Introducing a national earthquake vulnerability index

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Abstract: An earthquake is recognized as one of the most catastrophic geohazards for many countries in the world. Earthquakes can cause loss of life, damage to buildings and infrastructures as well as severe psychological destructions. The impact of psychological destructions is always beyond the local geographic scale and its significance depends on a number of parameters such as the loss of life and economic damages. It affects the whole nation and to some extent the neighbouring countries and worldwide.

In this article the concept of national earthquake vulnerability index is introduced and contributing parameters, potential applications and concerned countries are described. Finally a methodology for quantification of the index at global scale is presented.

Résumé: Précis- Le tremblement de terre est considère comme un facteur le plus catastrophique pour la plupart des pays. Il est capable de tuer beaucoup d'hommes, de détruire les constructions et les infrastructures ainsi que les destructions psychologiques. L'effet de ces destructions psychologiques va parfois au delà de la région géographique où cette catastrophe a eu lieu. Son importance dépend des paramètres comme le nombre des tués et des dommages économiques subis. Dans le cas où une grande catastrophe se trouve dans un pays, il est évident que tous les habitants et même les habitants des pays en voisinage en seront touches.

Dans cet article, nous allons vous présenter l'index de vulnérabilité nationale vis-à-vis un tremblement de terre. Les paramètres efficaces ainsi que les applications potentielles aux pays émus de cette catastrophe ont été expliquent. On va enfin présenter une méthode pour déterminer la quantité de cet index dans une mesure mondiale.

Keywords: earthquakes, geological hazards, models, seismic risk, data analysis, classification.

INTRODUCTION

In recent years, quantification of earthquake vulnerability has been an attractive topic for many scientists. Organizations involved in natural disaster mitigation programs are interested to predict the extent, the frequency, and the nature of losses in case of a major disaster. The objective of an earthquake vulnerability model is prediction of the extent of the losses at a projected scale and/or in a variety of scenarios. Therefore, earthquake vulnerability is a concept helping to create a better understanding of areas expected to undergo more losses in a certain geographic extent and a certain period of time. Accordingly, vulnerability has been viewed at different scales for a variety of issues. Available earthquake vulnerability models for residential buildings at different scale may be listed as follows (Zonno et al. 2003):

- Earthquake vulnerability for a single residential building
- Earthquake vulnerability for residential buildings at a district (locality) scale
- Earthquake vulnerability for residential buildings at scale of a town
- Earthquake vulnerability for residential buildings at scale of a state including several towns (regional)

Earthquake vulnerability for the following concerns has also been studied and modelled (Torres-Vera & Canas 2003):

- Life lines (in general)
- Hospitals
- Power systems
- Bridges and roadways

For each of the above-mentioned issues modelling may be conducted at different scales of regional, town, district or a single object. Common steps for an earthquake vulnerability modelling, independent of scale or concerns may be summarized as follows:

- Identification of important parameters,
- Generalization of parameters,
- Quantification of parameters,
- Modelling,
- And testing of the model.

INDEX DEFINITION

Introducing the concept of Country Vulnerability Index (I_{CV}) seems to be a global need for better understanding of earthquake vulnerability at country scale. The author defines this as an index for determining the most vulnerable countries against earthquake at a period of time. The index must be defined such that it could predict which countries are expected to suffer more from earthquake disasters, in certain period of time. This involves both economic and life losses. Likewise recent earthquake activities are the most reliable sources of information for any prediction attempts. Consequently, the first rank country based on this index must be a country that has experienced the most severe disasters in a long-term period of time.

As the basic economic strength and population of countries differ significantly, a certain amount of losses could have a different impact on the country depending on the basics of that country. On the other hand, the severity of an earthquake disaster could be judged from different points of view, as it will be discussed later in the text. Therefore the index must be able to reflect on all these facts.

PARAMETER STUDY

The general rule for a parameter study is, the smaller the scale of the earthquake vulnerability investigation, the less the number of influencing parameters. This is because at small scale, the number of objects (e.g. buildings) increases rapidly. If so many parameters were involved in practice, it would be impossible to collect and model all data. For example, modelling earthquake vulnerability of a single residential building may involve up to 50 parameters (Asef & Kessmati 2005), but the same model at smaller scales of a town involves less than 10 parameters (Zonno et al. 2003). Accordingly, the number of parameters, at country scale is not expected to be more that 5 or 6.

An investigation was conducted determining important parameters to incorporate in the model. Some parameters such as economic losses could be very useful, but availability and consistency of data for old records was a real question. Finally, the following parameters were considered:

- The number Fatality for each Country (F_C)
- The Country Population divided by one million (P_C)
- The number of Country Disaster Occurrences (D_{CO})
- The Magnitude of earthquake records (M)

The number of fatality is the most important issue in terms of psychological and economic concerns. The impact of this parameter could be at scale of a town, a state, a country and even the whole world depending on the severity of the disaster. As far as possible, an attempt was made to suggest most appropriate terminologies and abbreviation, while any two terminologies comprise similar first letter were avoided. This could help to escape duplicate abbreviations creating ambiguous acronyms. However a to z list of abbreviations used to create acronyms is presented in appendix. Using this appendix could help fast reading and understanding of the paper.

QUANTIFICATION METHODOLOGY

Having set the essential parameters, five criteria/indexes were defined in order to quantify the severity of earthquake records for each country compared to other countries. These criteria/indexes are as follows:

1) Country Fatality (F_C), defined as the sum of the fatality in earthquake disasters for each country in a certain period of time.

2) Country Fatality Burden (F_{CB}), a dimensionless criterion defined as the number of fatality in earthquake disasters for each country relative to its population in a certain period of time:

Country Fatality Burden $(F_{CB}) = (F_C) / (P_C)$

Based on this criterion, the worst case is when a country of small population encounters a disaster with a large number of fatalities. The logic behind, is that in case of a disaster, the psychological and economical shock to a country, to a large extent could be tolerated if enough man force is available to help in short time and replace the lost people afterwards. In other words, the competency of each country for crisis management in long term after a disaster, to some extent depends on its manpower. As a numerical example, Country Fatality Burden (F_{CB}) for an earthquake resulting in 10000 death in a country of 10 million population ($F_{CB} = 0.001$) would be equal to 100000 death for a country of 100 million population. Therefore, the Country Fatality Burden suggests for a country of 10 million-population vulnerability to economical and psychological losses as a result of an earthquake with 10000 deaths is considered the same as that for a country of 100 million population encountered an earthquake of 100000 deaths.

3) Another important aspect of country vulnerability to earthquake disasters is the magnitude of the earthquake records (M) in a period of time. However, the magnitude reported in Richter scale is logarithmic. And it is more convenient to express all parameters non-logarithmic. Therefore, the Energy (E) release for each record in the database was calculated based on the theoretical relationship between the magnitude and energy release according to Gutenberg and Richter (1956):

$$\text{Log } E = 4.8 + 1.5M$$

And then

$E_M = 10^{(4.8 + 1.5 * M)}$

It follows that, in a period of time for each country, the Country Energy Strike (E_{CS}) was defined as the sum of the energy release for each record relative to an earthquake with a magnitude of five (M = 5):

Country Energy Strike (E_{CS}) = Σ (E_M / E_5)

$E_5 = 10^{(4.8 + 1.5 * 5)}$

Considering the logarithmic increase of energy release and the wide range of recorded M values (from M=5 up to M=9), the use of a relative value instead of the absolute value of E could avoid extremely large figures.

4) The Country Disaster Occurrences (D_{CO}), defined as the number of disasters for each country in a certain period of time, is a criteria/index determining which countries experience earthquake disasters (of above 1000 fatality) more frequently. Considering the number of disasters rather than the number of large magnitude earthquakes is more convenient because it excludes after shock records related to the same disaster and also excludes earthquakes occurred in remote areas. This approach could help to find out where has been the most problematic area in the world for a certain period of time.

5) Country Fatality-Energy Index (I_{CFE}), defined as the rate of fatality per energy strike for each country, is a criteria/index determining the amount of energy strike, required to cause one death during a major disaster in that country, in a certain period of time. A major disaster here means an earthquake with more than 1000 fatality.

Country Fatality-Energy Index (I_{CFE}) = (F_C) / (E_{CS})

This criterion indirectly underlines in which countries the lowest amount of energy release causes the highest rate of fatality. A country aimed the first rank in (I_{CFE}), has experienced the highest rate of fatality for weak (low magnitude) earthquakes in a certain period of time, compared to other countries. A high rate of death in case of a low magnitude earthquake could be because of buildings earthquake vulnerability, disaster mismanagement, high population density, or a combination of these grounds. Besides, secondary natural disasters such as landslide, liquefaction, flooding etc. could cause dramatic increase of fatality.

Having defined the above criteria/indexes, a database of global earthquake disasters causing more than 1000 fatality (USGS 2005) plus the latest country population information (U.S. Bureau of the Census, 2005) was prepared. Therefore in this research, only records with more than 1000 death were analysed. A total of 35 countries were involved in this database. All records since 1900 were extracted. For each record the five criteria was computed. The rank of all countries for each criterion was determined. It was interesting that based on the five criteria/indexes defined above; five different countries obtained the first rank. A simple conclusion from this fact was obtained: Each criterion is an important characteristic of an earthquake disaster, confirming the severity of occurrences from one viewpoint. However, none of them individually, can sufficiently explain the severity of earthquake disasters for one country relative to other countries. The symptom is that, the first rank country is inconsistent with the five defined criteria (Table 1). Therefore, the Country Vulnerability Index (I_{CV}) cannot be defined based on any of these criteria, individually. Rather, it must be defined based on all these criteria.

Table 1. The first rank country based on the defined earthquake disaster severity criteria.

Criteria	**First rank C**	**Interpretation based on Criteria definition**
C Energy Strike (E_{CS})	Chile	The highest amount of energy stricken
C Fatality (F_C)	China	The largest number of fatality
C Fatality Burden (F_{CB})	Turkmenistan	The highest rate of fatality relative to the country population
C Disaster Occurrences (D_{CO})	Iran	The largest number of disaster occurrences
C Fatality-Energy Index (I_{CFE})	Morocco	The highest rate of fatality per energy release

C: Country

In order to combine these five criteria, it was necessary to unify the order of magnitude of the values obtained based on each criterion relative to other criteria. Accordingly, a simple methodology was introduced as follows (step by step from a to c):

a) For each criterion, the rank of each country relative to other countries was computed. Therefore, the worst case country would get (RF_c) = 1 and a country having the least fatality in the database would get (RF_c) = 35. The Rank parameters were obtained as described in Table 2.

Table 2. Rank parameters and descriptions based on the five defined criteria.

Rank parameter acronym	**Description**
(RE_{CS})	Country Rank in Energy Strike
(RF_C)	Country Rank in Fatality
(RF_{CB})	Country Rank in Fatality Burden
(RD_{CO})	Country Rank in Number of Disaster Occurrences
(RI_{CFE})	Country Rank in Fatality-Energy Index

b) Then the Normalized Rank parameter of each country for each criterion was computed. Equation definitions are presented in Table 3.

Table 3. Equation definition for five Normalized Rank parameters.

N Rank parameter	Description	Equation definition
(NRE_{CS})	N C Rank in Energy Strike	$= 100 * ([((RE_{CS}) – 1) / (A_{TC})])$
(NRF_{C})	N C Rank in Fatality	$= 100 * ([((RF_{C}) – 1) / (A_{TC})])$
(NRF_{CB})	N C Rank in Fatality Burden	$= 100 * ([((RF_{CB}) – 1) / (A_{TC})])$
(NRD_{CO})	N C Rank in Disaster Occurrences	$= 100 * ([((RD_{CO}) – 1) / (A_{TC})])$
(NRI_{CFE})	N C Rank in Fatality-Energy Index	$= 100 * ([(RI_{CFE}) – 1) / (A_{TC})])$

N: Normalized
C: Country
(A_{TC}) = Total Countries Affected = 35 (= countries in the database)

The primary value of the Normalized Rank parameter for each criterion was defined as the Rank parameter minus one (e.g. $(RF_c) – 1$) divided by the Total Countries Affected (A_{TC}). Although the primary value of the Normalized Rank parameters (e.g. $[((RF_c) – 1) / (A_{TC})]$) was a value ranging from 0 to 1, it was more convenient multiply it by 100 and report the values ranging from 0 to 100. Subtracting one increment from Rank parameter set the minimum value of the Rank parameter (the worst case country) to zero. When Rank parameter minus one (e.g. $((RF_c) – 1)$) is divided by (A_{TC}) the value of Normalised Rank parameter is converted in reverse order. The worst case country (e.g. China for F_c) acquires $(NRF_c) = 0$, and a country experienced the minimum number of fatality in the period of study would get $(NRF_c) = ((35-1)/34)*100=97.1$. The maximum Normalised Rank parameter $(NRF_c) = 100$, belong to a country with no records of fatality more than 1000 in a disaster (records out of the database). Based on this procedure, for each criterion the worst case country (first rank country) would obtain a value of zero and the minimum value would be near to 100 (≈97.1) for a country achieved the lowest value for that criterion (last rank country in the database).

c) Finally, the Country Vulnerability Index (I_{CV}) was defined as the average of the normalized country rank based on the five criteria:

$$(I_{CV}) = (1 / 5) * [(NRE_{CS}) + (NRF_{C}) + (NRF_{CB}) + (NRD_{CO}) + (NRI_{CFE})]$$

According to this definition, the value of (I_{CV}) for each country could vary from 0 to 100. A country with $(I_{CV}) = 0$ is a country obtained the first rank based on the five criteria. This means a country with $(I_{CV}) = 0$, has experienced the highest amount of energy stricken, the largest number of fatality, the highest rate of fatality relative to the country population, the largest number of disaster occurrences, and the highest rate of fatality per energy release. In reality, concerned countries may be vulnerable based on one or two criteria. However, a country with a high rank based on the five criteria will obtain the last rank in (I_{CV}) relative to other countries. Based on the database of the earthquakes with more than 1000 fatality in the last 105 years (since 1900) the last rank for Country Vulnerability Index (the worst country) is Iran with $(I_{CV} = 8.6)$. It should be noted that Iran is not only last rank country based on (I_{CV}), but also has achieved a value of (I_{CV}) very close to 0. This means that disaster occurrences in Iran have been sever in all respects and based on all the five criteria for more than a century. The value of (I_{CV}) for some other countries in order in the list is presented in Table 4. More details about the concerned countries and the value of (I_{CV}) will be published soon.

Table 4. The most vulnerable countries based on accumulated data since 105 years ago. Countries are sorted in ascending order of the value of (I_{CV}).

Country	Rank	(I_{CV})
Iran	35	8.6
China	34	14.9
Turkey – Italy	33	20.0
Japan	32	21.7
Indonesia	31	25.7

POTENTIAL APPLICATIONS

It is extremely important for all concerned countries to discover how vulnerable is their country relative to other countries, and what criteria can better explain their situation. The methodology presented in this paper delivers an alternative to achieve this objective. Organizations involved in natural disaster mitigation programs at global scale, are interested to know what the nature of vulnerability of different countries is in general terms. The criteria presented in this research could provide the means to classify countries on the basis of certain objectives. Classification usually helps to better understand the events, and better predict the future. Classifications could also provide a decision support means for planning earthquake mitigation programs at global scale, on the basis of the nature of disasters in most vulnerable countries. However, it is appropriate to remind the fact that earthquake is a natural disasters with lots of uncertainties. Therefore, any attempt towards classification and prediction should be viewed with respect to this fact.

Insurance companies operating at global scale, admire the same aspects explained above, plus an economic logic for their activities. The economic logic conventionally drives the company to obtain any feasible information and analysis to direct the company towards more comprehensible agreements. A good example is reinsurance contracts with countries of different vulnerability incentives.

CONCLUSIONS

The fact is that all countries experienced earthquakes with more than 1000 fatality in the last century are vulnerable against earthquake. However, the nature of severity of disasters could vary from one country to another. In this paper, the basic vision was that the economic strength and population of affected countries differ significantly, making a certain amount of losses to have a different impact on the country. This research identified five criteria/index of energy strike, fatality, fatality burden, the number of disaster occurrences, and fatality-energy index, to describe countries earthquake vulnerability. A methodology was suggested to quantify Country Vulnerability Index (I_{cv}). The value of (I_{cv}) can vary from 0 for the most vulnerable country to near 100 for the less vulnerable county compared to other countries in the database.

Amongst 35 countries experienced earthquake disasters of more than 1000 fatality since 1900, Iran has been the worst case country in all respects, obtaining the minimum value of Country Vulnerability Index ($I_{cv} = 8.6$). The value of 8.6 is very close to zero. This mean the disasters occurred in Iran were severe in all respects for more than a century. Other highly vulnerable countries in the list were China, Turkey, Italy, Japan, and Indonesia respectively.

The methodology presented in this paper delivers an alternative approach to discover how vulnerable a country relative to other countries is in general, and what criteria can better explain its situation. More specifically, the rank of each country for each criterion can reveal what are the main sources making a country so vulnerable compared to others. It could also provide the means to classify countries on the basis of certain objectives.

Organizations involved in natural disaster mitigation programs at global scale, and insurance companies operating at global scale, especially those involved in reinsurance contracts with countries of different vulnerability incentives could be potential users of this approach.

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APPENDIX

A to z list of abbreviations and meanings:

A: Affected
B: Burden
C: Country
D: Disaster
E: Energy
F: Fatality
I: Index
M: Magnitude
N: Normalized
O: Occurrence
P: Population
R: Rank
S: Strike
T: Total
V: Vulnerability