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REGIONAL CATASTROPHE RISK MODELLING, SOURCES OF COMMON UNCERTAINTIES

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SUMMARY

Natural catastrophe risk modeling has been under significant improvement in the last 10-15 years. Recent development in computer technology, information quality and need for natural catastrophe models provide necessary requirement for further investment and development of user-friendly catastrophe computer loss models. Probabilistic economical losses estimated by such models are ideally suited to risk management entities as well as to the growing insurance and reinsurance industries. Despite the user-friendly interface and often decision-making guidelines such models offer, less transparency is presented on the reliability and accuracy of their results which are important and crucial factors. This paper highlights some of the most common sources of uncertainties involved in natural catastrophe modeling in general and seismic risk modeling in particular. The methods and measures for proper treatment of such uncertainties, however, are beyond the scope of this paper.

INTRODUCTION

Destructive natural catastrophes resulting in significant economic losses and human casualties frequently hit developed and developing countries. Examples of such cases are recent destructive earthquakes in Taiwan, Turkey, India and Iran. The large number of casualties in these countries is due to both high seismic activity and high vulnerability of the built environment. Evaluating the social and economic impacts of natural catastrophes involves a number of different disciplines ranging from earth science to engineering. The real impact of an earthquake on an area depends on the geographical distribution of the hazard induced by earthquake, geographical distribution of the built environment, and their vulnerability to the earthquake hazard. Seismic risk can be a representative of overall social and economical impacts of natural catastrophe on human and built environment. Such impacts include loss of life, injury, damage to properties, business interruption, loss of profit and other short and long-term consequences of earthquake hazard. This integration of natural phenomena and it consequences is mathematically described as:

Risk = Hazard x Vulnerability x Value (Consequence or Exposure)

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Seismic risk is highest in areas with high seismic hazard and high concentration of vulnerable building stock. While seismic hazards are governed by regional seismotectonic and geological characteristics, seismic loss is controlled by geographical distribution of the built environment and their vulnerability to the hazard. Catastrophe risk management is an attempt to manage and minimize the damage and loss to built environment by proper management of hazard, exposure and buildings vulnerability.

Recent advances in computer and information technology have provided necessary tools to extend the application of probabilistic seismic hazard mapping from its traditional engineering use to many other applications such as risk mitigation, disaster management, post disaster recovery plan and financial risk management. Natural catastrophe computer loss models have been widely used by insurance and in particular reinsurance companies in the last 10-15 years, since the destructive impact of the Northridge earthquake in 1994. Due to the high severity and low frequency of natural catastrophe such as earthquakes, catastrophe loss estimation based on traditional actuarial methods and historical loss records are inadequate and incomplete. Significant advances have been made in computer technology in the recent years regarding analytical speed and storage media, provide tools and procedure to develop catastrophe loss model in a fast and flexible manner, which was not previously possible. Computer risk models can be used to estimate potential losses from future events and provide facilities for better controlling exposure to potential losses. Insurance companies also use the results of such models as a guideline to control their business development and to price their product to the ordinary policyholders. By identifying the locations of most exposed properties, insurers may also have the opportunity to correct their portfolio or seek for adequate cover before they turn into actual losses. In addition to that the technology also provides facilities for global reinsurance market to price the risk transferred from regional direct insurers. Availability, flexibility and user friendly interface of such models have made detail risk analysis a routine practice for most insurers, reinsurers and brokers. Catastrophe risk models are available to many underwriter, actuaries, and risk managers under annual license agreement. However, the reliability and accuracy of results generated by such models remain always an important and crucial factor, often hidden under the nice and user-friendly computer interface.

Due to the lack of proper knowledge with regard to all elements controlling natural catastrophes and their effects on built environment, there are always uncertainties associated with all steps involved in developing and using risk models. While some of these uncertainties can be controlled by more accurate and reliable input data, the majority remains with large scatter and therefore, contributes to the uncertainty of final results. This paper highlights some of the most common sources of uncertainties involved in seismic risk modeling, however, measures and methods for proper treatment of such uncertainties are beyond the scope of this paper. This paper in particular points out the sensitivity of seismic loss models to seismic source definition, spatial distribution of probabilistic events, event recurrence relationship, attenuation functions, source-to-site distance definition, vulnerability functions, built environment inventory, vulnerability functions and probabilistic and mathematical approaches used for risk modeling. Major components of each of these steps are described in the following sections with emphasis on the main sources of uncertainties described at the end of each section.

NATURAL CATASTROPHE RISK MODELLING AND INSURANCE

Natural catastrophe risk assessment has several applications in insurance/reinsurance industry. Examples of such applications are for risk-pricing guidelines; risk accumulation estimate and risk transfer system. An insurer/reinsurer may use a catastrophe model to estimate risk premiums by peril, region and type of risk. He may also use risk models to manage his written exposure versus his available capacity or to estimate the impact of some of the worst-case scenarios on his portfolio. Risk model are also used as a very efficient tool to help insurer/reinsurers to transfer risks to other companies.

Main Components of a Seismic Risk Model

Natural catastrophes are produced due to interaction and release of significant amount of energy created and stored by the nature. In the case of earthquake, seismic hazards are generally governed by the seismotectonic and geological characteristics of each region. There are certain parameters defining the earthquake source, such as its location, magnitude and released pattern. Earthquakes usually generate several types of hazards, each can translate into damage and human casualty depending on the hazard type and built environment characteristics. Except for some indirect seismic hazards such as landslide and liquefaction which can be somehow controlled by proper geotechnical measures, the most common and destructive type, i.e. ground shaking can not be reduced and therefore, translates into damage and loss of life. The severity of damaged to built environment is a function of several factors. Geographical distribution and proximity of built environment to the seismic source as well as local site conditions can be categorized under location factor. In the case of seismic ground motion for example, both distance to the source and ground characteristic at the site are vital. Translation of earthquake ground motion or other seismic related hazards to physical or monetary damage is done through vulnerability functions. Regardless of the type and nature of each natural catastrophe, several components need to be modeled in order to develop a risk model. In the following sections the main characteristic of each of these components with regard to a seismic risk model are discussed (Figure 1). The main objective of this paper, however, is to highlight the sources of uncertainties with regard to input data, assumptions and modeling techniques.

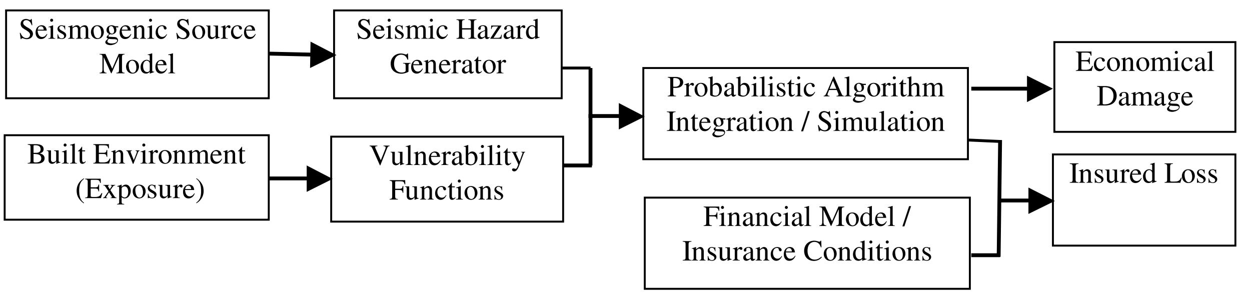


Figure 1: Main components of a seismic risk model

SEISMIC HAZARD ASSESSMENT

Traditionally insurance companies have been using a reference loss measure in order to price their risks as well as control their capacity. The term Probable Maximum Loss (PML) is a common measure used as such reference. There are several definitions for PML, depending on the type of analysis and assumptions used to estimate it. PML's can be estimated following either a deterministic or a full probabilistic definition of the disaster event and its consequences. In the first case, a given scenario (*e.g.* a repeat of a significant past event, or an extreme case scenario without considering its probability of occurrence, or an event with a certain probability of occurrence) is selected and simulated. In the second approach, a probabilistic analysis taking into account all potential sources is carried out, resulting in a probabilistic description of hazard defined by hazard curves. A hazard curve typically defines the probability of exceedance of a hazard level in a given duration of time.

Deterministic Seismic Hazard

Prior to introduction of proper probabilistic loss models, insurers have been using pure deterministic measures for their PML assessment, which still being used in some insurance market around the world. PML's can be estimated through a deterministic approach using scenario events. In a deterministic model, losses to a portfolio are estimation based on the effect of one or series of selected scenarios. Usually these events are selected to represent the worst-case scenarios, based on their severity as well as proximity to exposure. A deterministic earthquake loss model provides single outcomes, i.e. loss as a result of a maximum credible earthquake (MCE) at a given source. Depending on the type of available information, it may be possible to assign a return period or probability to each of the scenario events and their resultant losses. Return periods assigned to each scenario represent the independent likelihood of such event happening at its source. To obtain the total PML generated by a combination of all scenarios, one needs to combine all the scenarios, based on an understanding of their probability and any correlation which may exist between the them. In any case the term “probable” cannot be fully applied to such results, as they do not represent the full spectrum of events capable of generating losses. In other words, seismic hazard or seismic risk usually refers to a pair of figures representing severity and frequency of ground motion or its effect on the built environment.

Probabilistic Seismic Hazard

Seismic hazard expresses the distribution of future earthquake-related phenomena in size, time and space. In probabilistic approaches, the probability of different size earthquakes producing ground motions at different sites are taken into account. Besides, there are uncertainties associated with almost all of the elements involved in a seismic hazard or risk analysis which a probabilistic approach is able to incorporate. The probabilistic approach involves a randomization of the observed seismicity not only in time but also in space. Several computational approaches have been used to model such randomization. In a more generic term, as illustrated in Figure (2), these steps can be summarized as:

- Definition of seismic sources (points, faults, area or a combination of all)
- Determination of recurrence relationship, including an estimation of the maximum earthquake
- Choice of attenuation relationships for strong ground-motions
- Numerical calculation or simulation using probabilistic algorithms

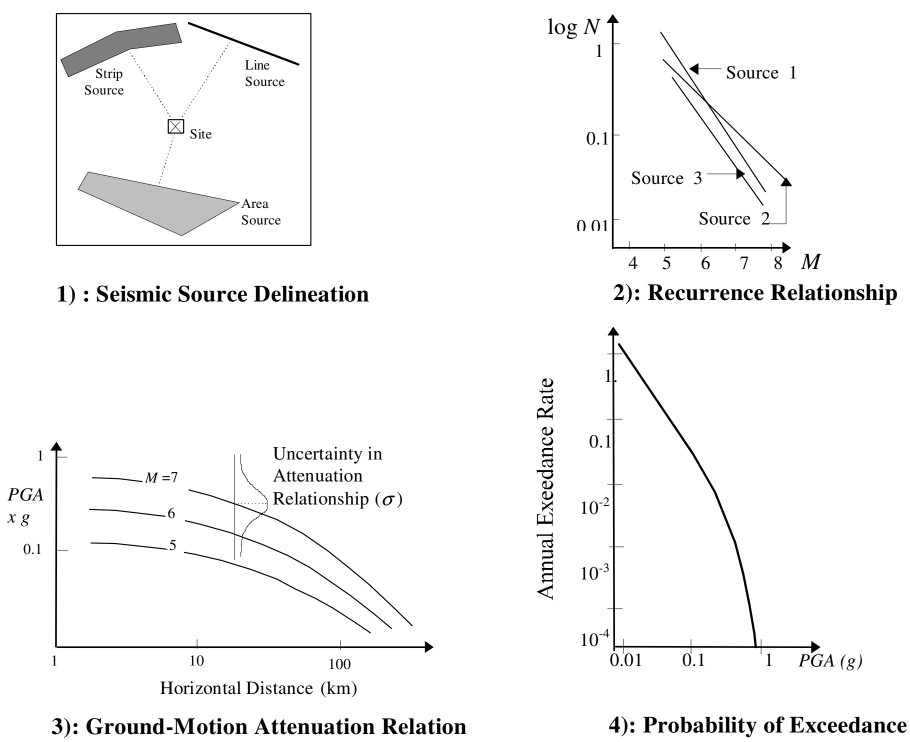


Figure 2: Steps in probabilistic seismic hazard analysis

Seismic Sources Definition

The seismotectonic setting of a given region needs to be simplified and modeled to represent the seismic sources for future potential earthquakes. Depending on the seismotectonic setting as well as quality and availability of required data, one or a combination of seismic source models may be used to model the seismogenic behavior of a given region. Characteristics as well as advantages and shortcomings of each of these approaches are presented here.

Fault Models

Faults are in general the main sources of tectonic earthquakes and it makes sense to define seismic sources based on active faults wherever possible. Fault rupture models are based on tectonic features characterized by fault geometry as well as pattern of historical and even geological earthquakes, and are used for faults with reliable information and capable of generating moderate to large events. Higher sophistication has been employed recently in modeling fault ruptures. New hazard programmers can model fault ruptures based on detailed fault characteristics such as 3D geometry of fault planes and rupture zones (length, area, dip angle, …), rupturing mechanism, activity history and slip rates, providing framework for capturing all the variation of ground motion resulted from faults with complex geometry, tectonic environment and fault mechanism (Figure 3a).

Modeling earthquakes on individual faults removes some of the randomness out of probabilistic process and replace that with deterministic features. Although that might add to the accuracy of hazard if enough and reliable information regarding location, geometry and activity of faults are know, however, if such details are not available or reliable enough it creates unrealistic bias in the final results.

Seismic Area Sources

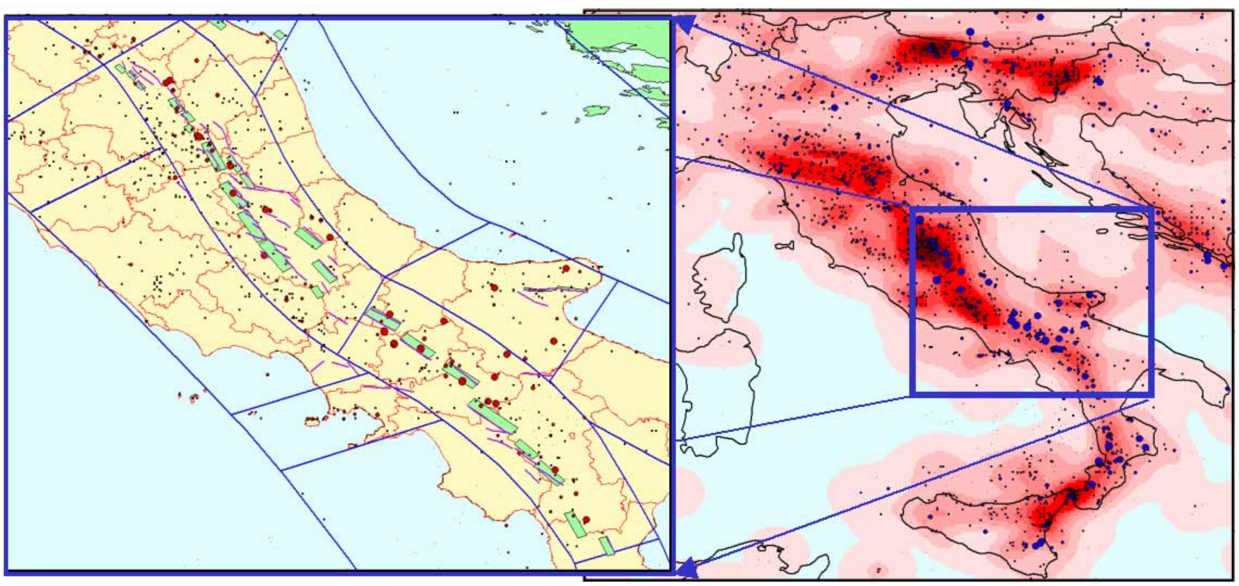
Surface faulting inevitably only samples the larger earthquakes, as during smaller events, faults do not break right through to the surface. Besides, many destructive earthquakes of the past typically occurred on blind faults or on offshore faults. For regions with seismic activity generated by diffused patterns of small to moderate faults, earthquake sources are modeled by area source zones that are usually defined based on a combination of historical seismicity and characteristics of tectonic features. The division of a region into seismic source zones is an attempt to reconcile past seismicity with tectonic theories. The seismicity data and tectonic characteristics of a region provide the basic information towards the seismic source regionalization. Seismogenic parameters defining recurrence relationships area also estimated based on historical seismicity falling within each source zone. Such parameters are usually assumed to be uniformly distributed over seismically homogeneous area sources (Figure 3a).

However, the geometry of seismic source zone boundaries, at best, are an approximation and even in regions with well known geology, tectonics and past seismicity, they may be defined significantly differently. The state-of-the-art of seismic hazard analysis has not yet described a practical procedure for the delineation of seismic source zones. The construction of seismic source boundary is mostly based on expert judgment and it is one of the deterministic elements introduced in probabilistic seismic hazard assessment. Such normalization of seismicity over a large area makes the calculated seismic hazard very dependent to the delineated seismic source boundaries. Seismic hazard maps produced using such seismic sources usually follow the same pattern as the delineated seismic source boundary. Such direct dependencies can be seen in many regional seismic hazard maps produced by these approaches.

Zone-Free Methods

Several other alternatives have been recently introduced to get away from the expert judgment involved in seismic source method, particularly in regions with unknown causative faults and tectonic structure. Zone-free method is an alternative to those based on defined seismic sources. In these approaches the spatially smoothed seismicity over a fine grid is used to model the temporal and spatial distribution of potential earthquakes. These approaches are usually used when it is hard to establish relationship between observed seismicity and tectonic features, sometimes to model background seismicity only. It is a less time-consuming approach and used for areas with low seismicity and high uncertainty. These methods use the spatial distribution of historical earthquakes as recurrence rate, while the Gutenberg-Richter b-value is assumed to be constant for the entire region (Figure 3b).

In the zone-free methods, locations of potential earthquakes are modeled according to the locations of historical seismicity, with no weight given to the new locations i.e. surprise and gap-filling earthquakes. Although the method based on seismic sources and uniform seismicity involves a large degree of expert judgment, on the other hand, the zone-free methods ignore the useful information available from regional tectonics and geographical pattern of past seismicity. Mathematical treatment of earthquakes as points in space with no weight given to other information available from tectonics, faulting and long-term pattern of seismicity is not in agreement with the physical causes of earthquakes. Further more, the seismicity in a region should be investigated with regard to completeness of earthquake catalogue, before being used for seismic hazard analysis. Historical seismicity alone is not always enough for understanding and predicting location, size, and frequency of rare large earthquakes.



a **b**

Figure 3: Seismogenic source modeling; a) Seismic source areas with defined fault sources, b) Zone-free method based on smoothed seismicity

Earthquake Recurrence Relationships

Recurrence relationships define the distribution of future earthquake in time and size. Historical earthquake catalogue is one of the most important source of information for regionalization and parameterization of seismogenic source model. Sources of uncertainties related to historical seismicity can be summarized as following:

- The time, location, and magnitude of historical earthquakes are usually estimated from macroseismic information and therefore, with high degree of uncertainties. Due to multiple sources of such events, often duplicated events get reported in the compiled catalogue resulting in overestimating rate of such events. More detailed information regarding earthquake sources such as focal depth and causative faults are not reported.

- Geographical as well as temporal incompleteness usually results in inhomogeneous earthquake catalogues. Use of incomplete earthquake database results in unreliable seismogenic parameters.
- Different size-scales are usually used for earthquakes size measure. Homogenizing magnitude scale adds further uncertainties to he earthquake catalogue.
- Inclusion of dependent events (fore- and after shocks) results in overestimating recurrence rate of small to moderate events.

Reliability of input data as well as parameters used to describe recurrence relationships depend on the type of source models used to describe geographical distribution of future earthquakes.

Recurrence Relationship- Zone Free Method
For seismic sources defined by zone-free method, recurrence rates are based on smoothed frequency of events on a uniform grid (Figure 3b). In some seismic hazard studies such modeling is used for background seismicity or for events with 3.0< Magnitude<6.5

Recurrence Relationship- Seismic Source Area
For seismic source zones, usually an exponential recurrence relationship, mostly the Gutenberg-Richter relationship is used. Such relationship is appropriate for small to moderate events (4.0< Magnitude< 7.0), however, for larger events particularly those that could be associated to their causative faults or fault zones, combined exponential and characteristic model provides better representation of recurrence relationship (Figure 4).

Recurrence Relationship- Major Faults
There are many examples where exponential models are not appropriate for individual faults. Major faults with distinct seismic history and defined activity, tend to release their seismic strain in a narrow range of characteristic magnitudes and at non-random time intervals. For such sources, recurrence rates are usually estimated from slip rates or pattern of historical events if known (Figure 4).

Maximum Magnitude Earthquake
In a deterministic approach, the hazard or risk is assessed as a result of a scenario event that could be a recurrence of a known historical event or a postulate event of a maximum size often called maximum credible earthquake (MCE). However, in a probabilistic seismic hazard analysis, the maximum magnitude refers to the maximum possible earthquake (MPE) that defines an upper bound to earthquake size associated with a specific seismic source. Depending on the type of seismogenic source modeling and availability and reliability of seismotectonic data, the maximum magnitude can be estimated from historical observations, from tectonic characteristics, or, where data are sufficient, from statistics of earthquake data.

In regions with long records of seismic history and rather shorter recurrence intervals between large events, maximum magnitude may be defined based on historical earthquakes. The historical maximum magnitude is always known as the minimum limit for the upper bound magnitude used in probabilistic seismic hazard analysis. If such earthquakes occurred in the past, there is a possibility that they will occur again in the future. The estimation of maximum magnitude based on historical data is more appropriate for area sources with a long recorded seismic history, and where the tectonic setting is very complex. The largest historical earthquake plus an increment of magnitude has been widely used as the maximum magnitude. However, the increment value (often considered to be one-half magnitude unit) is subjective as it may well underestimate the size of earthquake for small to moderate *Mmax* and overestimate it for large *Mmax*. For faults with well know seismic history and tectonic characteristics, *Mmax* might be estimated based on a combination of fault length, fault area, slip rate, seismic moment budget and

Paleoseismicity data. The methods based on historical earthquakes are more appropriate for area source characterizations, while the latter is more relevant for fault sources.

For seismic hazard and risk with short return periods, the choice of maximum magnitude is not a critical factor, because the predicted ground-motions for short return periods are mostly dominated by low-to-moderate magnitude events. However, the choice of *Mmax* has significant effect on hazard or risk with moderate to long return periods.

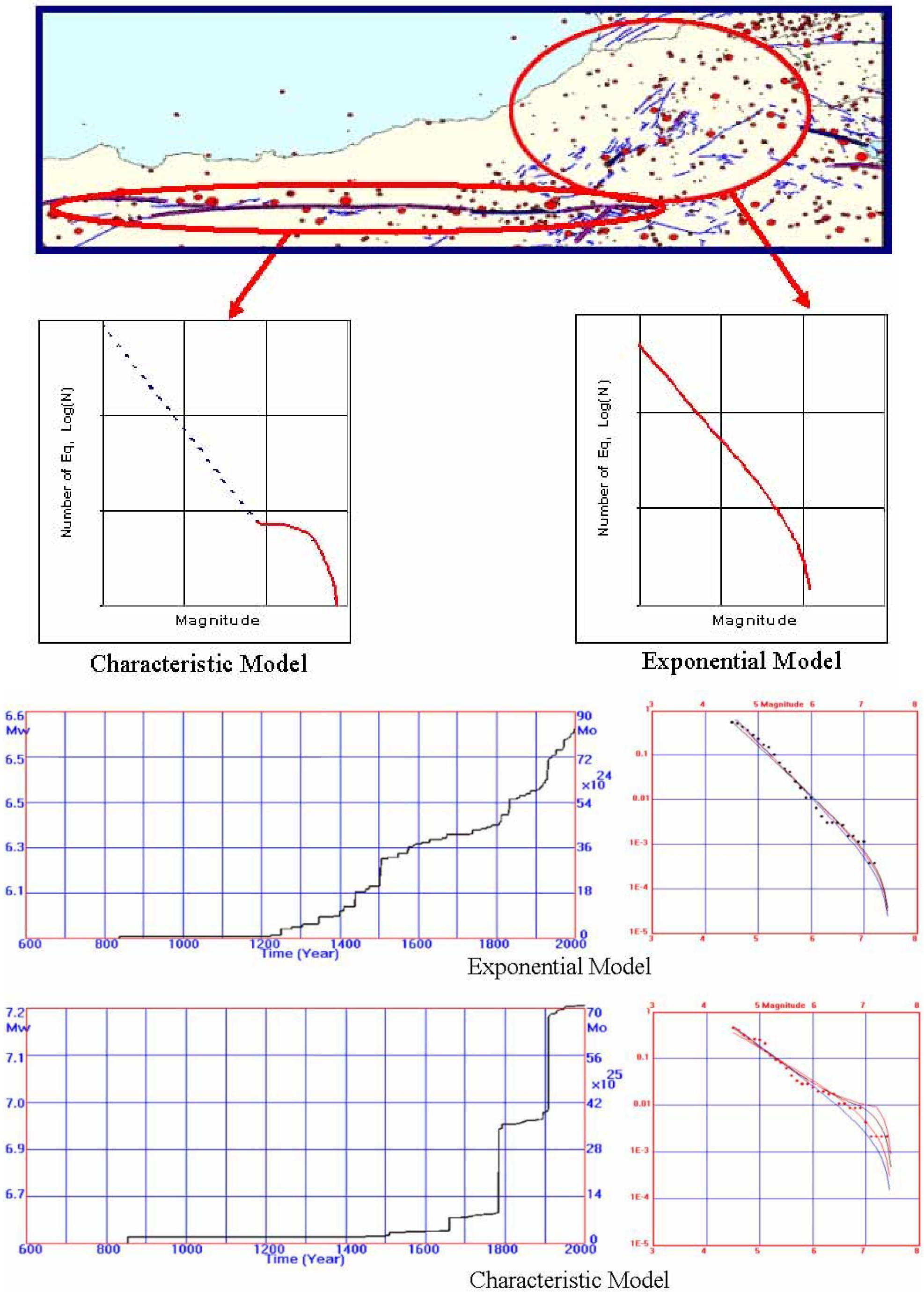


Figure 4: Recurrence relationship

Recurrence Stochastic Model

The most common stochastic model used to model probabilistic nature of earthquake occurrence is the Poisson model, which implies that earthquakes are independent events that occur randomly in time. The Poisson process, in fact, reflects a memoryless property of seismic activity in time by which the occurrence of an earthquake does not change the probability of future events. That is why foreshocks and aftershocks are not included in the recurrence relationship. In addition to temporal independence behavior of the Poisson process, the magnitude and location of future earthquakes are assumed independent of the magnitude and location of past earthquakes.

For large and active faults, pattern of historical earthquake show a non-random occurrence of events with some temporal dependency (Figure 4). For such cases, where possible, a time dependent model is used to define the recurrence probability of characteristic earthquakes. Such models have been already used for large and seismically active faults with magnitude range of 6.0< Magnitude< 8.5. (*e.g*. parts of San Andres Fault in California and North Anatolian Fault in Turkey).

Time-dependent probability is the conditional probability that an earthquake will occur on a fault within some specified period of time in the future (i.e., 2000 to 2050), given that a similar earthquake has occurred at some known date in the past. Causes of time dependent behavior are from secular stress increase due to long-term strain accumulation, permanent stress increase or decrease due to stress interaction from an earthquake on a nearby fault and transient stress increase or decrease due to stress interaction from an earthquake on a nearby fault (decays with time). Therefore, a time-dependent model relies on the following information and assumptions:

- Probability distribution of recurrence time
- Uncertainty in mean recurrence time
- Intrinsic randomness in recurrence time
- Dates of exposure period
- Date of previous earthquake

A fully time-dependent model removes the randomness nature of events in time and therefore, adds more bias to the final hazard and loss results. The degree by which a fault behaves Poissonian or time-dependent can be controlled by intrinsic randomness. Figure (5) shows, for example, comparison between recurrence probability obtained from Poissonian and time-dependent models for interface fault zone in Central America.

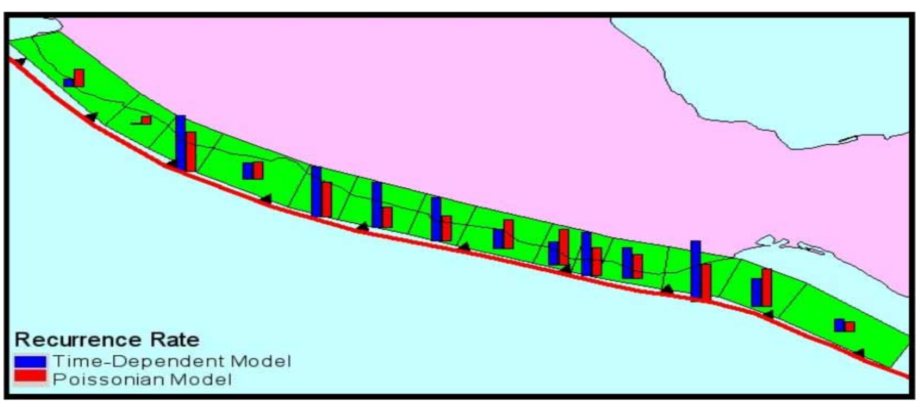


Figure 5: Comparison between earthquake recurrence probabilities estimated form time-dependent and Poissonian models

Attenuation Functions
Regional attenuation relationships can be developed and used where regional strong ground motion data are available. In the absence of such data, borrowed relationships are usually calibrated or used directly. Ground motion parameter used for seismic risk assessment should represent damage to properties. The choice of ground shaking parameter depends on the available data to correlate damage to earthquake hazard. For that reason, MMI has been used in many seismic risk models as ground shaking parameter. Uncertainties associated with the choice of ground motion parameters and attenuation relationship can be summarized as follow:

- MMI although a relatively good representative of damage, is a subjective measure and cannot be verified quantitatively. Besides, it dose not allow proper modification as results of local soil condition.
- Many attenuation relationships describing ground motions in various forms such as PGA, PGV, SA are available to use, however, translating these parameters to damage is not always simple.
- Often ground shaking parameters are converted using empirical relationships which in turn adds more uncertainties to the risk process.
- Parameters used to describe earthquake size; source-to-site distance and fault mechanism are not fully taken into account in hazard and risk assessment.

BUILDING VULNERABILITY

The rapid growth of the stat-of-the-art of earthquake engineering since 1950 has resulted in significant improvement in the seismic vulnerability of buildings constructed in recent decades. Seismic design codes often provide design load through a seismic zoning or seismic hazard map with specified peak ground motion. However, application of seismic design codes have not been a common practice in most developing countries, particularly until recently, and many older buildings were built without application of such codes.

Various agents of seismic hazard can produce physical damage to structures during an earthquake, including ground shaking, fault rupture, landslides, liquefaction, inundation (tsunami and seiche) and fire. Ground shaking, produces scattered but widespread damage and the effects of strong ground shaking are responsible for a large portion of building damage. Estimated seismic ground shaking can be translated to physical and monetary damage through vulnerability functions. Such functions are usually developed by region, for building, contents and business interruption, by many different construction classes and occupancies.

Use of expert opinion and empirical correlation on available earthquake damage data are the most practical way for developing such functions, however, for important and designed buildings, structural calculations, engineering studies, and results of dynamic tests can be incorporated too. Reliability and accuracy of risk assessment tools significantly depend on the input data, assumptions, and parameters used to define vulnerability functions. Except for some recent earthquakes in developed area from which damage correlation with engineering ground motion parameters (e.g. SA and Sd) are possible, for the majority of buildings such correlation does not exist. Even where there are data to correlate damage to ground motion parameters, high degree of uncertainties exist which result in large standard deviations. Main source of such variation includes:

- Seismic design code and date and effectiveness of its implementation
- Variation in implementing risk mitigation measures
- Variation in regional building practice and material quality
- Regional workmanship quality particularly with regard to new materials

- Effective inspection (design engineers, independent building inspectors and government)
- Old building and quality of maintenance
- Fast growing market, profit margin and property management
- Building characteristics and their relationship to their current occupancy and usage
- Variation of public awareness with regard to natural catastrophes

Risk managers, in addition to normal property and content damage, are also interested in losses as results of business interruption, such as loss of profit and compensation. Due to many factors controlling such losses, even higher uncertainties are associated which vulnerability functions defining business interruption losses.

BUILT ENVIRONMENT INVENTORY (EXPOSURE)

Regional built environment inventory data or as called by insurers "*exposure*" needs to be collected and properly mapped to vulnerability classes and hazard. In the last 15 years the loss modeling techniques as well as the quality and quantity of exposure data used for such modeling have improved significantly. For risk assessment practice used by insurers/reinsurers, each risk or group of risk needs to be characterized by at least the following information.

- Geographical location
- Vulnerability classes
- Monetary value
- Insurance conditions

Exposure Geographical Mapping

Properties or as called by insurers "*risks*" in a given portfolio need to be geo-referenced before it could be used for risk assessment. In other words, locations of risks need to be mapped on the hazard footprint prior to loss calculation. It is still common to use aggregated exposure by country or other low-resolution geographical units. For example CRESTA map units are what have being used by insurers and reinsurers for exposure data management worldwide (Figure 6a).

Accuracy and reliability of exposure mapping controls to some extend, the uncertainties with risk results. This is not only due to geographical variation of seismic hazard as determined by hazard model, but also variation in local soil conditions as described by soil and geological maps. Often aggregate exposure data presented for loss analysis are of very low resolution. This is in particular the case for reinsurance type of risk assessment. CRESTA map units are widely used for such purposes. Most of commercial loss models can now further disaggregates the aggregated data into much higher resolution using some kind of disaggregation process usually based on population or even actual property density (Figure 6b). Such solution adds more geographical variation to risk locations and sometime improvement to imported exposure data, however, it does not disaggregate aggregated risks to their actual locations and there are always uncertainties associated with that.

Improvements have been achieved by insurers collecting more detailed exposure data and also risk modelers modeling hazard and risk on a much higher geographical resolution. Some of the catastrophe loss models provides framework for site-specific risk modeling, allowing modeling each single risk by its longitude/latitude (Figure 6c). Risk models now can handle exposure data by a combination of different geographic units, but one needs to consider the level of uncertainties associated with each of these systems.

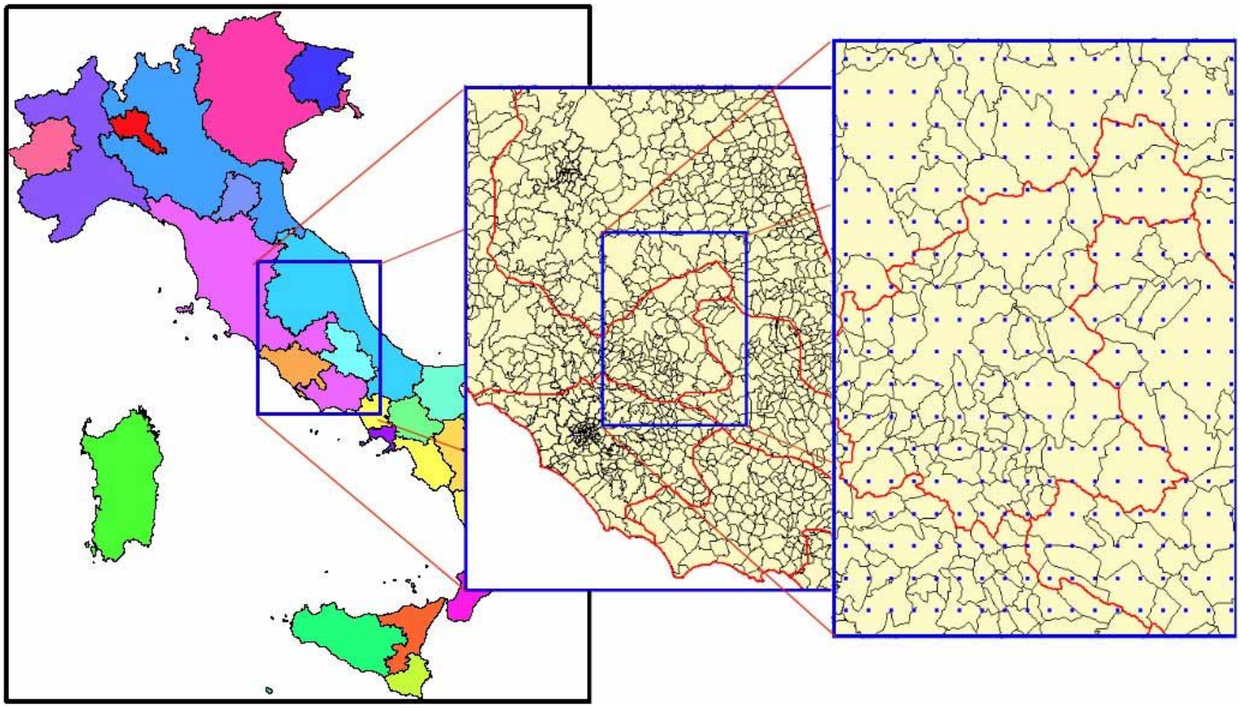


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Figure 6: Exposure data mapping and disaggregation model; a) CRESTA units, b) Disaggregation into Postcode units, c) Hazard defined on a fine grid allowing site-specific risk assessment

Vulnerability Characteristics of Insured Risks

Depending on the nature of each natural hazard, certain buildings characteristics are required to estimate damageability of buildings to hazard. Each risk or group of risks in the exposure database needs to be linked to a vulnerability class describing its damageability against the earthquake hazard. Except for large and important facilities, for which fairly well documented information may exist, for the vast majority of remaining buildings, detail information regarding structural behavior is not available. In these cases minimum vulnerability indicators in a broader definition of building characteristics would be used. Exposure data collected by insurers usually provides following information:

- Risk type (*e.g*. residential, commercial, industrial),
- Coverage (*e.g*. building, contents, business interruption)
- Building usage (*e.g*. house, office, shop)
- Construction type (*e.g*. masonry, reinforced concrete, steel)
- Other building characteristics (*e.g.* height, age, size)

As natural catastrophe risk modeling find its place among different government and financial sectors (risk managers, insurers, reinsurers, brokers and investors) more attention have being paid to collection, management and use of even more detailed exposure data.

Insured Values

In a catastrophe insurance portfolio, insured value represents replacement value of the property (building, contents, business interruption). In a detailed insurance policy with one-to-one reference for each risk, this value usually represents the actual replacement value of the risk. However, in most normal insurance policies, such figure does not necessary represent the replacement value but a maximum liability limit which insurer accepts to pay in the case of total damage, which could be lower or higher than the actual replacement value.

Vulnerability functions usually represent damages or losses based on total replacement value. For example policy insured value of a $100,000 house could represent its actual value or a limit of $200,000. A damage of 10% on such property could simply mean $10,000 or $20,000 respectively. There are other sources of uncertainties in the replacement value such as currency rate, inflation and demand surge in case of large disaster.

Insurance Conditions
There are certain mechanism for an insurer to expand his market share while offering competitive premium as well as managing and limiting his potential losses. Insurers usually exchange lower premium with high deductible, by which they manage to remove small but high probable losses out of their portfolio. Other mechanism is policy limits by which he caps the total losses he pays in event of total damage to property.

Policy conditions could be based on insured value or loss to the property. It could be a fix monetary value or a fraction of the value/loss or a combination of all. It could also change with the number of claims in a given year. In order to model such conditions correctly, not only detail insurance conditions but also clear representation of value and number of risks are needed. Due to high uncertainties associated with damage calculation, vulnerability functions are considered with their probability distributions. Usually a normal, lognormal or Beta distribution is used to describe damage variation. In the absence of any policy conditions, usually mean damage ratios are used for damage calculation. However, where policy conditions such as deductibles and policy limits are to be considered, these probability distributions need to be redistributed tanking into account such reductions. The choice of distribution functions and standard deviation plays a crucial role and could be further source of uncertainties.

RISK MODELS AND PROBABILISTIC ALGORITHM

Unlike deterministic method, in a probabilistic approach, the probability of various magnitude earthquakes producing damage at a given site is taken into account. This allows the temporal and spatial probabilistic pattern of all events from small to large size to be modeled. A proper probabilistic approach should be capable of handling uncertainties associated with all the components of risk model. Such uncertainties once modeled contribute to the severity and frequency of estimated losses. In a probabilistic seismic risk assessment, probabilistic distribution of the following components are combined:

- Probabilistic distribution of earthquakes in time, space and size (seismogenic model)
- Probabilistic variation of ground motions (attenuation functions)
- Probabilistic variation of damage (vulnerability functions)

The loss results obtained from such models are in fact probability functions too. Catastrophe loss models usually provide probabilistic loss curves describing losses as functions of probability or return periods. PML's are usually selected form a range of probabilistic losses based on insurer/reinsurer financial capacity as well as his risk appetite. In addition to probabilistic losses, insurers are usually interested to see an annual average or Annual Mean Loss (AML) for each portfolio. While the probabilistic losses help insurers to manage his capacity and strain against moderate to large losses, the AML helps him to price his service to the normal policyholders. In general there are two approaches to formulate a risk model and to combine these probability functions. These methods are described in the following sections.

Integration Algorithm
Since all variable defining components of a risk model can be represented probabilistically, one can solve them numerically as shown in Figure (7). Although this approach is more straightforward and provides full spectrum of losses, its application for insurance purposes faces some limitations as described below:

- Insurance and reinsurance risk managers have been traditionally managing their portfolio based on scenario events with defined location and magnitude. In other words, they would prefer to assign events with clear locations and magnitudes to each probabilistic loss, although such definition is against probabilistic hazard and risk definition. However, a risk model based on integration approach convolute all events with their probability distribution and therefore, no particular events can be assigned to losses with defined return period.

- Some insurance policies, either simple homeowner policies or reinsurance contracts, refer to the sequential order of events in a given year. In other words, the order of damaging events in a year defines the insurer's liability, in which for example he may be liable to all of the losses from the first event and only a fraction of looses of further events in a given year. Again in this approach there will be no signature of responsible event and therefore, such order does not exist.

- Probabilistic losses obtained from this approach represent loose per each event in a given year or so called by insurers "Per Occurrence Loss" which refers to the largest damaging event in each year. However, insurers are also interested to see probabilistic annual aggregate losses, which refer to probabilistic losses on an annual basis, in other word, the multi-event probabilistic losses. Due to the limitations described above, this approach cannot produce such estimate either.

- Depending on the approaches used to combine probability distributions, sometime further attention needs to be paid to any kind of correlation, which may exist in combining results obtained form this approach.

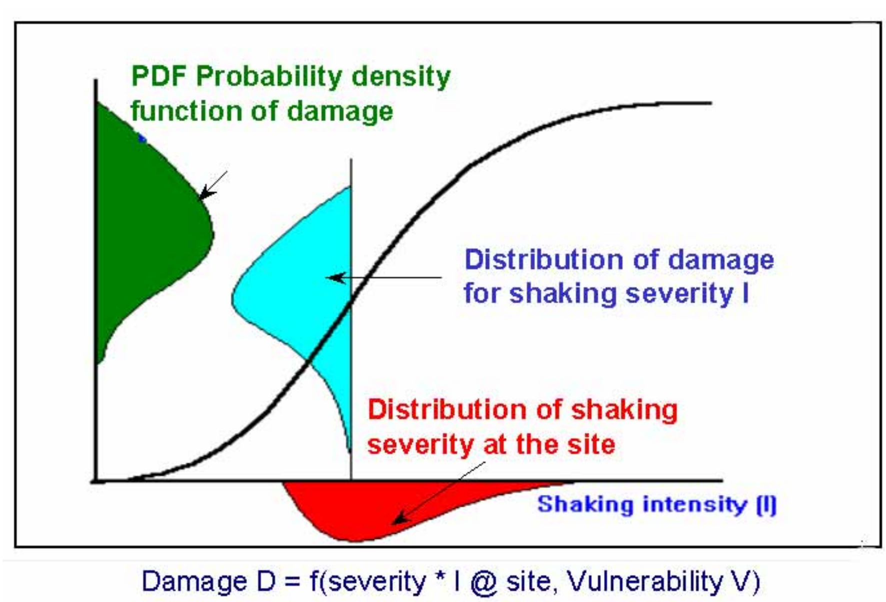

Figure (7): Full probabilistic distribution

Random Simulation Algorithm
Other alternative to solve the overall total probability distributions is through random simulation process. Monte-Carlo simulation is widely used for such process. By randomly selecting probabilistic variables controlled by their distributions, one may construct the probability loss curves. In this approach seismotectonic model is used to simulate a hypothetical earthquake catalogue for a given period (10,000 years for example). Such event set is supposed to represent the spatial and temporal distribution of future potential events. Using such event set, ground shaking and damage could be calculated for each event. Powerful computers in recent years have provided necessary tools for performing such simulations. This approach address losses by their causative events and therefore, can overcome deficiency with the integration approach. However, it has its own limitation as given below:

- Monte-Carlo simulation approach requires large number of simulations to provide results close to integration approach.
- Large computational power is required to perform required simulations.
- Unlike the integration approach in which variable uncertainties can be modeled with their probabilistic distributions, in this approach most of the variables have to be considered deterministically by their mean values. Allowing full probabilistic simulation requires a very large number of simulations.
- Due to computational power required for such simulation, most of loss models produced based on this approach contain pre-processed results and therefore, provide less flexibility to the end user for further manipulation on data and assumptions
- There is less contribution of uncertainties in the final results produced by this approach.

There are also hybrid approaches in which a combination of integration and simulation approaches are used to overcome the deficiency of each of these approaches.

Conclusion
Natural catastrophe loss models are essential tools for insurance and reinsurance risk mangers in recent years. They have been under significant improvement in recent years and now provide main tools for insurance risk pricing, risk accumulation estimate and risk transfer framework. These models are results of commercially oriented researches, which are often beyond the scale and affordability of scientific and governmental institutes. Their user-friendly environment and their ability to communicate with different financial enterprises, insurers, reinsurers, brokers and investors has created even more need and basis for further development in recent years.

However, due to many uncertain factors and assumptions used in developing and using these models, there are always uncertainties with results obtained from such models. More reliable data and more sophisticated catastrophe modeling may reduce some of these uncertainties, however, for the remaining factors, uncertainties should be traced and projected in the final results. Uncertainty should be captured at each modeling step as an integral part of the modeling design. It is insufficient to account for these uncertainties as an afterthought in the modeling process. Full probabilistic distribution should be computed throughout the process and not artificially derived at the end of the modeling process.