ASSESSMENT OF A CITY'S CAPACITY FOR EARTHQUAKE DISASTER PREVENTION

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ABSTRACT :
The first section of the paper should be a single paragraph abstract outlining the aims, scope and conclusion of the paper, and the length of the abstract should be limited between 100 and 250 words. The words of 'Abstract' and 'Keywords' are set in bold and full caps. The full paper length including abstract shall not exceed 8 pages.

KEYWORDS:
Seismic capacity; seismic risk; seismic disaster prevention; acceptable seismic losses; social aspects of disaster

1. INTRODUCTION

It is needless to say that a city should be well prepared for its seismic safety before the occurrence of the potential earthquake. However, the questions, such as to what extent the city should be prepared and how we can make a judgment before occurrence of the next quake whether the city is well prepared or not, are still to be solved. It is also essential for disaster management officials and professionals to understand before the occurrence of the earthquake if the city can mitigate the potential seismic risks. Furthermore, in the year of 2004 the Chinese Government made a crucial decision that **through fifteen year's consensus effort by each level of government and whole society, all the large-, middle- and small-sized cities in China should be enhanced on their capacities for mitigating earthquake disaster with the goal to resist earthquake of Magnitude Six or the corresponding seismic ground motion on the Chinese Seismic ground Zoning Map. T**hen, it raises a series of questions to be solved such as: what the definition of a city's seismic capacity is, how we can know and even measure the city's seismic capacity before occurrence of the potential earthquake, how many elements will give effects on the seismic of a city, what measure we should take in case a city is lacking of the necessary capacity to resist possible earthquake and so on.

In the last decade of the 20th Century, the Secretariat of the United Nations International Decade for Natural Disaster Reduction (IDNDR) launched a project titled "Risk Assessment Tolls for Diagnosis of Urban Areas against Seismic Disasters (RADIUS)" to improve understanding of urban earthquake risk, to identify the earthquake risk problems common to different urban areas of the world (Davidson, R.A. and Shah, H.C. 1997-1). This project was conducted in conjunction with a series of projects that aim to develop an Earthquake Disaster Risk Index (EDRI)(Davidson, R.A. and Shah, H.C. 1997-2) and to evaluate it for all major, seismically active cities worldwide. However the EDRI is a composite index that can only serve as a basis for comparing the relative overall earthquake risk of different cities among the limited "associate cities". The EDRI basically cannot reflect the real seismic capacity of a city against the future possible earthquake and it cannot either tell the absolute capacity of a city for preventing the earthquake disaster, or we cannot understand from the EDRI how strong earthquake the current city can resist.

In this paper the conception of a city's seismic capacity is presented and the criterion and framework for measurement of the seismic capacity of a city is developed. As an example, ten cities over the world have been assessed and compared in terms of their seismic capacities.

This paper consists of six parts. First, the conception of seismic capacity of a city for preventing earthquake disaster and the criterion for measuring the seismic capacity are presented. Second, a framework consisting of six main factors connecting with the seismic capacity of a city is developed. Third, a simplified method for assessing the possible life losses, economic losses during the future potential earthquake and the duration necessary for recovering of the city after the earthquake is introduced. Fourth, the acceptable risk levels in terms of human life loss, economic loss and the tolerable duration for post event recovering are investigated and recommended. Fifth, as an example, we make a test for measuring seismic capacity of ten cities over the world and the results are also presented. Finally, some critical points regarding the seismic capacity of a city and its implications are presented and discussed.

2. THE CONCEPTION OF SEISMIC CAPACITY OF A CITY

In principle, for its seismic safety a city should be constructed and maintained as strong and tough as possible with no losses in human life and economy under the attack of a target earthquake. However it usually needs much more invest. However, earthquake is an event with very low probability of occurrence and occurs infrequently, it is unlikely to construct and maintain all cities with seismic capacity strong enough to resist any earthquake. A stronger seismic capacity of a city usually needs higher investment. Therefore there should be some compromise between the capacity and investment. Such compromise can be reached through a wise choice of the acceptable risks such as life and economic losses for the target earthquake, which the city should resist.

The terminology of seismic capacity of a city is attempting to describe the strength of a city in mitigating the impacts of a target earthquake. If a city has a full SC against the target earthquake, it means that this city can mitigate the impacts of earthquake, or, the possible seismic loss of the city would not exceed the acceptable ones while the city would be hit by the target earthquake. Thus the SC of a city can be defined as the degree of reducing the seismic impacts to a city for a target earthquake. In general, the impact of an earthquake can be summed up in three basic elements: life losses, economic losses and necessary duration needed for post-event recovering. The greater the seismic capacity of a city, the less the life and economic losses and the recovering duration will be. Then we can establish the following criterion to judge if a city is of seismic capacity or not: if a city is of the seismic capacity to a target earthquake it will suffer life-losses and economic losses less than the acceptable ones and get recovering after event in a shorter duration than the expected time accepted by the society. Otherwise the city will be considered as lacking of seismic capacity. Furthermore, with the Analytic Hierarchy Process (AHP) (Saaty T.L. 1980) we can obtain the weighting for these three elements contributing to the whole impact as follows (Zhang, F.H. and Xie, L.L. 2002):

Life loss : Economic loss : Duration needed for recovering = 0.6 : 0.3 : 0.1

3. THE FRAMEWORK FOR ASSESSING THE SEISMIC LOSSES AND POSSIBLE RECOVERING DURATION

Based upon the conception of SC of a city and the criterion for judging city's seismic capacity, there are three key issues in determining the city's SC: (1) how to assess the potential life losses, economic losses and the possible recovering duration to the target earthquake, (2) how to determine the social acceptable risk in terms of life losses, economic losses and expected recovering duration after a earthquake, (3) how to measure the city's SC with the results of (1) and (2). In this paragraph, we will discuss the main factors that constitute a framework by which we can assess the potential seismic losses and determine the possible necessary time duration needed for post earthquake recovering. The framework and the corresponding factors are shown in Fig. 1.

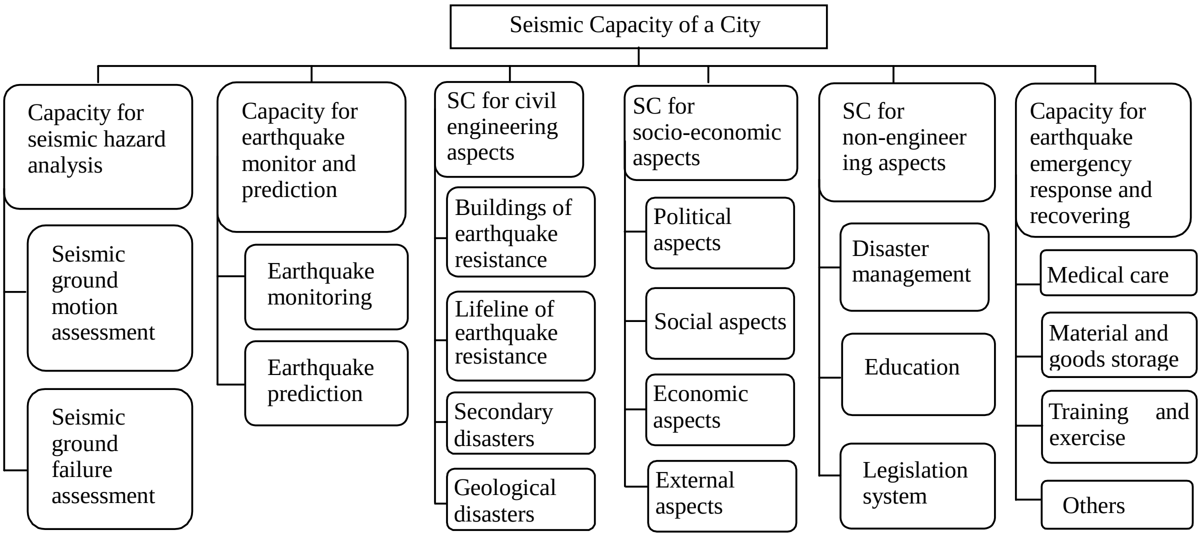

Figure 1. A framework and its main factors regarding city's seismic capacity

In the framework there are six main factors that contribute to a city's seismic losses and recovering time. These factors are: (1) Capacity for seismic hazard analysis, (2) Capacity for earthquake monitoring and prediction, (3) SC for civil engineering aspects, (4) SC for socio-economic aspects, (5) SC for non-engineering aspects, (6) Capacity for earthquake emergency response and recovering. Table 1 shows the weighting of each main factor contributing to the seismic human life losses, economic losses and recovering duration respectively. From Fig. 1 we can find that each of these six main factors is disaggregated into the more specific sub-factors. The contribution of each sub-factor to its main factors can be obtained respectively through the testing or calculating with mathematical models.

TABLE 1. WEIGHTING OF EACH FACTORS CONTRIBUTING TO LOSSES AND RECOVERING DURATION

Factor	Weighting		
	To life losses	To economic losses	To recovering duration
Capacity for seismic hazard analysis	0.04	0.05	0.03
Capacity for earthquake monitor and prediction	0.15	0.07	0.07
SC for civil engineering aspects	0.41	0.48	0.42
SC for socio-economic aspects	0.11	0.13	0.16
SC for non-engineering aspects	0.10	0.10	0.11
Capacity for emergency response and recovering	0.19	0.17	0.21

3.1. Assessment of seismic losses

The approach for assessment of the potential seismic losses of a city is sketched in Fig. 2.

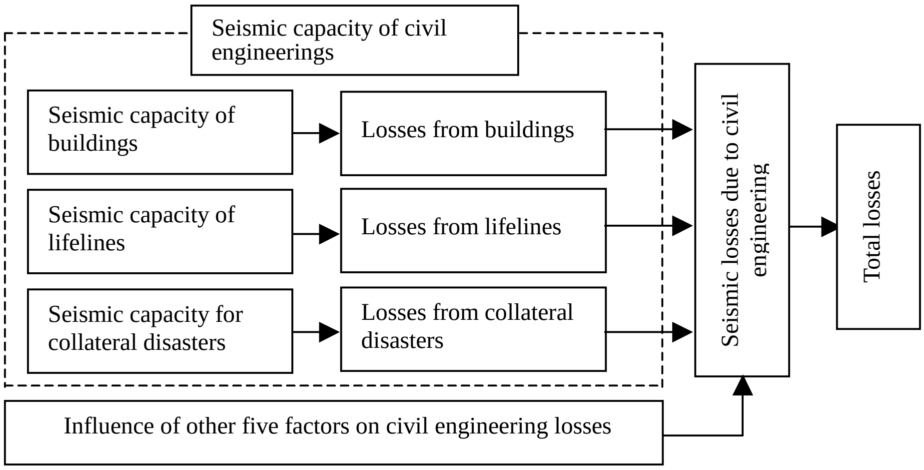

Figure 2. The approach for assessing earthquake losses

This approach is based on the assumption that the damage to the civil engineering is the main reason causing the seismic losses and the other five factors illustrated in the Fig. 1 are the factors that give only influence on the seismic losses. In this approach both life losses and economic losses directly caused from damaged buildings, failure of lifelines and potential collateral disasters are taken into consideration here and contribution of other five factors to the seismic losses and recovering duration will be discussed later (Zhang, F.H. and Xie, L.L. 2002; Coburn, A.W. *et al*. 1992; Taniguchi, H. 2001). For example, based on our research, the potential life losses to the target earthquake could be estimated by an empirical formula (3.1)

$$Y = 6.856X^2 - 1.353X + 1.766 \tag{3.1}$$

Where, X is the seismic capacity index of buildings and Y the negative logarithm of the ratio of the casualty to the population of a city (Zhang, F.H. and Xie, L.L. 2002). With the same way we can estimate the economic losses as well as the necessary recovering duration in terms of seismic capacity index of buildings.

3.2. Assessment of seismic losses due to failure of lifelines

In estimating the seismic capacity of the lifelines it is assumed that the lifelines constructed in good condition can work properly in case of intensity of earthquake under VIII. It will decrease the seismic capacity of buildings to ζ for different qualities of lifelines and different intensities of earthquake. It is shown in Table 2 that the coefficient ζ varies from 1.0 to 0.2 with variation of the construction quality and the intensity of target earthquake.

TABLE 2. VARIATION OF THE MODIFICATION COEFFICIENT ζ

Quality / Earthquake intensity	Good	Fair	Bad
VI	1.0	1.0	0.8
VII	1.0	1.0	0.6
VIII	1.0	0.8	0.6
IX	0.8	0.6	0.4
X	0.6	0.4	0.2

3.3. Assessment of possible death toll due to collateral disasters

Coburn A.W. *et al* (1992) made a statistical analysis on the contribution of the collateral disasters to the seismic death toll from 1,100 earthquakes occurred in the last century and pointed out that in average the life loss due to collateral disasters is about 15% of the total death toll during all the events. With this result, we adopt a modification coefficient η in account of the contribution of the collateral disasters to the seismic loss. It is shown from Table 3 that the coefficient η varies from 1.0 to 1.3.

TABLE 3. VARIATION OF THE MODIFICATION COEFFICIENT η

Earthquake intensity	Severeness of potential collateral disasters		
	Low	Moderate	High
VI	1.0	1.0	1.0
VII	1.0	1.0	1.05
VIII	1.0	1.05	1.1
IX	1.05	1.1	1.2
X	1.1	1.15	1.3

3.4. Assessment of necessary duration for recovering to target earthquake

According to the ATC-13 Report (Applied Technology Committee 1991) and the study on correlation of the recovering duration with seismic capacity index of the building and severeness of the damage to city's lifelines, it is concluded that the necessary duration for post recovering is increasing with the decreasing of seismic capacities of buildings as shown in Table 4.

TABLE 4. RECOVERING TIME LENGTH VERSUS SEISMIC CAPACITY INDEX OF BUILDINGS

Seismic ability index	0.8	0.6	0.4	0.2
Recovery time/day	7	45	150	300

3.5. Effects of other five factors on seismic losses and duration for recovering

As mentioned above what the potential seismic losses and necessary recovering duration we estimated in the last paragraph is the contribution due to only the failure of city's civil engineering. It means that the contributions from all other five factors have not yet been taken into consideration. However, the empirical formulae we used in estimating the losses were derived from the historical records and each of those historical records or historical data were produced in a certain environment with certain seismic capacities of other five factors. Therefore we assumed that the results from those empirical formulae imply that the seismic losses due to the damage to civil engineering are in an environment with other five factors in average levels. When we are assessing the seismic capacity for a specific city, what we need to do is only to estimate the weightings of other five factors of this city and compare them with the weightings of an "average city". Finally, we can estimate the effects of five factors on the calculated seismic losses and recovering duration by multiplying the losses due to damage to the civil engineering by the modification coefficients λs as follows:

$$\lambda_L = 1 - \sum_{i=1}^{5} (a_i - \bar{a}_i)\phi_i \tag{3.2}$$

$$\lambda_E = 1 - \sum_{i=1}^{5} (a_i - \bar{a}_i)\eta_i \tag{3.3}$$

$$\lambda_T = 1 - \sum_{i=1}^{5} (a - \bar{a}_i)\mu_i \tag{3.4}$$

where, λ_L, λ_E and λ_T are the modification coefficients of other five factors to life losses and economic losses caused by civil engineering and the recovering duration respectively, coefficients a_i (i=1,2,3,4,5) are the seismic capacity of each of other five factors contributing to the seismic capacity of the given city and $\bar{a}_i$ (i=1,2,3,4,5) the average weighting of each factors, and coefficients ϕ_i, η_i and μ_i denote the contribution of each of other five factors to the life losses, economic losses and recovering duration as shown in Table 1.

4. ACCEPTABLE EARTHQUAKE RISKS RECOMMENDED FOR CHINESE CITIES

Based on a series of researches on the realistic losses from all natural disasters, traffic and medical accidents in the past thirty years in China, it recommends a long list of acceptable risks to different cities' decision-makers for references. Table **5** shows one example of this list that is recommended for the Chinese general cities and some important cities. It is shown that the acceptable life losses, in terms of the ratio of the life losses to the city's population, economic losses, in terms of the ratio of economic losses to the city's GDP value and the acceptable recovering duration are increasing with the intensity of earthquake. According to the recommended acceptable life and economic losses, a city will be considered as the city with seismic capacity for the target earthquake, only if the realistic losses or the assessed losses happened to this city are less than the recommended acceptable losses. Otherwise the city will be considered as a city of lacking of seismic capacity.

TABLE 5. THE RECOMMENDED ACCEPTABLE EARTHQUAKE LOSS LEVELS

For general cities					
Intensity of target earthquake	VI	VII	VIII	IX	X
Ratio of casualty to population	8×10^{-6}	2×10^{-5}	5×10^{-5}	2×10^{-4}	1×10^{-3}
Ratio of economical loss to GDP	2%	4%	5%	8%	10%
Recovery time/day	7	15	30	45	60
For more important cities					
Intensity of target earthquake	VI	VII	VIII	IX	X
Ratio of casualty to population	8×10^{-7}	6×10^{-6}	1×10^{-5}	2×10^{-5}	4×10^{-4}
Ratio of economical loss to GDP	1%	2%	3%	4%	5%
Recovery time/day	7	15	21	30	45

5. EXAMPLE

As an example, we applied the method mentioned above to the ten cities over the world for a testing of their seismic capacities. All the data we used in this paper regarding these ten cities are obtained respectively from the papers listed in the References below. The profiles of the ten cities and the assessed results are shown in Table 6 and 7 respectively. Perhaps those data might be out of date, however it will not constitute any problem to demonstrate the idea of the SC of a city and the process of measuring city's capacity for mitigating earthquake disaster.

TABLE 6. PROFILES OF THE TEN CITIES

City	Abbr.	Country	Population /10^4	Per GDP/$	Areas/km^2	Basic intensity
Tashkent	TSGN	Uzbekistan	208	6100	326	VII-VIII
Addis Ababa	ASNY	Ethiopia	263	530	540	VII-VIII
Guayaquil.	GYJR	Ecuador	210	5000	340	VIII
Bandung	WLON	Indonesia	240	1000	19	VIII
Skopie	SKPL	Macedonia	44.5	2200	338	VII
Tijuana	THAN	Mexico	115	21000	230	VII

Anto fagasta	ATFJ	Chile	228	49000	90	Ⅷ
Izmir	YZMR	Turkey	217	7000	650	Ⅵ—Ⅷ
Xiamen	XMEN	China	152	2500	450	Ⅶ
Quanzhou(part)	QNZH	China	25	2150	52	Ⅶ

Notes: All data from the relevant report listed in the References

TABLE 7. SEISMIC CAPACITIES OF THE TEN CITIES

City	Intensity of the target earthquake				
	Ⅵ	Ⅶ	Ⅷ	Ⅸ	Ⅹ
TSGN	Moderate	Poor	Poor	Poor	Poor
ASNY	Poor	Poor	Poor	Poor	Poor
GYJR	Moderate	Moderate	Moderate	Poor	Poor
WLON	Moderate	Poor	Poor	Poor	Poor
SKPL	Strong	Moderate	Poor	Poor	Poor
THAN	Moderate	Poor	Poor	Poor	Poor
ATFJ	Strong	Moderate	Poor	Poor	Poor
YZMR	Strong	Strong	Moderate	Poor	Poor
XMEN	Strong	Strong	Poor	Poor	Poor
QNZH	Moderate	Moderate	Poor	Poor	Poor

From the analysis of the results it is interesting to point out that the results provide not only a basis for comparison of the seismic risks among various cities, but also provide the absolute quantities of cities' seismic capacity in preventing the possible seismic disaster each of those cities may confront. Also, it can provide not only the quantitative results of the cities' SC, but also indicate the reason why each of them are strong, moderate or poor in their seismic capacity.

6. CONCLUSIONS AND DISCUSSIONS

(1) The concept of the seismic capacity of a city and the criterion for estimating the seismic capacity can work well. The results provide not only a basis for comparison of seismic risks among various cities, but also provide absolute quantities as a measure of the cities' seismic capacities.

(2) The framework we established for estimating the city's seismic capacity consists of six main factors, however it is more or less flexible. For some region it may add or delete some factors based on the regional characteristics.

(3) It must emphasize that the seismic capacity of a city is relative to the target earthquake and also relative to the acceptable losses and recovering duration. With different target earthquake or different acceptable losses and recovering duration the results will be different.

It is important to point out that the methods and mathematical models we developed in this project are opened. It can be upgraded timely while more advanced methods and mathematical models are available.

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