Research on Acceptable Risk Level for Cities' Ability in Reducing Earthquake Disasters

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ABSTRACT :

This paper presents the study on the acceptable risk level for city's ability in reducing earthquake disasters. The so-called acceptable risk level refers to the threshold for the safety level based on the risk analysis and assessment. It defines the acceptable risk levels for the corresponding risk-prevention measures, including failure probability and the consequences of measure failure, such as human casualty and economic loss, etc. In more detailed way, the paper has discussed the methods to use ALARP principle and F-N curve to determine the acceptable risk and their applications in the city's ability in reducing earthquake disasters. However, it remains a controversial issue to make accurate assessment of the acceptable risk level in the actual situations, which is still left be solved through the joint efforts of the governmental departments, engineers, scholars and the public concerned.

KEYWORDS: safety management engineering; acceptable risk level; F-N curve; ALARP principle

1. INTRODUCTION

During the last decade there has been an increasing societal concern on sustainable developments focusing on the conservation of the environment, the welfare and safety of the individual and at the same time the optimal allocation of available natural and financial resources (DEFRA，2002；Faber M H，2003). As a consequence the methods of risk and reliability analysis in earthquake engineering, mainly developed during the last decade, are increasingly gaining importance as decision support tools in earthquake risk management (Xie Lili, 1996; Ma Yuhong, 2000). However, their value in connection with the quantification and documentation of risk and the planning of risk reducing and mitigating measures is not fully appreciated in the earthquake engineering profession at large, although it is in some specialist areas and interest in risk management is increasing rapidly. Therefore, the authors carried out a study of risk literature aimed at giving an overview of quantitative risk measures. Measures that deal with the risk qualitatively were not considered. Emphasis is given to the need of establishing a formal basis for risk analysis taking into account decision theory and to identify and discuss the various shortcomings from this point of view.

2. ASPECTS OF ACCEPTABLE RISK

Almost every activity involves risk. The goal is to eliminate the risk, but it would be naïve to believe that this may be completely achieved; hence we will always face the acceptable risk problem. The issue of acceptable risk has been discussed extensively in the literature, and a very good starting point is given in the book "Acceptable Risk" by Fischhoff *et al.* in 1981. They claimed that risk is never acceptable unconditionally. Risk is only acceptable if some benefit can compensate for the risk or putting it another way: it is the decision yielding risk which is acceptable, not the risk in itself. Therefore they argue that the acceptable risk problem is a decision, i.e.. a choice between alternatives.

2.1 Definition of acceptable risk

Risk measures play an important role in communicating the whole risk assessment process. A risk measure is defined as a mathematical function of the probability of an event and the consequences of that event. This risk measure constitutes the basis for evaluation of risks by the decision-makers (Xiao Yi, 2005).

2.1.1 Individual risk measures

The first measure is the individual risk (IR), as used by the Dutch Ministry of Housing, Spatial Planning and Environment (VROM). It is defined as the probability that an average unprotected person, permanently present at a certain location, is killed due to an accident resulting from a hazardous activity (Jonkman S N，2003；Vrijling J K，1995).

$$IR = P_f \times P_{d|f} \tag{2.1}$$

Where P_f is the probability of failure and $P_{d|f}$ probability of dying of an individual in the case of failure, assuming the permanent unprotected presence of the individual.

2.1.2 Societal risk measures

The aggregated weighted risk (AWR) is calculated by multiplying the number of houses inside a certain area with their IR level （Jonkman S N，2003；Vrijling J K，1995）:

$$AWR = \iint_A IR(x,y)\,h(x,y)\,dxdy \tag{2.2}$$

Where $IR(x,y)$ is the individual risk on location (x,y); $h(x,y)$ number of houses on location (x,y) and A is area for which the AWR is determined.

By integrating the individual risk levels and the population density the expected value of the number of fatalities can be determined:

$$E(N) = \iint_A IR(x,y)\,m(x,y)\,dxdy \tag{2.3}$$

Where $E(N)$ is the expected value of the number of fatalities per year and $m(x,y)$ is the population density on location (x,y).

2.1.3 Economic Risk

Beside the danger of loss of life due to certain activities, the economic risk plays an important role in decision-making. A FD-curve displays the probability of exceedance as a function of the economic damage. The FD-curve and the expected value of the economic damage can be derived from the pdf of the economic damage ($f_D(x)$).

$$1 - F_D(x) = P(D > x) = \int_x^{\infty} f_D(x)\,dx \tag{2.4}$$

$$E(D) = \int_0^{\infty} x f_D(x)\,dx \tag{2.5}$$

Where $F_D(x)$ is the probability distribution function of the economic damage and $E(D)$ is the expected value of the economic damage.

2.2 F-N Curve

A distinction is often made between individual and societal risks. Individual risks are expressed in terms of fatalities per year, fatalities per year of exposure, etc., whilst societal risks are typically represented in terms of an F-N curve which is a plot of cumulative frequency (F) of n or more fatalities versus number of fatalities (N). The ways that risk is presented can well affect risk perception. The F-N curve, originally introduced for the assessment of the risks in the nuclear industry (DEFRA，2002；Vrijling J K，1995), is used in various countries to express and limit risks, predominantly of hazardous installations. As part of the Dutch ariesexternal safety policy, the so-called group-risks are determined on a national level for various. These are shown in the F-N curve in Fig.1. In several countries an F-N criterion line limits the risks of various hazardous activities. These standards can be described with the following general formula:

$$1-F_N(x)<\frac{C}{x^n} \qquad (2.6)$$

Where n is the steepness of the limit line and C the constant that determines the position of the limit line. A standard with a steepness of n = 1 is called risk neutral. If the steepness n = 2, the standard is called risk averse (Jonkman S N，2003). Fig.1 gives the values of the coefficients for some international standards and the F-N limit lines. For example, an individual fatality risk of 10^{-5} is equivalent (in a statistical sense) to a societal risk of 10^{-8} of killing 1000 people. Yet, society seems more concerned about catastrophic events that harm large numbers of people rather than a series of lesser failure events that collectively harm a similar number of people. This preference is reflected in a typical F-N curve, where for example Fig.1 shows that an individual annual fatality risk of 10^{-4} has the same preference as an event killing 10 people with a frequency of 10^{-6} per year.

Societal risk is often represented graphically in an F-N curve. This curve displays the probability of exceedance as a function of the number of fatalities, on a double logarithmic scale.

$$1-F_N(x)=P(N>x)=\int_x^{\infty} f_N(x) \qquad (2.7)$$

Where $f_N(x)$ is the probability density function (pdf) of the number of fatalities per year, $F_N(x)$ the probability distribution function of the number of fatalities per year, signifying the probability of less than x fatalities per year. A simple measure for societal risk is the expected value of the fatalities per year, $E(N)$, in literature often referred to as the potential loss of life (PLL):

$$E(N)=\int_0^{\infty} x f_N(x)\,dx \qquad (2.8)$$

Ale et al. proposes the area under the F-N curve as a measure for societal risk. Vrijling and van Gelder have shown that this measure equals the expected number of fatalities per year (Jonkman S N, 2003):

$$\int_0^{\infty}\left(1-F_N(x)\right)dx=\int_0^{\infty}\int_x^{\infty} f_N(u)\,du\,dx=\int_0^{\infty}\int_x^{u} f_N(u)\,dx\,du=\int_0^{\infty} u f_N(u)\,du=E(N) \qquad (2.9)$$

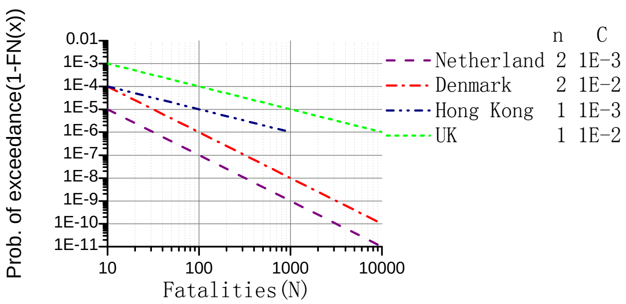

Figure 1 Some international standards in F-N format

2.3 The ALARP(As Low As Reasonably Practicable) Region

ALARP (As Low As Reasonably Practicable) guidelines originated a famous legal dispute between Edwards and the British Coal Ministry in 1949. Afterward, the British Healthy Security Committee (HSE) pointed out explicitly must use this criterion to carry on the risk management and the decision-making; it has become the standard framework established by the acceptable risk criteria. A conceptual model combining the key issues is shown in Fig.3. In the area of unacceptable risk, it is compulsory to implement means to reduce the risk to the

ALARP region. In the ALARP region additional efforts may be used to reduce the risk further. How far to reduce the risk should be the result of a tradeoff analysis.

At the same time, the ALARP criterion contains two risk boundaries, namely the two level lines in Fig.2: acceptable risk level line and neglectable risk level line. An acceptable risk is not a single value; first, it identified the risk values corresponding with the two level lines, then estimated the disaster's risk and compared it with the value of the two level lines, and then determined which region does the risk fall on, at last, decision-makers should carry on the decision analysis. Therefore, acceptable risk level instructs the decision-making level and finally determines by the decision-making. Many countries research these two risk lines according to their own actual situation. For example, the British Health and Safety Committee advices the risk values of the acceptable risk line and the neglectable risk line respectively for the constructions and the proposed facilities. To the constructions, the acceptable risk line and the neglectable risk respectively is 10^{-4} and 10^{-5} per year, to the proposed facilities, these two lines respectively is 10^{-4} and 10^{-6} per year. Generally speaking, neglectable risk value is less than acceptable risk value 1~2 magnitudes.

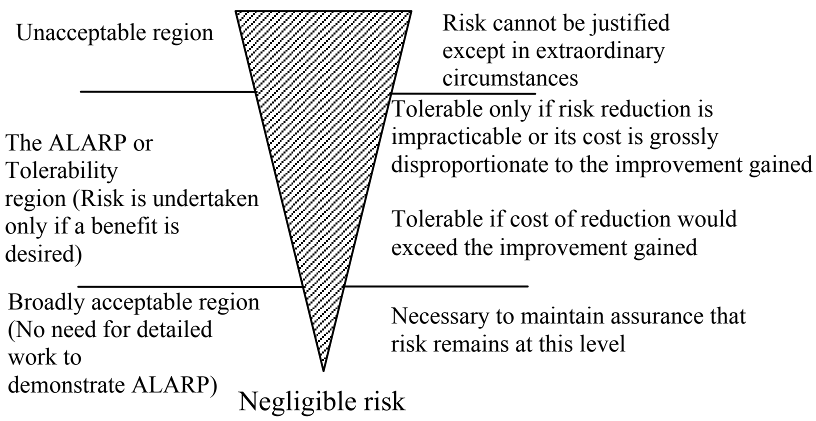

Figure 2 Levels of the risk and ALARP

3.ACCEPTABLE RISK LEVEL FOR CITIES' ABILITY IN REDUCING EARTHQUAKE DISASTERS

Cities' ability reducing earthquake disasters is a complex system involving numerous factors; moreover the research on evaluating cities' ability reducing earthquake disaster relates to multi-subject, such as earthquake science, social science, economical science and so on. This ability describes the strength of a city in mitigating the impacts of a target earthquake. It could be evaluated with three basic elements – the possible seismic casualty and economic loss during the future earthquakes that are likely to occur in the city and its surroundings and time required for recovery after earthquake; based upon these three basic elements, a framework, which consists of six main components, for evaluating city's ability reducing earthquake disasters is proposed; then the statistical relations between the index system and the ratio of seismic casualty, the ratio of economic loss and recovery time are gained utilizing the cities' prediction results of earthquake disasters which were made during the ninth five-year plan; at last, the method defining the comprehensive index of cities' ability reducing earthquake disaster is presented. Thus the relatively comprehensive theory frame is set up. So as the evaluation standards, the acceptable risk is the most important judgment criterion in the frame. This paper take the acceptable life risk in the earthquake as an example, has carried on the detailed discussion to the evaluating index.

3.1 personally acceptable level of risk

The smallest component of the social acceptance of risk is the personal cost-benefit assessment by the individual. The actual personal risk levels inherent to various activities show statistical stability over the years and are approximately equal for the Western countries, indicating a consistent pattern of preferences. To limit the risks, the Dutch Ministry of Housing, Spatial planning and Environment (VROM) has set the following standard for populated areas IR < 10^{-6} per year. Risk lower than 10^{-6} per year should always be reduced to a level which is as low as reasonably achievable (ALARA). For the boundary between the tolerable and the unacceptable regions no widely applicable criterion is given. However, an HSE document on the tolerability of risks in nuclear stations suggests IR_{HSE} values of 10^{-3} for workers and 10^{-5} for the members of the public, as a boundary between the tolerable and the acceptable regions.This standard is set for more or less involuntary imposed risk related to the locating of hazardous activities. The method of the Technical Advisory Committee for Water Retaining Structures (TAW) gives the opportunity to limit a broader set of risks, ranging from voluntary activities, such as mountaineering, to more involuntary risks, such as those of hazardous installations. The following standard is proposed by TAW:

$$IR < \beta \times 10^{-4} \tag{3.1}$$

In this expression the value of the policy factor β varies according to the degree to which participation in the activity is voluntary and with the perceived benefit. It ranges from 10 in the case of complete freedom of choice like mountaineering, to 0.01 in case of an imposed risk without any perceived direct benefit. Fig. 3 gives the acceptable personal risks for a few activities, deduced from the statistics of causes of death and the number of participants per activity. In this expression we can see only a purely voluntary activity such as mountaineering entails a higher risk. According to earthquake's accidental and destructiveness, it may be inferred that the public should choose the lower value of the factor β. When the public encounters the earthquake frequently occurred, we take the β value of 0.1, but encounters the rare earthquake, and we take the β value of 0.01. Therefore, this method can be estimated that the acceptable personal risk for the earthquake is about 10^{-5} to 10^{-6} per year. This risk value is accordance with the earthquake damage statistics from many years. So we can set the individual acceptable risk value as 10^{-6} per year.

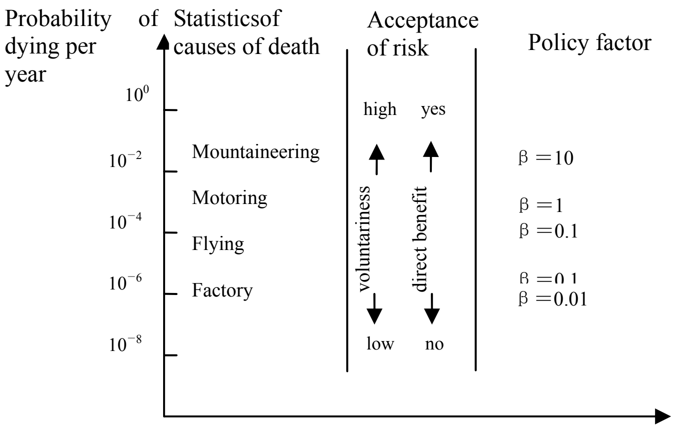

Figure 3 Personal risks in Western countries, deduced from the statistics of causes of death and the number of participants per activity

3.2 societal acceptable level of risk

A quick overview of the societal risk measures reveals that two types of expressions can be distinguished. On the one hand, it should be determined by the repercussions of the public for the number of fatalities in an earthquake, namely ALARP criterion method. On the other hand, it should be determined by the expected value of the number of fatalities $E(N)$, it uses the product of the earthquake probability and consequences resulting from it as the quantitative index, namely based on F-N curve method.

3.2.1 societal acceptable level of risk based on ALARP criterion

This paper determined the risk value by the many source of value, it includes: (1) the number of the fatalities caused by the devastating earthquake at home and broad and the social repercussions about it; (2) the number of the fatalities caused by the natural disasters (floods, typhoons, etc.) and man-made disasters (fires, traffic accidents, etc.); (3) the foreign criterion and references value about the acceptable level of risk; (4) the statistical result of the experts' questionnaires. Based on the statistical results and analysis, considered about the uneven development in politics, economy and social culture, it can be found that the policy-maker and the public have different views on the acceptable risk. Therefore, this paper has not given the certain values, but only proposes the different acceptable levels of risk; the policy-maker can make reasonable choices in accordance with local conditions.

Table 1 The acceptable level of seismic death rate proposed by this paper

Intensity	Ⅵ	Ⅶ	Ⅷ	Ⅸ	Ⅹ
Grade ①	1.0×10^{-5}	2.0×10^{-4}	5.0×10^{-4}	2.0×10^{-3}	1.0×10^{-2}
Grade ②	5.0×10^{-6}	5.0×10^{-5}	1.0×10^{-4}	5.0×10^{-4}	5.0×10^{-3}
Grade ③	1.0×10^{-6}	2.0×10^{-5}	5.0×10^{-5}	2.0×10^{-4}	1.0×10^{-3}
Grade ④	5.0×10^{-7}	5.0×10^{-6}	1.0×10^{-5}	5.0×10^{-5}	5.0×10^{-4}
Grade ⑤	1.0×10^{-7}	2.0×10^{-6}	5.0×10^{-6}	2.0×10^{-5}	1.0×10^{-4}

According to the acceptable risk value proposed by this paper, when a medium-sized city which has 1 million people encounters Ⅵ, Ⅶ, Ⅷ, Ⅸ, Ⅹ intensity of the earthquake, its societal acceptable casualty respectively is 1, 20, 50, 200, 1000 people. The result shows that the number of the acceptable casualty reduces by comparing the result of the literature (Xie Lili, 1996; Ma Yuhong, 2000) proposed, namely the public increase requirements on their own safety. Therefore, With the development of economy, human ability to withstand natural disasters has been continuously strengthened, the public requirements for their own security also will be enhanced, it reflects the reasonable social trends.

3.2.2 Societal acceptable level of risk based on F-N curve

The expected value of the number of fatalities is the general quantity expressing method on the risk research, it is the product of the value s of the abscissa and the ordinate on F-N curve, namely the product of the number of the fatalities caused by one disaster and the probability of the disaster (person/year*type of disaster). Referenced by this principle, statistics and analysis of the 214 earthquake sequences with M s≥4 0 in China from 1966 to 2006 are made, this paper proposed the values of the acceptable level of the earthquake risk (see table 2). Then it makes the F-N curve of the seismic disaster with the different exceeding probability in design reference period of the Seismic Design Code for Buildings as abscissa and the number of fatalities as vertical coordinate, which takes Yunnan Province as an example (see Fig. 4).

Table 2 The acceptable level of risk proposed by this paper(person/year*earthquake)

Intensity	＜Ⅵ	Ⅶ	Ⅷ	Ⅸ	Ⅹ
Grade ①	0.005	0.05	0.5	5	150
Grade ②	0.004	0.04	0.4	4	140
Grade ③	0.003	0.03	0.3	3	130
Grade ④	0.002	0.02	0.2	2	120
Grade ⑤	0.001	0.01	0.1	1	100

From table 2, based on the grade 1, we can see that the acceptable fatalities is 1 person when the city is hit by 5 earthquakes with Intensity＜Ⅵ in 40 years, if the casualty is bigger than 1 person, the public can not accept it.

It reflects the macroscopic socially acceptable risk, which shows that whether or not the number of fatalities was accepted by the public caused by the certain intensity earthquake in certain years.

As Figure 4 shows that the risk curves of the number of the fatalities caused by the earthquakes with M≥4 0 in Yunnan Province from 1966 to 2006. It compares the actual fatalities caused by the earthquakes with the number of deaths calculated by the different grades acceptable risk proposed by this paper. For example, when the Yunnan Province encounters the moderate earthquake, the actual number of deaths is lower than the number calculated by the grade ④ of the acceptable risk; it means that these fatalities are acceptable by the public with little repercussions. But when it encounters the low or high intensity earthquake, its casualty is higher than the request of the acceptable level of risk, which means it should strengthen the public ability for the earthquake resistance to avoid the great panic in society caused by the enormous casualties.

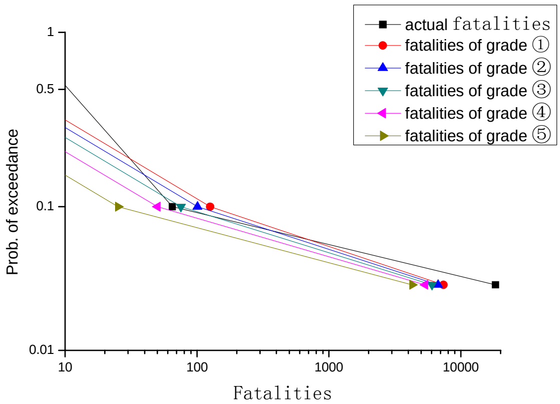

Figure 4 Risk curve of the Yunnan Province

4.CONCLUSION

Urban acceptable level of earthquake risk is the evaluation criterion of the cities' ability reducing earthquake disasters and the basis for decision-making in risk management. Based on the historical data of the seismic disaster, this paper discusses the research method of the acceptable life risk according to the different aspects. However, the research for acceptable risk relates to multi-subjects, such as sociology, economics, cultural and legal etc.; we need further research on it by the public comprehensive participation and the cooperation between government and academic circles.

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