Development of a Catastrophe Risk Model to Manage Earthquake Risk and to Promote Catrisk Insurance in Iran

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Abstract
Many cities in Iran are exposed to seismic hazards with high potential for future human and economic disasters. There have been devastating earthquakes in recent decades with significant economic, social and political consequences. These events highlight the importance of effective risk management initiatives and have created demands for reliable assessments of catastrophe risks exposures in Iran. Among other concerns, demands for catrisk models to manage catastrophe risk transfer in terms of commercial insurance have been growing in recent years. This paper summarizes the methodology and preliminary results for a first-hand effort to provide a full probabilistic earthquake loss model for Iran. In this paper application of catrisk model for insurance and reinsurance risk pricing as well as accumulation control measures are presented. The paper also attracts attentions on how computer loss modelling can aid optimal design of property insurance program for mega cities in the developing countries where people generally cannot afford full risk-based insurance premium. It highlights how catastrophe risk assessment tools, used together with reliable building inventories and scientific knowledge, can help the insurance industry design affordable yet manageable catastrophe insurance products. It goes on to suggest how probabilistic catastrophe loss modelling can help local insurers to manage their portfolios and facilitate risk sharing among insurance companies and households.

Keywords: Catrisk Insurance, Catastrophe Loss Modelling, Developing Countries, Seismic Risk
1 INTRODUCTION

Population in many large cities in Iran has seen rapid growth in recent years mostly as a result of economic and social migration. Rapid urbanization in conjunction with high concentration of economic assets in urban areas in Iran have exposed big portions of population and economic resources to natural hazards. Earthquake, flood, storm and drought are among the most destructive natural hazards in this region. The increasing trend seen in the frequency and severity of natural catastrophes world-wide is far devastating in Iran, mostly due to high concentration of vulnerable exposure across the country. Financial authorities in Iran are looking for approaches to transfer risk responsibility to households and businesses in exposed areas through insurance mechanisms as well as transferring such risks to worldwide stakeholders through reinsurance and alternative risk transfer mechanisms. This approach has been effective in many developed countries with well-established private-sector insurance structures that are capable of spreading risks nationally and internationally. In the case of natural catastrophes, the risk transfer concept is structured laterally through the involvement of several actors. In general, ordinary people and property owners are on the front line of natural catastrophes dealing with their immediate consequences: loss of life and damage to or the complete destruction of properties. Furthermore, indirect and macroeconomic losses are sometimes related to the response of these groups. Business interruption, reduction in demand and loss of human capital, also depend on the response of ordinary civilians, property owners and building occupiers to natural hazard events. Insurance companies pave the way for catastrophe risks to be shared among households within an insurance company or further transferred to group of insurers using reinsurance and the wider population of economic agents using the financial and capital markets.

Essential to any well-structured catastrophe risk transfer system is proper and reliable assessment of the severities and frequencies of potential losses caused by future earthquakes. In today’s insurance and reinsurance market, catrisk models are key element for such assessments. Catrisk models have become an important part of insurers’ capital and underwriting processes, bringing a scientific and objective view of natural catastrophe risks. These models have also become a key component used in reinsurance purchase decisions and in many cases form the basis of reinsurance cost negotiations. This paper presents the modelling approach as well as basic statistics on the simulated probabilistic earthquake losses for Iran. CATRISK-ELMI calculates an event by event (EBE) damage probability distribution for each modelled risk. The model presents probabilistic risk estimates for different line of business and allows sensitivity analysis
on the effect of various insurance risk management measures such as insurance deductible and limit.

**Figure 1: Main catastrophe risk stack holders**

![Diagram of catastrophe risk stack holders](image)


2 DEVELOPING COUNTRIES AND NATURAL CATASTROPHES

Natural catastrophes, due to their unpredictable nature on one hand, and potential implications for the built environment and human activity on the other, have long caused disruptions to communities and damage to economies, especially in underdeveloped and developing countries. Such events, in addition to the short-term humanitarian and social disruptions, usually entail long-term economic and financial consequences that survivors must endure for months, if not years and years, after the catastrophe. A brief review of the natural catastrophe financial and economic effects of events in the last couple of decade reveals an increasing trend in the annual average losses related to natural catastrophes. Despite significant scientific and technological achievements made in recent years with regard to the assessment and mitigation of natural hazards, one may point to several reasons for continuing upward trend in the catastrophe related casualties and economic losses. The increase in the frequency and severity of natural catastrophe losses is the direct result of human actions. While geo-related hazards are considered natural phenomena, their losses are not completely natural and are correlated to the development growth.

3 DEVELOPING COUNTRIES AND CAT RISK MANAGEMENT

Governmental disaster management agencies have traditionally focused on actions that can be taken immediately before, during, or shortly after disasters to reduce the loss of life and economic damage. Effective natural catastrophe risk management is becoming a legitimate responsibility for many government and development agencies around the world and the approach to disaster management has recently evolved towards the wider concept of risk management principles. Governments in developing regions have become greatly concerned about the fiscal implications of total responsibility for natural
catastrophe losses. Many governments in the developing countries have begun to take proactive measures to minimize their exposure to natural catastrophe through a number of risk management principles such as risk assessment, vulnerability reduction and risk transfer.

3.1 *Cat Risk Assessment*

The first step towards any rational risk management efforts is the thorough understanding of spatial and temporal distributions of natural catastrophe risks. This is usually achieved through assessment of regional natural hazard, built environment inventory and their vulnerability. Natural catastrophe risk modelling has been under significant improvement in the last 15-20 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 loss estimates from such models are ideally suited to risk management entities as well as to the growing insurance and reinsurance industries.

3.2 *Cat Risk Reduction*

Risk reduction measures are considered to mitigate damage from natural hazards. Such measures for existing buildings address reduction of vulnerability through measures such as retrofit, strengthening and relocation. Other actions could be taken in order to reduce the vulnerability of the new buildings, through the implementation and enforcement of building standards, environmental protection measures, and land use planning that recognizes hazard zones and resource management practices. Despite such measures there are several factors which still remain outstanding in the developing countries which have resulted in a lack of improvement in the vulnerability of new buildings. In countries with proper implication of seismic design code, better performance is expected for newer buildings.

3.3 *Cat Risk Transfer*

For potential losses which could not be mitigated through structural or preventive damage reduction measures, or those exposed to very low frequency but high severity hazard, insurance mechanisms are used to transfer risks to other parties, including standard insurance and reinsurance contracts as well as the creation of contingency funds to build up economic and fiscal resilience in the face of natural hazards. Financial authorities in developing countries are seeking ways to transfer risk responsibility for the necessary coverage to households and businesses in exposed areas. This approach has shown to be effective in many developed counties with well-established private sector insurance structure in place, capable of spreading risks nationwide and internationally. Risk transfer is considered an important step towards transferring responsibility for post-
disaster recovery from the government to households in risk zones, and in doing so provides incentives for property owners to retrofit their apartments and take other mitigation measures (Gurenko & Lester, 2004). Due to the low frequency and high severity of natural hazards, natural catastrophe poses a unique challenge to the insurance industry, both for developed and developing countries. The diversification of catastrophe losses is difficult, sometime even at the global level, as some of these events have the potential of absorbing large quantities of capital and beyond those of regional or even international insurance capacities.

4 CAT RISKS AND INSURANCE INDUSTRY

Despite fast growing urbanization and high concentration of exposure in hazard prone areas, insurance companies in the developing countries retain most of their exposed risks. This is mostly due to undeveloped state of their domestic insurance markets and the lack of enough understanding of their accumulated risk which result in their inability to transfer risk to international reinsurance markets. In most developing countries, providing property insurance coverage on a national scale is still a challenging task for domestic insurance companies which are mainly due to:

- Small size of insurance industry and thin capitalization
- Low property insurance penetration
- Limited range of insurance policies
- Public perception of insurance premium as kind of government taxation
- Lack of a regulatory framework for effective risk pricing and validation of vulnerabilities
- Affordability to pay adequate premium given the level of hazard and vulnerability of existing building stock
- Limited risk transfer alternatives given high costs of reinsurance especially with foreign companies
- Insufficient expertise and capital to adequately protect policyholders
- Insolvency or failure to pay claims in case of a large event

In a healthy free insurance market, insurance premium is in principal based on proper risk assessment measures. In addition to pricing issues, insurance companies must evaluate and control their financial capacity, the number and the sum values of insured properties, and the amount of risk to be transferred to the upper layers.

5 EARTHQUAKE LOSS MODEL FOR IRAN (ELMI)

Due to the high severity and low frequency of natural catastrophe such as earthquakes, the use of traditional actuarial methods based on historical loss records, are inadequate
and incomplete. Natural catastrophe risk modelling has been under significant improvement in the last 15 to 20 years. Availability, flexibility and reliability of such models have been under improvement in recent years which made detailed risk analyses a routine practice for most insurance, reinsurance and brokers. In this paper a computer loss models is presented which will be used to evaluate potential losses from future events and provide facilities for better controlling exposure in Iran to potential losses. Once created, such tools will help insurance market in Iran to rationally quantify their status with regard to catrisk insurance rate, catrisk policy terms based on risk pricing and homeowner affordability, risk mitigation, healthy insurance penetration, risk-based premium, national awareness, catastrophe insurance law, design of cat pool, reinsurance purchase and many other insurance related measures. The development and application of a catastrophe risk model for Iran allows for the design of sound property insurance solutions for better risk sharing between households, local insurers and international reinsurers.

In general, an insurance-based catastrophe risk model consists of several main components as shown in Figure (2). The real impact of an earthquake on an urbanized area depends on the geographical distribution of the hazard induced by earthquakes, geographical distribution of the built environment and building vulnerability to the earthquake hazard. There are certain parameters defining natural event characteristics at its source, in the case of earthquake for example, earthquake locations, earthquake magnitudes and energy released patterns. Several factors control the severity and frequency of building damage caused by natural hazards. Geographical distribution of natural event and their induced hazards can be categorized under hazard factor and modelled by hazard models. The key to improving the ability to manage earthquake risk not only depends on the reliable assessment of seismic hazard but also on building-specific information. Such information include the knowledge of location, structural characteristics, usage and value of assets exposed to seismic hazard. Translation of natural hazards to physical or monetary damage is performed by vulnerability functions. Inventory of building stock is also required in order to estimate financial impact of natural hazard on built environment.

Figure 2: Main components of an insurance-based seismic loss model
5.1 Earthquake Hazard Model

In this study a regional and homogenous seismic hazard model is developed which covers Iran and the surrounding region. Regional tectonic features, together with historical and instrumental earthquakes were studied, to delineate seismic source zones and to determine seismicity parameters. Tools using geological and tectonic maps of the Middle East were created, with seismic interpretation such as spatial distribution of earthquake epicentres, earthquake ruptures and seismic moment distribution. This allowed us to delineate seismic source areas, to study the completeness of the earthquake catalogue, to determine seismic activity, and to define recurrence parameters for each seismic source.

To cover a complete picture of probabilistic seismic losses, a large set of synthetic earthquake scenarios were simulated using the seismic hazard model. The synthetically generated earthquake catalogue represents thousands year of possible future earthquakes for the study area, using characteristics of defined seismic source and their seismogenic parameters. The samples are representative of the spatial, temporal and size distribution of possible future events (Figure 3). Each simulated earthquake in CATRISK-ELMI acts like a real scenario with full seismotectonic characteristics derived from seismotectonic model. These synthetic earthquakes, in conjunction with ground motion attenuation relationships, provide probability density functions of shaking intensities at population centres.

Empirical Ground Motion Prediction Equations (EGMPE), were used to model shaking intensity distribution in terms of spectral acceleration. A selection of the NGA (Next Generation Attenuation) functions are used to allow epistemic uncertainty to be modelled, while the aleatory uncertainty is taken into account by full numerical integration of a lognormal distribution for each relationship. Full numerical integrated of uncertainties associated with ground motions prediction models as well as temporal and spatial distribution of probabilistic earthquakes, using total probability theory, results in probabilistic ground motion distribution. Examples of such maps for given return periods are used by engineers for design and urban planning policies.
5.2 Exposure Handling

Exposure data quality in Iran varies from country to country. Insurance and reinsurance underwriters are often facing with property insurance exposure data in aggregated format with little or no descriptions of risk characteristics and often with proxy location descriptions. CATRISK-ELMI provides tools and data models to import underwriting exposure and to distribute aggregated exposure to detailed locations and classes of vulnerabilities. To enable this, a database of hazard foot prints have been developed on a set of points in space on a variable resolution grid (VRG) with clear mapping of various administrative levels such as CRESTA zones, provinces and cities (Figure 5). This provides flexibility for mapping exposure of various administrative levels, and allows further disaggregation of aggregated exposure for more accurate loss calculation.
Figure 4: Geographical distribution of a 1000 years synthetically simulated earthquake catalogue for northern Iran [Zolfaghari, 2015]

Fig. 5: Variable resolution grid system used to sample seismic hazard distribution across the region

5.3 Vulnerability Module

CATRISK-ELMI has a library of vulnerability functions, providing estimates of damage distribution by spectral acceleration, and for various types of risks, classified by; Region, Risk Type, Coverage, Structural Material, Structural Height and Structural Quality. In addition to detailed vulnerability functions, default functions based on regional built environment are also provided for aggregate exposure with unknown vulnerability classes. The vulnerability functions also provide the mean and standard deviation of damage for each ground motion level. This distribution (for instance, Beta or lognormal) expresses the relative cost of repairs that a structure might require at a given hazard level.

6 CATRISK-ELMI FEATURES AND BENEFITS

This model numerically convolutes probability distributions associated with various model components to develop a probability distribution of overall damage for each building or group of buildings. Imported risks are first mapped to their right vulnerability classes to assign vulnerability functions. Each risk is also linked to a location on the
ground to read the pre-processed hazard distribution. In order to minimize the loss calculation run-time, hazard footprint for each earthquake has been pre-processed and plugged into the damage calculation engine.

6.1 Handling Uncertainties
There are many sources of uncertainty associated with data and assumptions used to model hazard and vulnerability modules that contribute to modelled loss statistics. The current practice for loss modelling either ignores some of these uncertainties or, if they are incorporated, uses proxy statistical approaches. In CATRISK-ELMI the effect of each simulated earthquake on individual risk is first represented by a hazard probability distribution, sampled in equally sized bins. Intensity measures, represented by each hazard bin, are combined with vulnerability functions to return a damage distribution. Full numerical integration of hazard and damage distributions is performed, resulting in event damage distributions. These distributions are sampled further using Monte Carlo simulations to allow the correct aggregation of loss at other levels.

Figure 6: Full numerical integration of uncertainties associated with various components
6.2 How CATRISK-ELMI Can Help

Development of catastrophe risk model based on engineering, science and real experience are well established in the insurance and reinsurance market for the developed countries, with an overall expense of 400-500 million dollars a year. However, due to low penetration of catastrophe insurance in Iran and the lack of proper attention to risk transfer during the sanction years, there has been no or little interest to develop such model for Iran. The author believes that creation of CATRISK-ELMI not only help the insurance industry to step into classic risk management and risk transfer principles, but also helps higher penetration of property insurance which in turn helps the development of domestic insurance market. Additional benefits of such tools for Iran include:

- Actuarial studies to determine risk-based rates for catastrophe insurance
- Preparation of policy terms and conditions based on risk pricing as well as regional affordability and risk attitude
- To increase the healthy penetration of insurance market, taking into account risk-based premium derived from proper risk assessment exercise
- Assessment of accumulate potential exposure for each company and across the country
- Assess benefits of portfolio diversification, hence reduce capital requirements
- Perform dynamic financial analysis to improve selection of risk, reduce risk transfer cost, improve risk pricing and offer competitive advantage
- To bring specialized expertise in catastrophe risk management to the domestic insurance sector and assist the industry to build a well-capitalized professionally managed specialized insurance market
- To investigate available alternative risk transfer solutions
- To review of the existing legislation and preparation of the catastrophe insurance law
- To develop a risk-based underwriting and pricing system which provide supports for changes in land use planning, help mitigation and building retrofit programs and improve building construction practices
- To increase national awareness and education on the risk of natural disasters
- Could be used also in disaster management applications, such as response planning, post-disaster damage assessment, and reconstruction financing estimation

7 CATRISK-ELMI SAMPLE RESULTS

In this study, the residential building stock for entire country, derived from the latest census are modelled against probabilistic earthquakes in order to assess potential
economic losses. The building in each census block are associated to their vulnerability classes and then analysed against seismic hazard from simulated earthquakes. Each simulated earthquake acts like a real earthquake scenario. Instead of simulated earthquakes one may assess simulated losses from all recorded earthquakes in the last centuries. For example, Figure (7) shows the size of estimated economic damages to residential building stock as result of recoded earthquakes in the last few centuries.

Catastrophe loss assessment tools, in addition to scenario loss estimates, provide probabilistic loss statistics in terms of Exceedance Probability (EP) curves and Annual Mean Losses (AML) mostly used by insurers to estimate their PML and premium. AML is representative of the long-term annualized expected losses that insurance company may suffer and therefore, on top of which other costs (surcharges, profits and uncertainties) are loaded to arrive at an insurance premium. Despite high potential natural catastrophe exposure, the penetration of property insurance in Iran is relatively low. Among many factors contributing to low insurance penetration are lack of proper risk assessment measures towards effective risk pricing and also low affordability for the general public to pay for adequate premium, given the level of hazard and vulnerability of existing building stock.

As another example, CATRISK-ELMI is used to show how computer loss modelling can help in the optimal design of property insurance contracts, where people cannot afford the full risk-based insurance premium. It demonstrates how residential insurance policies can be designed to better facilitate the degree of risk sharing between households and insurance companies by using policy conditions such as risk deductibles and limits. To illustrate such concepts, the effects of risk deductibles and limits on insured losses (PML’s and AML’s) for residential buildings in the study area are investigated. Figures (8) show the effect of various policy deductible on probabilistic seismic losses for this area. The reduction in the insurer’s liability at different return periods are also shown in Figure (8).
Figure 7: Assessment of economic losses to residential building stocks due to recurrence of historical earthquakes

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<th>Policy Conditions</th>
<th>Probabilistic Seismic Loss Ratio</th>
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<td>Limit (%)</td>
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Figure 8: Effect of policy deductibles and limit on insured losses for residential buildings a) Probabilistic loss curves b) Loss reduction ratios induced by policy deductible and limit (Zolfaghari, 2008)

8 CONCLUSIONS
The adverse economic effects of natural hazards on developing countries such as Iran are far more significant than with developed countries. This is mainly due to limited financial resources available to developing countries and the lack of proper risk management strategies and programmes. Dealing with natural hazard makes several challenging issues for governments in these countries. Managing and sharing the limited financial resources between risk mitigation measures and pooling for post-disaster recovery plans remains a key challenge. One of the reason for current undeveloped state of the domestic insurance market in Iran is some 10 years of international sanction which resulted in their inability to transfer risk to international reinsurance markets. This paper has attempted to highlight how a catastrophe risk assessment tool, used together with reliable building inventories and scientific knowledge, can help the insurance industry to price, regulate and transfer cat risks for Iran. The development and application of this tool can open up the possibility of the creation of a robust property insurance framework...
one that allows for the improved risk sharing between households, national or regional insurers, and international reinsurers.

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10 REFERENCES
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