	12.0	32.0
0.007	21.0	11.3	30.7
0.012	20.0	10.6	29.4
0.017	19.0	10.0	28.0
0.022	18.0	9.3	26.7
0.028	17.0	8.6	25.4
0.034	16.0	7.9	24.1
0.040	15.0	7.2	22.8
0.047	14.0	6.5	21.5
0.055	13.0	5.9	20.1
0.062	12.0	5.2	18.8
0.070	11.0	4.5	17.5
0.079	10.0	3.8	16.2
0.088	9.0	3.1	14.9
0.097	8.0	2.4	13.6
0.107	7.0	1.7	12.3
0.117	6.0	1.0	11.0
0.128	5.0	0.3	9.7
0.139	4.0	0.0	8.4

0.151	3.0	0.0	7.1
0.163	2.0	0.0	5.8
0.176	1.0	0.0	4.5
0.189	0.0	0.0	3.2

BUILDING CLASS #3 ANNUAL EXPECTED DAMAGE [PERCENT] = 0.017389

BUILDING CLASS #4

Annual Prob. [PERCENT]	Expected Damage [PERCENT]	+/- SD	
0.001	22.0	10.0	34.0
0.004	21.0	9.4	32.6
0.008	20.0	8.8	31.2
0.012	19.0	8.2	29.8
0.015	18.0	7.6	28.4
0.020	17.0	7.0	27.0
0.024	16.0	6.5	25.5
0.029	15.0	5.9	24.1
0.034	14.0	5.4	22.6
0.039	13.0	4.9	21.1
0.045	12.0	4.3	19.7
0.051	11.0	3.8	18.2
0.057	10.0	3.3	16.7
0.064	9.0	2.8	15.2
0.071	8.0	2.3	13.7
0.078	7.0	1.9	12.1
0.086	6.0	1.4	10.6
0.093	5.0	0.9	9.1
0.102	4.0	0.5	7.5
0.111	3.0	0.0	6.0
0.120	2.0	0.0	4.4
0.129	1.0	0.0	2.9
0.139	0.0	0.0	1.3

BUILDING CLASS #4 ANNUAL EXPECTED DAMAGE [PERCENT] = 0.012607

BUILDING CLASS #5

Annual Prob. [PERCENT]	Expected Damage [PERCENT]	+/- SD	
0.001	23.0	11.0	35.0
0.005	22.0	10.4	33.6
0.009	21.0	9.8	32.2
0.013	20.0	9.2	30.8
0.018	19.0	8.6	29.4
0.024	18.0	8.0	28.0
0.029	17.0	7.4	26.6
0.035	16.0	6.9	25.1
0.042	15.0	6.3	23.7
0.048	14.0	5.8	22.2
0.056	13.0	5.2	20.8

0.063	12.0	4.7	19.3
0.071	11.0	4.1	17.9
0.080	10.0	3.6	16.4
0.088	9.0	3.1	14.9
0.098	8.0	2.6	13.4
0.107	7.0	2.1	11.9
0.117	6.0	1.6	10.4
0.128	5.0	1.1	8.9
0.139	4.0	0.7	7.3
0.151	3.0	0.2	5.8
0.163	2.0	0.0	4.3
0.175	1.0	0.0	2.7
0.188	0.0	0.0	1.2

BUILDING CLASS #5 ANNUAL EXPECTED DAMAGE [PERCENT] = 0.017546

BUILDING CLASS #6
=============================

Annual Prob. [PERCENT]	Expected Damage [PERCENT]	+/- SD	
0.001	21.0	12.4	29.6
0.003	20.0	11.6	28.4
0.005	19.0	10.9	27.1
0.006	18.0	10.2	25.8
0.009	17.0	9.5	24.5
0.011	16.0	8.8	23.2
0.013	15.0	8.1	21.9
0.016	14.0	7.4	20.6
0.018	13.0	6.8	19.2
0.021	12.0	6.1	17.9
0.024	11.0	5.5	16.5
0.027	10.0	4.9	15.1
0.030	9.0	4.2	13.8
0.034	8.0	3.6	12.4
0.037	7.0	3.0	11.0
0.041	6.0	2.4	9.6
0.045	5.0	1.8	8.2
0.049	4.0	1.3	6.7
0.054	3.0	0.7	5.3
0.058	2.0	0.1	3.9
0.063	1.0	0.0	2.4
0.068	0.0	0.0	0.9

BUILDING CLASS #6 ANNUAL EXPECTED DAMAGE [PERCENT] = 0.0059799

BUILDING CLASS #7
=============================

Annual Prob. [PERCENT]	Expected Damage [PERCENT]	+/- SD	
0.002	21.0	13.3	28.7
0.004	20.0	12.5	27.5
0.006	19.0	11.8	26.2

0.008	18.0	11.1	24.9
0.010	17.0	10.4	23.6
0.013	16.0	9.7	22.3
0.016	15.0	8.9	21.1
0.019	14.0	8.2	19.8
0.022	13.0	7.5	18.5
0.025	12.0	6.8	17.2
0.029	11.0	6.1	15.9
0.032	10.0	5.4	14.6
0.036	9.0	4.7	13.3
0.040	8.0	4.0	12.0
0.044	7.0	3.3	10.7
0.049	6.0	2.6	9.4
0.053	5.0	1.9	8.1
0.058	4.0	1.3	6.7
0.063	3.0	0.6	5.4
0.069	2.0	0.0	4.1
0.074	1.0	0.0	2.8
0.080	0.0	0.0	1.4

BUILDING CLASS #7 ANNUAL EXPECTED DAMAGE [PERCENT] = 0.0071149

BUILDING CLASS #8
=============================

Annual Prob. [PERCENT]	Expected Damage [PERCENT]	+/- SD	
0.000	22.0	12.9	31.1
0.003	21.0	12.2	29.8
0.006	20.0	11.5	28.5
0.009	19.0	10.8	27.2
0.012	18.0	10.1	25.9
0.016	17.0	9.4	24.6
0.020	16.0	8.7	23.3
0.024	15.0	8.1	21.9
0.028	14.0	7.4	20.6
0.033	13.0	6.7	19.3
0.037	12.0	6.1	17.9
0.042	11.0	5.4	16.6
0.048	10.0	4.8	15.2
0.053	9.0	4.1	13.9
0.059	8.0	3.5	12.5
0.066	7.0	2.8	11.2
0.072	6.0	2.2	9.8
0.079	5.0	1.6	8.4
0.086	4.0	1.0	7.0
0.093	3.0	0.4	5.6
0.101	2.0	0.0	4.2
0.109	1.0	0.0	2.8
0.117	0.0	0.0	1.4

BUILDING CLASS #8 ANNUAL EXPECTED DAMAGE [PERCENT] = 0.01056

BUILDING CLASS #9

Annual Prob. [PERCENT]	Expected Damage [PERCENT]	+/- SD	
0.001	22.0	12.8	31.2
0.004	21.0	12.1	29.9
0.007	20.0	11.3	28.7
0.010	19.0	10.6	27.4
0.014	18.0	9.9	26.1
0.018	17.0	9.2	24.8
0.022	16.0	8.5	23.5
0.026	15.0	7.8	22.2
0.031	14.0	7.1	20.9
0.036	13.0	6.4	19.6
0.041	12.0	5.7	18.3
0.047	11.0	5.1	16.9
0.053	10.0	4.4	15.6
0.059	9.0	3.7	14.3
0.065	8.0	3.1	12.9
0.072	7.0	2.4	11.6
0.079	6.0	1.8	10.2
0.087	5.0	1.2	8.8
0.094	4.0	0.5	7.5
0.102	3.0	0.0	6.1
0.111	2.0	0.0	4.7
0.120	1.0	0.0	3.3
0.129	0.0	0.0	1.9

BUILDING CLASS #9 ANNUAL EXPECTED DAMAGE [PERCENT] = 0.011651

BUILDING CLASS #10

Annual Prob. [PERCENT]	Expected Damage [PERCENT]	+/- SD	
0.002	21.0	12.3	29.7
0.004	20.0	11.6	28.4
0.006	19.0	10.8	27.2
0.008	18.0	10.1	25.9
0.011	17.0	9.4	24.6
0.014	16.0	8.7	23.3
0.017	15.0	8.0	22.0
0.020	14.0	7.4	20.6
0.023	13.0	6.7	19.3
0.026	12.0	6.0	18.0
0.030	11.0	5.3	16.7
0.034	10.0	4.7	15.3
0.038	9.0	4.0	14.0
0.042	8.0	3.4	12.6
0.046	7.0	2.8	11.2
0.051	6.0	2.1	9.9
0.056	5.0	1.5	8.5
0.061	4.0	0.9	7.1

0.066	3.0	0.3	5.7
0.071	2.0	0.0	4.3
0.077	1.0	0.0	2.9
0.083	0.0	0.0	1.5

BUILDING CLASS #10 ANNUAL EXPECTED DAMAGE [PERCENT] = 0.0074156

BUILDING CLASS #11

Annual Prob. [PERCENT]	Expected Damage [PERCENT]	+/- SD	
0.001	22.0	12.9	31.1
0.003	21.0	12.2	29.8
0.006	20.0	11.5	28.5
0.009	19.0	10.9	27.1
0.012	18.0	10.2	25.8
0.016	17.0	9.5	24.5
0.020	16.0	8.9	23.1
0.023	15.0	8.2	21.8
0.028	14.0	7.6	20.4
0.032	13.0	6.9	19.1
0.037	12.0	6.3	17.7
0.042	11.0	5.6	16.4
0.047	10.0	5.0	15.0
0.052	9.0	4.3	13.7
0.058	8.0	3.7	12.3
0.064	7.0	3.1	10.9
0.071	6.0	2.5	9.5
0.077	5.0	1.8	8.2
0.084	4.0	1.2	6.8
0.091	3.0	0.6	5.4
0.099	2.0	0.0	4.0
0.107	1.0	0.0	2.6
0.115	0.0	0.0	1.2

BUILDING CLASS #11 ANNUAL EXPECTED DAMAGE [PERCENT] = 0.010371

BUILDING CLASS #12

Annual Prob. [PERCENT]	Expected Damage [PERCENT]	+/- SD	
0.001	21.0	11.9	30.1
0.002	20.0	11.2	28.8
0.003	19.0	10.5	27.5
0.005	18.0	9.8	26.2
0.006	17.0	9.0	25.0
0.008	16.0	8.3	23.7
0.010	15.0	7.7	22.3
0.012	14.0	7.0	21.0
0.014	13.0	6.3	19.7
0.016	12.0	5.6	18.4
0.018	11.0	5.0	17.0

0.020	10.0	4.3	15.7
0.023	9.0	3.7	14.3
0.025	8.0	3.0	13.0
0.028	7.0	2.4	11.6
0.031	6.0	1.8	10.2
0.034	5.0	1.1	8.9
0.037	4.0	0.5	7.5
0.040	3.0	0.0	6.1
0.044	2.0	0.0	4.7
0.047	1.0	0.0	3.2
0.051	0.0	0.0	1.8

BUILDING CLASS #12 ANNUAL EXPECTED DAMAGE [PERCENT] = 0.0045109

ANNEX C: VALUES OF POPULATION PER DISTRICT

The following table indicates the number of inhabitants present in 48 districts of the EThekwini Municipality area.

District	Population
Amanzimtoti	13813
Bhekulwandle	4859
Blackburn	23960
Botha's Hill	2190
Cato Ridge	3874
Clansthal	3211
Clermont	52075
Cliffdale	2298
Durban	595061
Emachobeni	8321
Folweni	30402
Georgedale	10354
Gillitts	8661
Golokodo	35055
Gunjini	8031
Hambanathi	10755
Hazelmere	6751
Hillcrest	13329
Inanda	178418
Inchanga	1008
Kingsburgh	16368
Klaarwater	26157
Kloof	29704
KwaDabeka	54953

Matabetule	13247
Molweni	7208
Mophela	5517
Mount Edgecombe	7323
Mount Moreland	241
Mpumalanga	62406
Nkomokazi	596
Ntuzuma	125394
Nungwane	7518
Pinetown	144026
Qhodela	2127
Queensburgh	54846
Redcliffe	14220
Salem	781
Shongweni	24
Tongaat	42554
Umdloti	1778
Umgagaba	1552
Umhlanga	24238
Umkomaas	2716
Verulam	37273
Westville	30508
Ximba	1587
Zwelibomvu	8887

ANNEX D: BUILDING CLASS DISTRIBUTION WITH EQUIVALENT VALUES OF ANNUAL EXPECTED DAMAGE PER DISTRICT

The following table indicates the values of building classes and annual expected damage with their correspondent district.

District	Building Class	Description	Annual Expected Damage
Adams Rural	1	Reinforced concrete shear wall with moment resisting frame, low rise.	0.009
Ak	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Amanzimtoti	8	Reinforced Concrete Shear Wall without Moment Resisting Frame, Medium Rise.	0.01
Assagay	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
Bhekulwandle	1	Reinforced concrete shear wall with moment resisting frame, low rise.	0.009
Blackburn	1	Reinforced concrete shear wall with moment resisting frame, low rise.	0.009
Bothas Hill	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
Buffels Kloof	1	Reinforced concrete shear wall with moment resisting frame, low rise	0.009
Buffelsdraai	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Canelands	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
Cato Ridge	2	Light Metal, Low Rise.	0.005
Chesterville	6	Reinforced Concrete Shear Wall with Moment Resisting Frame, Medium Rise.	0.005
Clansthal	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017

Clermont	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
Cliffdale	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Craigieburn	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
Crestholme	6	Reinforced Concrete Shear Wall with Moment Resisting Frame, Medium Rise.	0.005
Danganya	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Dassenhoek	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Drummond	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Duffs Road	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Durban	11	Precast concrete, Low Rise.	0.01
Emachobeni	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Emansomini	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Emona	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Everton	6	Reinforced Concrete Shear Wall with Moment Resisting Frame, Medium Rise.	0.005
Ezimbokodweni	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Folweni	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
Fredville	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Georgedale	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Gillitts	6	Reinforced Concrete Shear Wall with Moment Resisting Frame, Medium Rise	0.005
Golokodo	3	Unreinforced Masonry Bearing	0.017

		Wall, Low Rise.	
Hambanathi	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
Hammarsdale	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Hammarsdale Rural	2	Light Metal, Low Rise	0.005
Harrison	1	Reinforced concrete shear wall with moment resisting frame, low rise.	0.009
Hazelmere	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Hillcrest	10	Braced Steel Frame, Low Rise.	0.007
Ilanga	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Ilfracombe	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Imbozamo	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Inanda	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
Inchanga	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
Inkangala	1	Reinforced concrete shear wall with moment resisting frame, low rise.	0.009
Inthuthuko	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Inwabi	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Isipingo	6	Reinforced Concrete Shear Wall with Moment Resisting Frame, Medium Rise.	0.005
Kingsburgh	6	Reinforced Concrete Shear Wall with Moment Resisting Frame, Medium Rise.	0.005
Klaarwater	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012

Kloof	9	Reinforced Concrete Shear Wall without Moment Resisting Frame, High Rise	0.011
KwaDabeka	5	Unreinforced Masonry Load Bearing, Medium Rise.	0.018
KwaMakhutha	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Kwamashu	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
KwaNdengezi	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
KwaNqetho	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
KwaNtamntengayo	1	Reinforced concrete shear wall with moment resisting frame, low rise.	0.009
KwaSondela	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Kwenkwezi	1	Reinforced concrete shear wall with moment resisting frame, low rise.	0.009
Lamontville	6	Reinforced Concrete Shear Wall with Moment Resisting Frame, Medium Rise.	0.005
Langefontein	6	Reinforced Concrete Shear Wall with Moment Resisting Frame, Medium Rise.	0.005
Lindokuhle	2	Light Metal, Low Rise	0.005
Lovu	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
Lower Illovo	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Lower Langefontein	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
Mabedlane	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Madundube	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Magabheni	1	Reinforced concrete shear	0.009

		wall with moment resisting frame, low rise.	
Matabetule	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Mgangeni	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Mgezanyoni	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Mkholombe	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Mlahlanja	1	Reinforced concrete shear wall with moment resisting frame, low rise.	0.009
Mngcweni	1	Reinforced concrete shear wall with moment resisting frame, low rise.	0.009
Molweni	5	Unreinforced Masonry Load Bearing, Medium Rise.	0.018
Mophela	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Mount Edgecombe	6	Reinforced Concrete Shear Wall with Moment Resisting Frame, Medium Rise.	0.005
Mount Moreland	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Mpumalanga	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
Mshazi	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
New Germany	8	Reinforced Concrete Shear Wall without Moment Resisting Frame, Medium Rise.	0.01
Ngonweni	1	Reinforced concrete shear wall with moment resisting frame, low rise.	0.009
Nkomokazi	1	Reinforced concrete shear wall with moment resisting frame, low rise.	0.009
Nsulwana	1	Reinforced concrete shear wall with moment resisting	0.009

		frame, low rise.	
Ntuzuma	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Nungwane	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Ogunjini	1	Reinforced concrete shear wall with moment resisting frame, low rise.	0.009
Osindisweni	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Ottawa	5	Unreinforced Masonry Load Bearing, Medium Rise.	0.018
Peacevale	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Pinetown	8	Reinforced Concrete Shear Wall without Moment Resisting Frame, Medium Rise.	0.01
Pinetown Rural	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Qhodela	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Queensburgh	8	Reinforced Concrete Shear Wall without Moment Resisting Frame, Medium Rise.	0.01
Redcliffe	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
Riet River	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Salem	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
Senzokuhle	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
Shallcross	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
Shongweni	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Summerveld	6	Reinforced Concrete Shear Wall with Moment Resisting Frame, Medium Rise.	0.005

Tongaat	6	Reinforced Concrete Shear Wall with Moment Resisting Frame, Medium Rise.	0.005
Umbogintwini	2	Light Metal, Low Rise.	0.005
Umbumbulu	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
Umdloti	7	Reinforced Concrete Shear Wall with Moment Resisting Frame, High Rise.	0.007
Umgababa	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Umhlanga Rocks	12	Long Span, Low Rise.	0.004
Umkomaas	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
Umlazi	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
Verulam	4	Unreinforced Masonry Load Bearing Frame, Low Rise.	0.012
Verulam Rural	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Waterfall	6	Reinforced Concrete Shear Wall with Moment Resisting Frame, Medium Rise.	0.005
Waterloo	3	Unreinforced Masonry Bearing Wall, Low Rise.	0.017
Welbedagt	1	Reinforced concrete shear wall with moment resisting frame, low rise.	0.009
Westville	10	Braced Steel Frame, Low Rise.	0.007
Ximba	1	Reinforced concrete shear wall with moment resisting frame, low rise.	0.009
Yellowwood Park	6	Reinforced Concrete Shear Wall with Moment Resisting Frame, Medium Rise	0.005
Zwelibomvu	1	Reinforced concrete shear wall with moment resisting frame, low rise.	0.009