Multidisciplinary Integrated Tools in Seismic Risk Management

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Abstract

Earthquake disaster is inevitable but it is possible to manage the potential risk by assessing contributory factors in a hierarchical manner. In this paper the risk assessment techniques are classified into two major groups: *Conventional Methods*, based on the classical perspective of reducing consequences or impacts of earthquake damages; *Holistic Models*, based on modelling characterisation of the risk sources through a multidisciplinary approach. Since the conventional methods target a limited audience, holistic models are suggested to cover a new range of applications. A decision support tool is proposed which includes a matrix presents a multi attribute technique to demonstrate the ability and scope of analysis appropriately. General framework of the indicator system as core concept in holistic models is also discussed. This tool would help decision makers to incorporate the knowledge of seismic risk to build an appropriate strategy at national, regional or local level.

Keywords: seismic risk management, holistic models, indicator system

1. Introduction

Making decisions in high-seismic regions usually involves different considerations than in areas without any earthquake threat. Mitigation projects without effective risk assessment may fail to reduce the seismic risk and its consequences. Mora et al (2006) pointed out many reasons for lack of proactive risk management and stressed on incorporating multi attribute factors of mitigation, such as financial and social protection to control the cause and consequence of seismic risk in early stage of projects. Chen et al (2005) developed an economical index (e.g. GDP) to address the significant increase in loss due to earthquake events. Nevertheless, the performance of any risk analysis is mainly dependent upon the methodology used and the comprehensiveness of the available data to be collected from focused region. In the context of seismic risk due to large uncertainty in both methodology and hazard data, selecting the appropriate tools considering these issues seems to be a crucial decision.

Traditionally, wide range of techniques is still available to estimate the seismic risk, regardless of their capability, effectiveness and degree of uncertainty; however, several studies have shown that few techniques could be used in practice effectively and efficiently. Moreover, the variety of tools and data may be misleading in the selecting of appropriate technique by decision makers (DMs). Consequently, within different contexts, there is a strong need for a metric to be employed in risk identification and assessment and registration. To cover this gap, a decision support tool is developed. This tool comprises a comparative matrix that assists DMs to choose appropriate technique considering different aspects of methodology, range of data, degree of subjectivity and scale of analysis.

2. Risk and uncertainty

The concept of risk can have variable meanings depending on the context either qualitatively or quantitatively. The most common definition of risk states the risk as a product of likelihood an event and consequence of it as displayed below:

Risk = Likelihood x Consequence (Ansell 1992; FEMA 2004)

Based on the above definition the qualitative measures of seismic risk can be expressed in a matrix (Figure 1).In the risk matrix, the qualitative risk scale can be categorized as low, moderate and high which is the multiple product of severity of consequence and degree of likelihood. For example, earthquake hazard is recognized as low-likelihood, high consequence event and according to this matrix, it is deemed as a moderate risk.

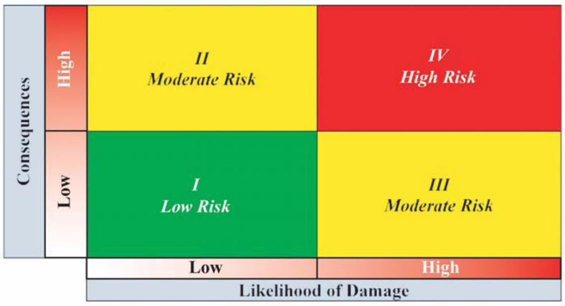

Figure 1: Qualitative expression of seismic risk (FEMA 2004)

In contrast, quantitative definition of risk, which is described by Varnes (1984) considers risk as a product of "V=vulnerability", "H=hazard" and "E=exposed elements or assets" in equation of ***R= HxVxE.*** This expression has gained international acceptance according to UNDRO (1982) and adopted by FEMA (2004). "Exposed elements "or "Elements at risk" are objects which posses the potential to be adversely affected, e.g. people, properties, infrastructure and economic activities including public services (Hufschmidt 2005; Cardona 2007). Since the quantitative measure of risk is not always possible, due to a lack of data, so qualitative estimation may be applied based on expert opinion. However, it is acknowledged by practitioners that considerable uncertainties exist in any analysis of risk based on subjective expert experience. These uncertainties might be caused by many sources in both quantitative and qualitative approaches due to imprecision in data or parameters, modelling and incompleteness of knowledge in general.

2.1 Seismic Risk Management (SRM)

Having accepted the risk management as “the reaction to perceived risks”, SRM can be admissible as a set of activities and decision making in every stage of a project to reduce or mitigate the impact of earthquake (Muhlbauer 2004; FEMA 2004).Hence, the new concept of seismic risk management is consistent with four distinct components: mitigation, preparedness, response and recovery (Canton 2007). Different views on SRM are proposed in various analytical concepts which attempt to systemise the model through holistic approach. A distinguished conceptual framework of seismic risk which referred many factors from various disciplines is presented by Davidson (1997) and adopted by Bollin et al (2003). This framework considers seismic risk as product of hazard, vulnerability, exposure and capacity measures as shown in Figure 2.While Vulnerability is defined through four different factors, hazard is characterised by probability and severity. In contrast, while exposure is determined using structures, population and economy factors, capacity and measures is closely addressed the resilience concept.

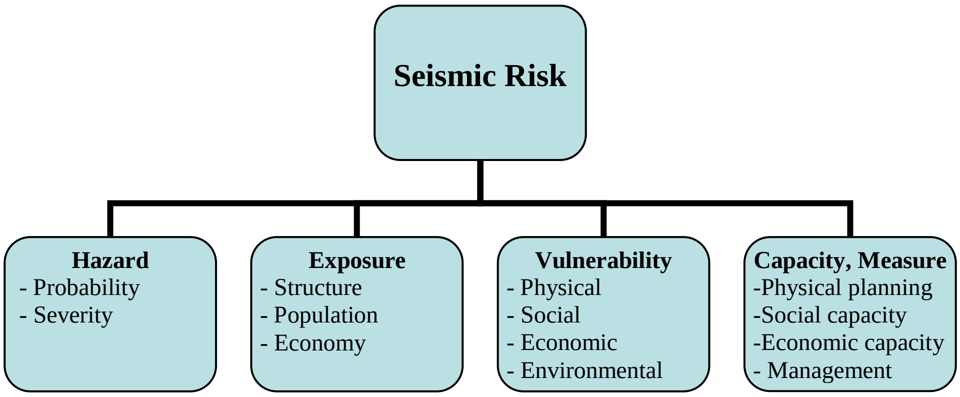

Figure 2: The conceptual framework to SRM (Davidson 1997, Bollin 2003)

Many approaches are developed to model seismic risk and vulnerability by integrating data. While inductive approaches, model the risk through weighing and combining different hazard, vulnerability and risk reduction variables (i.e. risk indexing system),deductive approaches , whereas it is also possible to use historical pattern to define a new scenario of likely earthquake (i.e. disasters, damage and loss estimation methods). A major impediment of inductive modelling is lack of standard procedures for assessing values and weights to the different risk contributing factors (i.e. hazard, vulnerability and exposure).Deductive modelling, in the other hand, due to large uncertainty of data, could not completely reflect the risk when frequency of hazards are low and thus historical data are not available (Cardona, 2003).Despite of this weakness, deductive approaches is utilised effectively in regional scope to assess the risk using severity of hazards and to validate the results from inductive models.

Quantification of various sources of uncertainty is crucial to develop the models of SRM. The modelling and evaluation of low-probability, high-consequence natural events involve significant uncertainties arising from imperfect knowledge and modelling, simplifications, and limited databases. To assess the uncertainties in the SRM, many techniques have been introduced including analytical methods, sensitivity analysis and Monte Carlo simulation. All of these techniques examine the interaction of variability between input and output parameters in risk analysis.

3. Risk indicator system

Risk indicator system employs different subjective indicators to reflect multiple aspects of risk, vulnerability, preparedness and mitigation (Birkmann 2007).Various indicators can be designed for risk analysis and risk management purposes. Using indicators to estimate or measure risks, allow combination of factors relating to vulnerability, hazards and exposure qualitatively and quantitatively. Indicators allow the identification of attributes that are not feasible, to estimate easily or turn to be imprecise using mathematical models or algorithms (Cardona et al 2003). System of indicators are also stressed in Hyogo Framework for Action (HFA) 2005-2015, multi scales in order to assess the impact of disasters on social, economic and environmental conditions (UN 2005). The character of an index comes from the particular elements and values chosen as important for measurement, the subjects and scope (local, regional, national, global) of analysis, the methodology used to generate the index from input data and the specific data sources used.

Risk indicator application is proposed by Davidson (1997, 1998) as "Earthquake Disaster Risk Index" (EDRI), a composite index to compare the relative risk of cities subject to various socio-economic factors. The newer version of indicator system which is developed by Cardona (2001) focused on different zones of a city based on holistic view. He considered the conceptual framework consist of exposure and socioeconomic characteristics of the different localities (units) of the city as well as disaster coping capacity or resilience factor. The model was made to guide decision making in risk management, helping to identify the critical zones of the city and different aspects of vulnerability (e.g. physical, economic). Carreno et al (2007) have developed a revised version of the holistic model to evaluate risk in terms of "physical damage", obtained from exposure and physical susceptibility ,and an "impact factor", obtained from the socio-economic fragilities and lack of resilience (Birkmann 2006).

4. Models in seismic risk management

Depending on risk assessment methodology, current techniques falls into two categories include:

- *Conventional Methods*; based on the predicting probable losses to a given element at risk over a specified time frame (Coburn and Spence 2002)

- *Holistic Models* ; based on modelling characterisation of risk sources through a multidisciplinary approach

4.1 Conventional Methods

The conventional methods use the statistical database to deduce the seismic risk and try to fit probability distributions to the data from which predictions can be made. This traditional concept focus on reducing the expected consequences or impact of earthquake damage and economic loss as it is distributed throughout a region. Impact of earthquake is then created by estimating death, injuries, damaged buildings or other economical factors. Two common approaches in this context are pointed in following subsections.

1.1.1 Loss Estimation

Earthquake loss models use a probabilistic approach in which predicted damages in various categories of structure and facilities in the region concerned are estimated and added together to obtain a total loss for particular intensity ranges (Coburn and Spence 2002). Such approach requires detailed inventory database of the structures and facilities in the region, which is not always readily available in many regions of the world. The most comprehensive work toward earthquake risk calculation until today is provided in HAZUS (FEMA 2003) which is developed mainly for damage estimation caused by earthquakes in the United States.

Current loss estimation methodologies have several limitations, due to lack of data and complex nature of contributing factors. Most methods for estimating earthquake losses require a detailed inventory of the facilities and structures in the region. In many cases, however, difficulties in acquiring such database, coupled with insufficient knowledge of local faults and soil conditions render difficulties undertaking this kind of loss studies. Also, the basis upon which a loss estimate is made by a particular city may not be used by another, or even outside its city limits. Consequently, earthquake loss estimation is mostly done for individual cities or areas (e.g., Algermissen, 1989; Steinbrugge et al., 1987).

4.1.2 Earthquake Scenario

The scenario study is an analytical approach which is also based on statistics of past earthquake damage, such as the 1985 Mexico City damage, which provided a wealth of experience could be used in later scenarios and for calibration(Molina et al 2007). They are used to estimate the likely losses of extreme earthquake, to check the financial resilience and resources needed for emergency disaster management. To build a scenario, often the “maximum probable” or “maximum credible” severity of earthquake is assumed (Coburn *et al.*, 2002).

Scenarios are widely used to understand better and to help planning for the future by improving awareness and response to a certain earthquake and its specific impacts. It helps decision makers to visualize specific impacts that are based on currently accepted scientific and engineering knowledge. By describing a single, catastrophic event, a community can produce a scenario that realistically describes the earthquake risk and potential impacts, giving clear reasons for individuals, businesses, and policy makers to act now and prevent devastating losses. However various source of information such as local seismicity and geology, GIS data, current characteristics of the building stock are needed to build and project an earthquake over a community to get a plausible feedback.

4.2 Holistic Models

Holistic models are referred to ways of describing risk as product of multiple factors in a given indicator system. In the framework of indicator system, numerous factors can be brought together and classified in order to simplify the complexity of the seismic risk concept. The most recent classification developed by UNDP and GTZ have been proposed for the national and regional levels and include several quantifiable risk indicators (UNDP 2003; GTZ 2003). Throughout the process, a decision support system (DSS) can be employed to generate the risk indices by processing multi-attribute information in a hierarchical structure as indicated in Figure 3.These indices can help DMs to benchmark and compare the seismic risk in different regions.

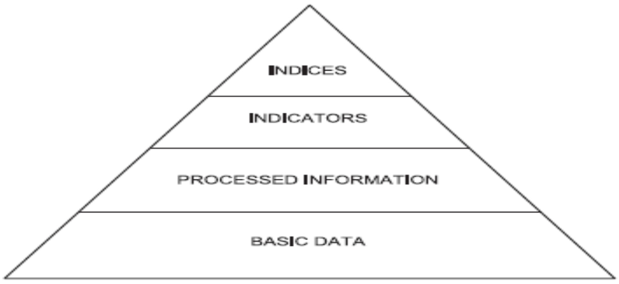

Figure 3: The hierarchical structure of data in holistic concept (Birkmann 2006)

All approaches presented in this context are based on a common theory which defines the disaster risk as a product of three major elements, the frequency or severity of the hazard, exposure and the vulnerability. Moreover, all the approaches aim to measure risk and vulnerability through selected comparative indicators in a quantitative way in order to be able to compare different areas or communities (Dilley et al., 2005; Peduzzi, 2006; Bollin et al, 2006; Cardona, 2005). Defining the scope of analysis, the model implements appropriate indicators which may contribute in the risk's elements. Mathematical combination is then employed for scaling different range of indicators. Analytical ranking/scoring methods could be utilised to make a relative importance of indicators contribute in risk. The combination of scaled indicators could generate seismic risk indices which can be implemented in final stage of procedure.

Typically, the procedure of holistic approaches can be demonstrated as shown in Figure 4. In contrast to the conventional methods which are targeted limited scope of audience such as national and global scale, the holistic models could also focus on regional and local scale as well. However, the weakness of indicator system is principally associated with large subjectivity in estimation, selection of variables, measurement techniques used, and the aggregating procedures employed (Cardona et al 2003).

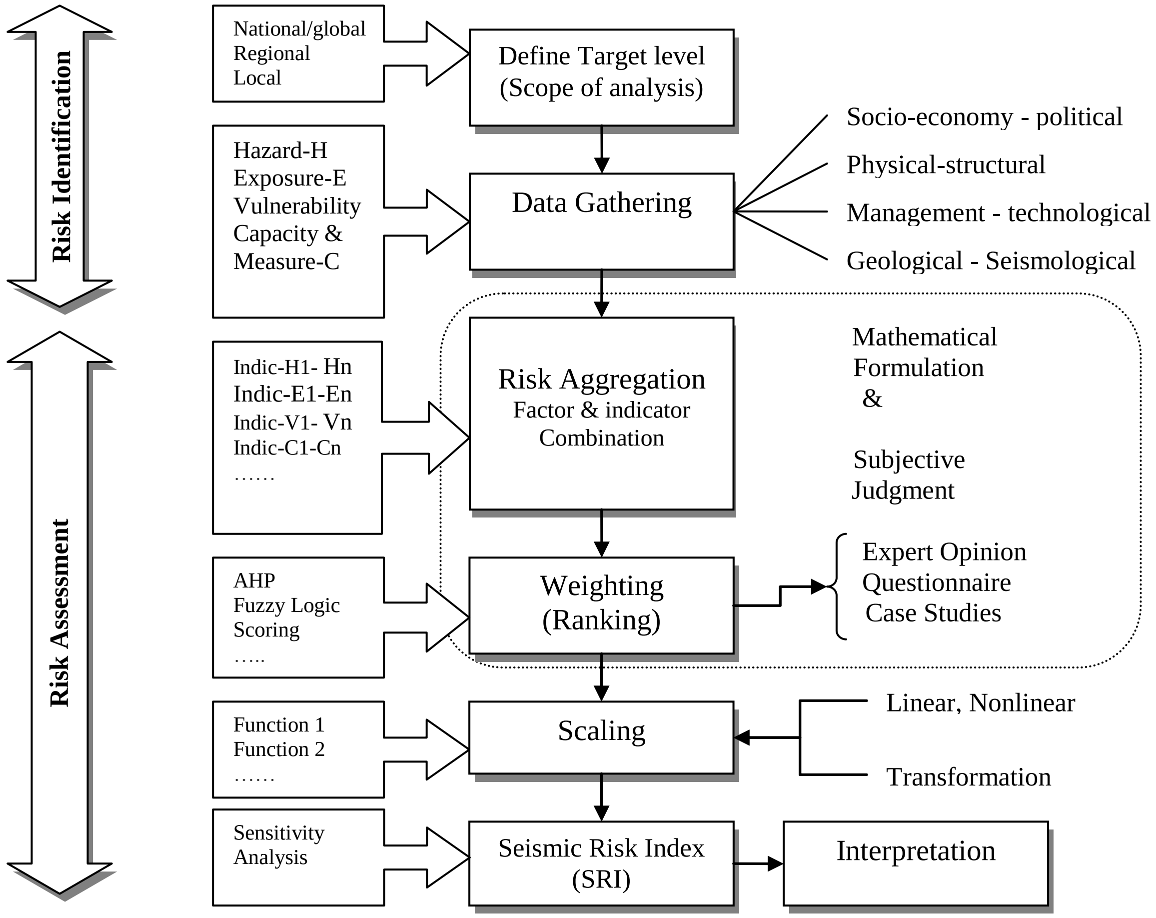

Figure 4: Process of Holistic Risk Assessment (Indicator-Based System)-Author

A problem often occurred in compiling indices relates to the summing and weighing of its components. Moreover, there are no standard procedures for measuring or weighing the effectiveness of risk assessment.

5. Findings

Current paper has introduced holistic methodology on the basis of indicator system which contributes with both range of qualitative and quantitative information available in most of regions. Different methodologies in seismic risk management are classified in a following table which can be used as a comparative tool in seismic risk management.

Table 1: A comparison matrix for conventional and holistic models

	Holistic methods – (Deductive)		***Conventional methods (Inductive)***	
Tools	*Earthquake Disaster Risk Index **(EDRI)***	*Urban Seismic Risk Index **(USRi)***	*Loss Estimation*	*Scenario Studies*
Input	*Quantitative Data (Low)*	*Quantitative Data (Low)*	*High Detailed*	*High Detailed Technical info.*
Main Elements	*Hazard, Exposure, Vulnerability, Response and resilience factor*	*Physical loss and Impact factors, Socio-economic fragility and resilience factor*	*Assets in Regions Hazard dependant factors (site specific)*	*Population and Buildings density , EQ magnitude records*
Output	*Overall Composite Risk Index and indicators in cities*	*Risk Index in cities and urban districts Resilience indicators*	*Loss estimation & distribution within the cities*	*loss estimation & distribution of resource needed*
process	*Math combination Weighting& Scaling components using AHP*	*Math. combination Scaling Transform Weighting with AHP Normalizing*	*Consequence effect and Cost-Benefit analysis*	*Consequence-based risk assessment*
Scope	*Global, National, Regional*	*Global, Regional, Local*	*Regional, Local (Specific portfolio)*	*National , Regional*
Software	*User defined*	*User defined*	*HAZUS*	*HAZUS,MAEviz*
Range	*Evaluating and Benchmarking the risk in metropolitan area and international*	*Evaluating and addressing the risk and resilience capacity of a city*	*Multi-Loss evaluation Individual or Portfolio of buildings*	*Evaluation of Seismic risk strategy for emergency planning*

Various seismic risk models, the input/output and range of application in conventional and holistic approaches are shown in Table 1. Conventional approaches as an inductive methodology uses probability and impact concept that often require a detailed inventory database (record) of the structures and facilities in the region may not always available in many regions (Chen et al 1997).Holistic models, in addition, consider socio-economic characteristics of different regions as well as seismic coping capacity or degree of resilience (Carreno et al 2009).

In contrast with conventional view which takes account on seismic risk in terms of physical damage, victims and economic equivalent losses; the holistic approaches add more factors in term of social, organizational and institutional. This holistic concept is characterized using a multidisciplinary evaluation of risk indicators. The interpretation of different set of heterogeneous indicators into the qualitative metrics reduces the impact and hides complex nature of factors (Taubenbock et al 2008). Rather, quantitative combination of the indicators brings deeper insight into the complex processes of interrelation, and thus it makes a more tangible concept on vulnerability and risk than conventional methodology.

6. Conclusion

This paper has described a means of holistic view by examining different methodologies in seismic risk assessment. Holistic methodology is highlighted as indicator based system which can contribute both range of qualitative and quantitative information available in most of regions. Conventional approaches are also suggested for local areas when direct estimation of losses is intended. However, this approach should be implemented with care as it may overestimate the loss in high magnitude earthquakes and underestimate in lower cases alternatively.

All approaches in risk context are associated with some degree of uncertainty. Uncertainties arise from limitations of data or our understanding of the relationship between natural contributing elements at risk, or failure to model all relevant relationship in calculations. Good practice requires that the analyst identify as many sources of uncertainty as possible and attempt to account for them in calculation, rather than consider the values which are already fixed and guaranteed (Haque 2005).

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