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DEVELOPMENT OF EARTHQUAKE ENGINEERING IN CHINA

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SUMMARY

In China, there are now national seismic design codes for various kinds of engineering works, such as buildings, industrial structures, hydraulic structures, highways, railways, nuclear power plants, etc., and also national codes for seismic hazard evaluation, zonation, evaluation and strengthening of existing structures. Our current seismic codes require a two-stage limit design: an elastic and an ultimate. The design spectra are given in the zonation maps for the whole nation, and its width varying with both the regional seismicity and the local site condition. The 2001 code for buildings includes also a separate chapter for base isolation and energy dissipation requirements. The current design principle is performance-based, but an idea of consequence-based design principle was suggested a few years ago, which considers the indirect social and economic effects of the local region. Included are also development of studies of structural analysis, disaster mitigation measures, and engineering seismicity problems.

1. INTRODUCTION

The development of earthquake engineering in China may be described into three stages. The initial stage in 1950's – 1960's was marked with the initiation of this branch of science from its creation in the first national 12-year plan of science and technology by specifying earthquake engineering as a branch item and IEM was one important participant. The first earthquake zonation map and the first seismic design code were completed in the 1950s and used in engineering design. Site effect on ground motion was seriously studied in the second stage in 1960s – 1980s marked with the occurrence of quite a few strong earthquakes in China, from which many lessons were learned and corresponding considerations were specified in our design codes, which are forced to follow in construction practice. The third stage from 1980s to present is marked by disaster management of government documentations, leading by a national law of the People's Republic of China on the protecting against and mitigating earthquake disasters adopted at the meeting of the Standing Committee of the National People's Congress of China in 1997 [1] and then followed by some provincial and municipal laws to force the actions outlined in the national law. Lastly, possible future developments are also discussed. This paper will be presented in the following four sections, i.e., (1) seismic hazard assessment (SHA) or design ground motion to be used for earthquake input to the structures, (2) seismic design of structures, (3) structural responses to strong earthquakes, and (4) disaster evaluation and mitigation.

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2. SEISMIC HAZARD ASSESSMENT (SHA)

SHA means the estimation of ground motion at a given location for the design of a specific structure and a map giving estimations for all locations in a given region is usually referred to as seismic zonation map, which is required for the design of ordinary structures in the region.

2.1 Ground motion observation

Strong earthquake motion observation on grounds and structures in China started early in the 1960s, mostly in regions of recent strong earthquakes, such as the 1966 Xingtai, 1970 the Tonghai and the 1976 Tangshan earthquakes, trying to record 3-component strong motions from strong aftershocks. Thousands of acceleration time history records were accumulated, but most of them are weak motions, with maximum acceleration less than 0.3g. Recently, after the mass production of the new digital instruments in the world, a program of a few thousands stations is planned [2] and started a couple of years ago, to have observation net works all over China. The accumulation of strong ground and structural records is certainly slow, because strong earthquakes in the mainland of China are widely scattered, all-over the Western China and region near Beijing. Taiwan is the only region in China with frequent strong earthquakes, and dense networks were established many years ago, and therefore the accumulation of strong motion records there is quick, especially for the 1999 Ji-ji Earthquake [3] and the SMART networks.

2.2 Ground motion parameters Y(M,R; P) required in the seismic codes

The following notations are used in this paper for design response spectrum, to be consistent with the present code as close as possible. Consider a single mass system:

Q = $ck\beta\,(T, \zeta)\,G$ = max. base shear

c = a coefficient to consider the design level of the structure, being 1/3 for ordinary buildings and 1 for critical structures

k = a/g = max. peak ground acceleration and a letter A was used in early days

$\beta(T,\zeta)$ = response spectrum, where T is the natural period of the structure and ζ the damping ratio of the structure

W = weight of the mass

Tg = the first characteristic period of the response spectrum

T_{max} = the max. period of the response spectrum considered

Ground motion parameter Y used in seismic design codes of ordinary structures in China before 2000 was only a peak acceleration a, which was converted according to Table 1, from intensity I given in the zonation map. The seismic inertia force F on the mass G of the structure is

$$F = k\beta\,(T)\,G \tag{1}$$

where $k=a/g$, ka_{max} is the seismic coefficient, and here the ratio $\beta(T,\varepsilon)/\,ka_{max}$ is the response spectrum used in 1959. Damping ε usually taken as 5%.

(1) I – a conversion

Since the Chinese seismic zonation map was given in terms of intensity defined by the intensity scale before 2001, it was necessary then to provide a relationship between the macro-seismic intensity I and the ground acceleration $k=a/g$, needed in the China design code. For this purpose, peak ground acceleration a recorded at locations of known intensities I from past strong earthquakes over the world were collected and analyzed. Some results are shown in Fig.1. For regressions 3 (3a and 3b) the coordinates I and lg$a$ should be normalized to non- dimensional variables first. The method, which variable is taken as given, has not been seriously considered in the world. The author's opinion is that both a and I are functions of both magnitude M of the earthquake and distance R from the epicenter, and therefore both are not given, regressions 3 should be used [4-5]. As can be seen from Fig.1, the results of different regression principles, 1, 2 or 3, are quite different. According to data collected by the Author, the differences are shown in Table 2. But it was often ignored and seldom questioned and same situation remains in other codes in the world. This kind of conversion is suddenly no good, because intensity is a very rough measure of damage and peak ground motion A is only one parameter of motion related to damage. Though the author prefers the third regression principle but the best way is to forget the term of intensity I in seismic design, because we know much more now about the estimation of ground motion directly from earthquake parameters. Earthquake intensity may still be used for daily life problems just like wind scale of 12 grades.

Table 1 a values used in the design codes

Design intensity I	VI	VII	VIII	IX
$k=a/g$, 1959 code	---	1/40	1/20	1/10
$k=a_{max}/g$, 1964	0.05	0.10	0.20	0.40
$k(frequent)=a_{max}/g$, 2001	0.04	0.08, 0.12	0.16, 0.24	0.32
$k(rare)=a_{max}/g$, 2001	---	0.50, 0.72	0.90, 1.20	1.40

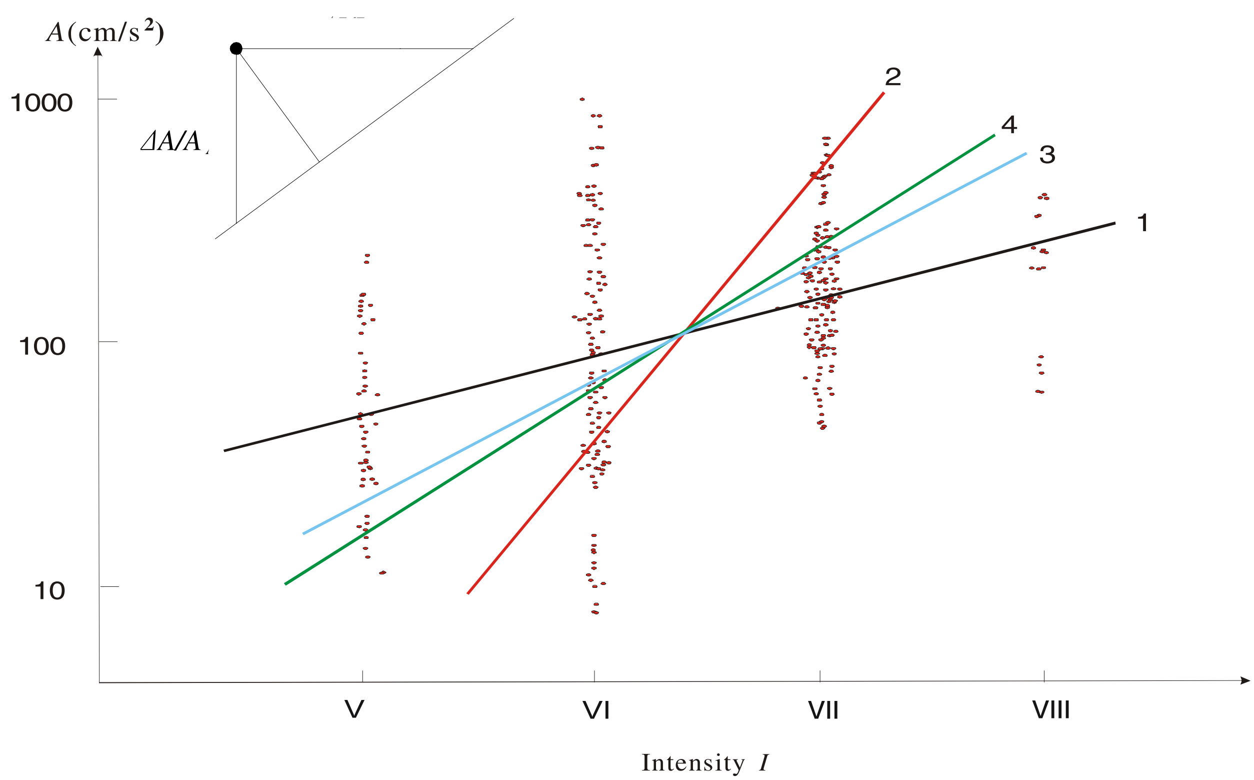

Fig.1 Relation between peak acceleration A and intensity I

$1 -- \sum(\Delta A)^2 = \min.$ $\quad 3 -- \sum\left[(\Delta A/A_{Av.})^2 + (\Delta I/I_{Av.})^2\right] = \min.$

$2 -- \sum(\Delta I)^2 = \min.$ $\quad 4 -- \sum(d)^2 = \min.$

Table 2 Results from different regression targets

regression / a/g / intensity	Regression 1	Regression 2	Regression 3a
VII	0.082	0.038	0.059
VIII	0.140	0.447	0.217
IX	0.235	8.000	0.795

Because of the inertia of tradition and less communication between seismologists and engineers, the zonation maps of China before 2000 were given in terms of macro-seismic intensity, defined by intensity scales, such as heavy, strong, many, few, etc., not in terms of numeric measures at all. It was natural in the 1950s or 1960s, when few instrumental records of ground motion, to accept intensity zonation for seismic design, but it was still unfortunately used in many countries in the world now.

Trying to improve the rough conversion of the macro-seismic intensity I into peak acceleration *a*, author has suggested, roughly 20 years ago, *a (M,R)* method to consider the large difference of peak acceleration for the same intensity from different *M* and *R* combination. This approach has been used in China in the past 10 or 20 years. The result is that, for the same intensity, smaller earthquake at a shorter epicenter distance will require a peak acceleration greater than that from a larger earthquake magnitude *M* at a longer distance *R*, because smaller acceleration with longer duration will be able to give approximately the same intensity when larger acceleration is combined with shorter duration.

(2) Design levels in the China design code

In the early stage, the Chinese code required only one-level design. The seismic design code in China before 1959 followed closely the former Soviet Union Code, which had two important features. Firstly, it included all kinds of structures, such as residential buildings, industrial buildings, bridges, water works, etc. in one code. Since 1964, the Chinese codes separated into many codes of different structures, such as residential buildings, industrial buildings, highways, railways, dams, etc., and the leading code is that for the building. Secondly, the seismic coefficient was separated into two: the actual peak acceleration, roughly three times as much as the one used in 1959. Secondly, the design target changed from one level design to two or three levels in 1978, a small one was for strength check and a large one, roughly three times as much, for yield or deformation check. The background idea behind this specification is to consider three levels of design: (1) a small one, corresponding to exceedance probability 63% in 50 years, to take care of frequent earthquake with no damage; (2) a moderate one, corresponding to exceedance probability 10% in 50 years, to take care of the probable large earthquake with reparable damage, and (3) a largest one, corresponding to exceedance probability 1~2% in 50 years, to consider the maximum possible one with no collapse to save human lives; and the moderate one would be automatically satisfied if the first and the last ones are satisfied. This is also accepted in our current code.

It is worthwhile to mention here that the phrase “in 50 years” really means “in 50 years to come”. Because our engineering seismologists believe that they have enough data to show a clear trend of non-stationarity in seismicity in China and it is then considered in our ground motion estimation for our zonation map for ordinary structures as well as individual estimation for important structures.

Roughly in the early 1980s, the probabilistic estimation of design ground motion, firstly applied to seismic design by Prof. C. A. Cornell in 1968, was applied in China to ground motion estimation of important structures, such as high dams and nuclear power plants, and the ground motion levels were then related to the probability of occurrence of strong earthquakes. Since then, a two-level design principle was specified in the Chinese seismic design codes, not only for nuclear power plants but also for ordinary structure. Following this trend, the Chinese codes adopted an important modification, the probabilistic definition of design acceleration.

2.3 Site effect Y (G) on Y (M, R, G; P)

One major advance in the Chinese seismic design code at this stage (1960-1990) is the probabilistic consideration of the occurrence of strong earthquakes in the region. Another major advance of the Chinese Code is the way of consideration of site effect.

Before 1964, the Chinese code specified the same spectral shape for all site conditions and the site effect was considered by increasing the design intensity by one grade for soft sites and decreasing it by one grade for very hard sites, which means a change by a factor of 2 for the design acceleration. Since 1964, the Chinese seismic design code adopted different design spectra for deferent site conditions on the basis of our independent research, but with data of strong ground motion records from USA, as shown in Fig.1. Rock site records are not shown here. As far as I know, both in USA (1974 ATC-3 model code; Seed, 1976) and Japanese (1981 code) seismic design codes were based on much more data of strong motion records on various site conditions, and similar conclusions were obtained. But similar specifications were adopted about 10 or 20 years later, and the trend of design spectra is quite similar with ours.

As can be seen in Fig.2, strong motion data with known site conditions are few, but that were what I could collect at that time. Though the data are far from enough, but they gave a result compatible with theoretical reasoning and the damage phenomena. This early decision seems correct [6].

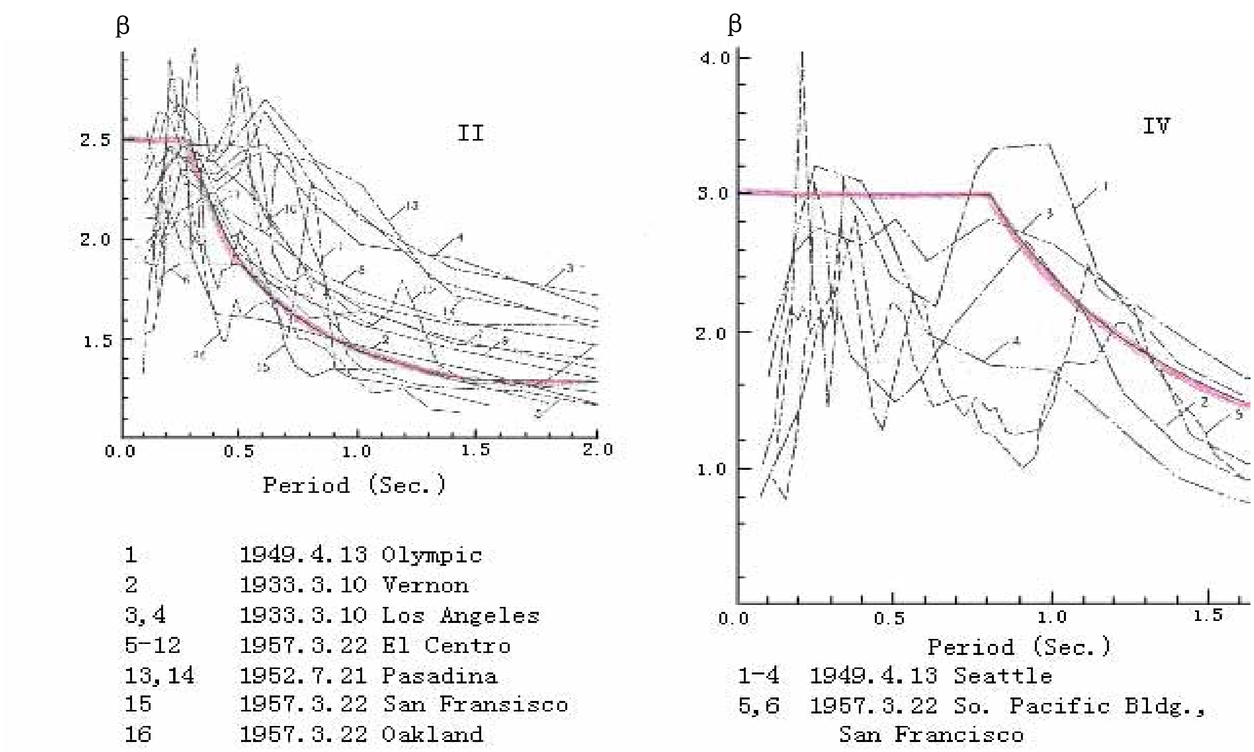

Fig.2 Spectra of different site conditions

2.4 Duration of strong ground motion

Duration of strong motion is not considered yet now in the seismic design codes of ordinary structures in the world. But it is universally agreed that duration is important for important structures such as nuclear power plant. It is also important for very tall structures of long natural period, such as tall buildings of a natural period more than 10 sec. There seems no universally agreed suggestion yet. It is the author's opinion that the duration of ground motion is important at least in three kinds of problems, i.e. for very important structures, for structures of long natural periods, and for low-cycle fatigue problems.

Maximum response of a structure subjected to dynamic ground excitation is controlled by at least three factors: the amplitude, the period, and the duration of the excitation, or in other words, the amplitude and the resonance effect. For structures with small damping, the resonance possibility is related to the period of motion and duration. The natural period of ordinary residential building is usually less that 5 sec., and thus for its response an ordinary time-history of ground motion of 10 sec. would be long enough to reach its peak response. But, for structures of longer natural periods, such as a tall building of 100-story height, it needs then perhaps 30 sec. or more to reach its max. response. The trouble here is that the routine old type of accelerogram is usually not long enough to reach the resonance of structures with natural period longer than, say, 5 or 10 sec. To consider the resonance effect, a combination of equivalent peak acceleration and strong motion duration should be better than peak acceleration alone. We have tried to study the response of long natural period structures and suggested that both the definition of magnitude of an earthquake and the digital records obtained from the new type of accelerographs may be of help.

2.5 Long period ground motion

Since the number of high-rise and long-span structures, with natural period close or even greater than 10 sec., is fast increasing, a design spectrum with max. period of 7 sec. is certainly not enough. It is then obvious to extend the design spectrum to 10 sec. or even more. Because the available accelerograms are obtained mostly by the traditional accelerographs, which cannot record accurately motions of period longer than 3-5 sec. The records obtained by the new accelerographs or the digital instruments are still limited in number and in regions, it is then necessary at least for recent years to find some way to estimate the ground motion of longer periods.

Author's group has suggested a ready and easy method [7], which is reasonable and adequate. It is easy, because no additional data or theory is needed. It is reasonable, because it follows directly from the definition of magnitude used in the attenuation relations. It is adequate because it matches with the spectrum obtained from the accelerograms available now.

The definition of earthquake magnitude has a relation with amplitude, period and distance. For example, the surface magnitude recommended by IASPEI is defined as follows

$$Ms = \log\left(\frac{A}{T}\right)_{\max} + 1.66\log\Delta + 3.3 \qquad (2)$$

where A is the amplitude of horizontal component surface wave (in μm), T is the corresponding period, Δ is epicentral distance in degree. In China, when measuring the magnitude, the period T must be greater than 3 sec. and $\Delta \geqslant 1°$. Because the magnitude is a function of ground displacement amplitude, period and distance, the ground displacement can then be estimated also from the corresponding period, distance and magnitude.

To have a good estimation of the long-period spectrum, two sets of data are obtained from the point of view of the seismologists. The first set is obtained directly from the definition of surface wave magnitude (Eq. 2). The displacement response spectrum value S_d is taken as $S_d = 2.5A$, where A is the displacement amplitude in Eq. 2 and the factor 2.5 is the amplification of the ground motion to response, which is related to a damping of 0.05 for the spectrum. The spectrum value for displacement S_d is then converted to spectrum value for acceleration S_a. The second set of data is obtained from 152 horizontal components of digital broadband records in China. Fig.3 shows that after1 sec., Huo's results are irregular and not dependable in the long-period range and that the dotted line is Huo's result based on US data; solid line is the new result obtained by the suggested approach. The results presented here show a good smoothness at least.

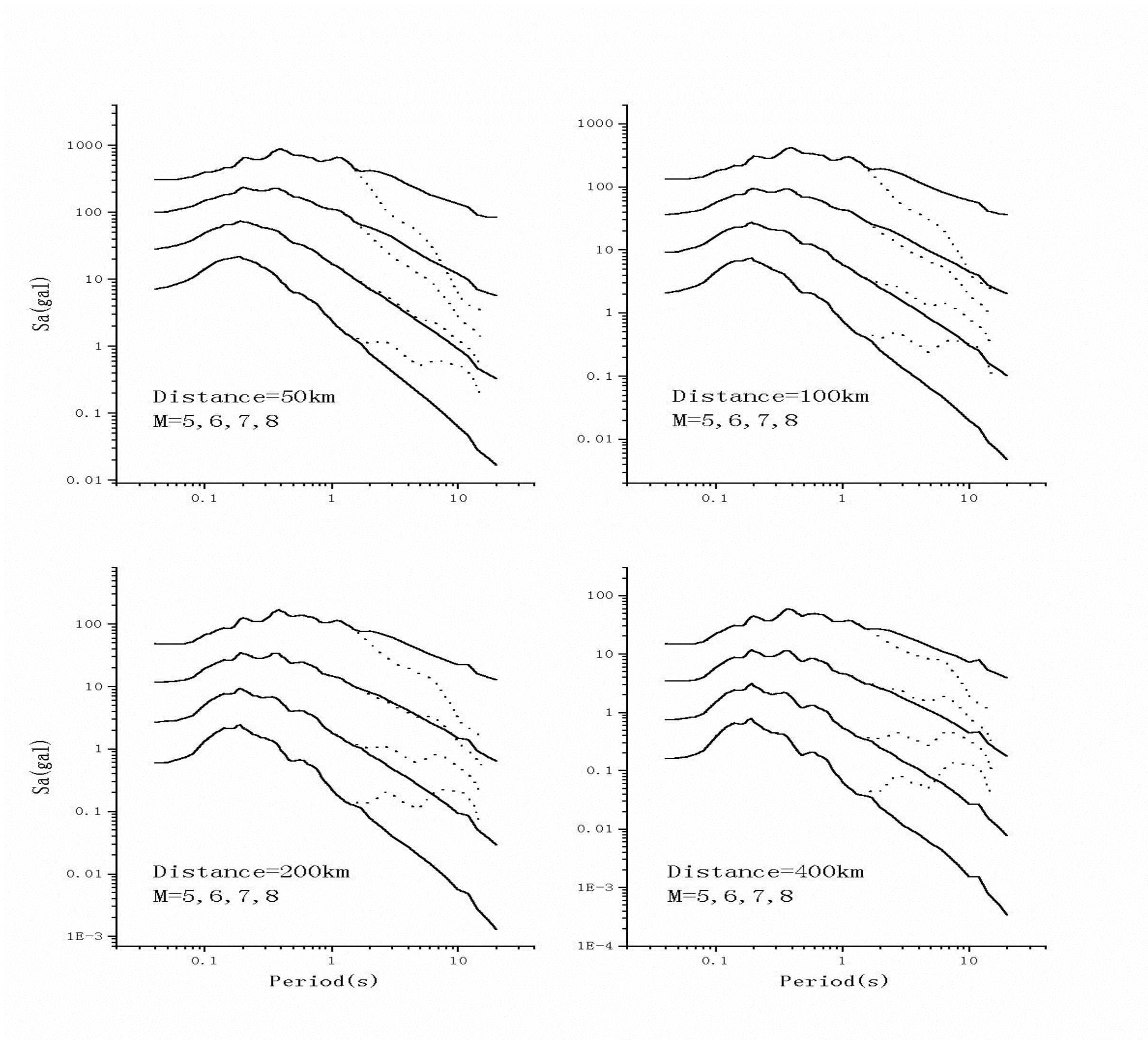

Fig.3. Acceleration response spectrum Sa (T, ξ=0.05) 1/28/2004 up to T=20 sec.

2.6 Zonation maps in China

To facilitate the design of ordinary structures, it is necessary to divide a large region into sub-regions according to the strength of shaking. Index of shaking strength was taken as macro-seismic intensity, defined by macro-seismic ranks of damage level of a region, such as collapse, heavily damage, damage, slightly damage, and intact, corresponding to intensityⅨ, Ⅷ, Ⅶ, Ⅵ, and V or less. The maps before 1990 in China was in terms of intensity, but was changed in 2001 into ground motion parameters of acceleration and characteristic period *Tg* which is proportional to the ratio of spectral velocity *v* and spectral acceleration *a*, or *v/a*, quite similar to the US zoning maps since 1991. Figs. 4 are the current seismic zonation maps in China and the effect of site condition is given in Table 3 [8,9].

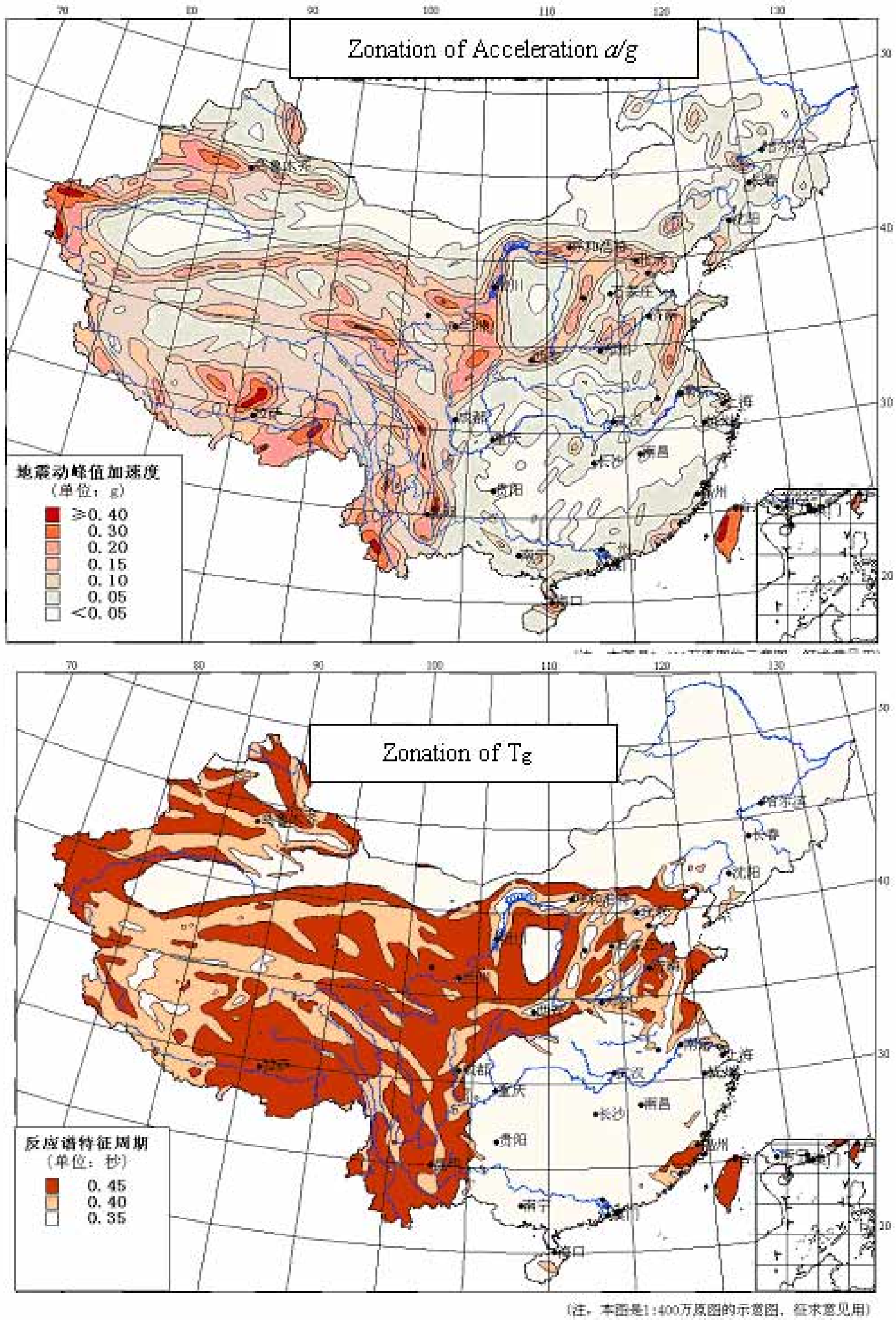

Fig 4 The 2001 Zonation maps of China

Table 3 Effect of Site Condition on Tg

Zone \ Site	I	II	III	IV
1	0.25	0.35	0.45	0.65
2	0.30	0.40	0.55	0.75
3	0.35	0.45	0.65	0.90

There are several new features in our new zonation map. Comparing with previous maps, the width of the design spectra is extending to the longer period side not only for softer sites as several other codes in the world, but also for regions with possible earthquakes of larger magnitude at a longer distance. This additional consideration results in the larger *Tg* values. The second new feature is the consideration of the uncertainties in the potential seismicity assessment, which consists of two steps: (1) consideration of the effect of five possible different assignments of seismic province zonation, two of which are shown in Figs. 5A and 5B, and (2) modification of the zonation map to consider the effect of uncertainty in assignment of seismic province zonation. Fig. 5 shows the effect of uncertainty, in terms of coefficient of variation, in ground motion assessment from the uncertainties in zoning the seismicity provinces. Analysis reveals that regions of large variation are those with much less earthquake information and their seismicity regional assessment is mainly based on personal choice.

2.7 Uncertainty analysis in seismic hazard assessment

In almost any topics related to earthquake prediction or estimation, such as ground motion attenuation, relation between earthquake intensity and ground motion parameters, magnitude definition, magnitude-frequency relation, ground motion attenuation, etc., the uncertainty involved is always very large. The reason is very simple because there are too many uncertainty factors involved. For example, the magnitude of an earthquake is calculated from instrumental records obtained. It is very common to have quite different magnitudes determined from individual stations, a difference of 0.2 in M being the common case. A difference of 0.2 or 0.3 in magnitude M means a difference 30% or 50% error in ground motion values. The reason for this big difference comes from the simplification of the measure of earthquake magnitude and the peak values of ground motions. For predictions, another kind of uncertainty is also very large, i.e. the prediction of the peak values of ground motion at some given locations during future earthquakes in given regions. The situation is then there are various uncertainties from various estimations. For example, there are 10 stations recorded one earthquake. The magnitudes of this earthquake calculated from each station record may differ from each other by 0.5, or the difference of one station from the average may be 0.3 or 0.4 in magnitude, which means an error of 30 or 50% in peak ground motion. To engineers, this accuracy is too large. Of cause, there are other sources of errors.

To take care of such big errors, uncertainty analysis is introduced in earthquake engineering problems. A probabilistic approach of earthquake ground motion evaluation was firstly introduced by Professor Allen Cornell in the 1968, which assumed the possibility of the occurrence of earthquakes in a given region is uniformly random and was widely adopted later in the world. Professor N.C. Lind considered in 1985 that there are two types of uncertainties in the problem. There are random events, which can be treated by probability theory, such as the possibility of the occurrence of an earthquake of 6, say, in a region may occur any where in the region with equal probability, same as Cornell’s assumption. But Professor Lind considered another type of uncertainty, the uncertainty from ignorance, which may be dealt with by subjective probability. He mentioned that there is a third kind of uncertainty, the fuzzy uncertainty, with which he suggested no method.

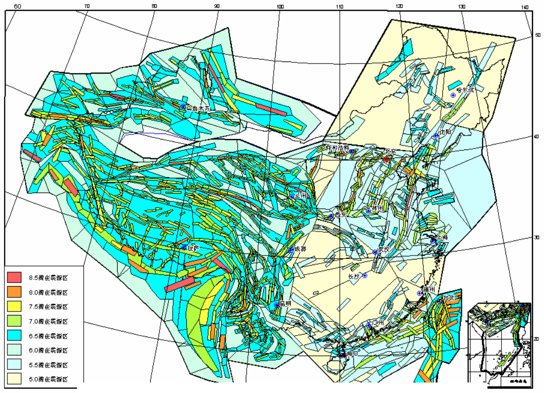

Fig.5A Seismic province zonation No.3

Fig.5B Seismic province zonation No.4

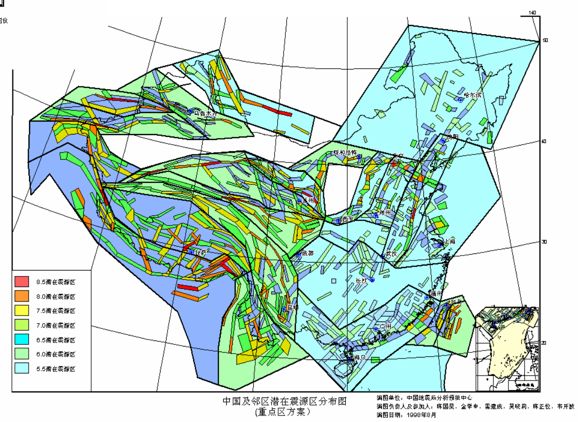

Fig.5C Uncertainty from Seismic Provence

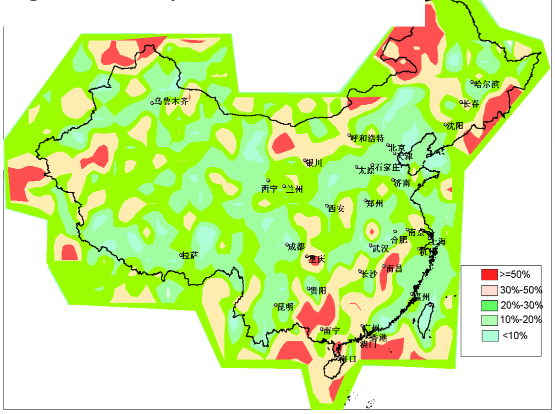

Fig.5 Seismic Province and Its Uncertainty

Author suggested a general probabilistic approach to consider all kinds of uncertainties by a probabilistic approach [10]. Usually, uncertainties may be classified into three types, namely, random, fuzzy, and ignorant and they may be dealt with respectively by probability, fuzzy set, and multi-subjective probability. The key point is to transfer the membership function

$$\mu(x) = \mu_1/x_1 + \mu_2/x_2 + \ldots\ldots \mu_n/x_n \quad = \Sigma\mu_i/x_i$$

where the plus and summation signs are not arithmetic, but mean only assembly, and μ/x is not a fraction but a membership relation, i.e. member x_i has a right to belong to the fuzzy set A, μ_i= 0.3 means 30% right. Another widely accepted idea is probability of fuzzy event A

$$P[A] = \sum_{i=1}^{n} P[x_i | \mu_A(x_i)]$$

where $P[A]$ is the probability of occurrence of fuzzy set A, and $P[x_i]$ the probability of occurrence of member x_i. The probability mass function of a fuzzy set A over its members x_i.(i =1, 2, …… ,n) is

$$P[x_i|A] = \mu_A(x_i) \Big/ \sum_{i=1}^{n} \mu_A(x_i)$$

2.8 Strong-motion observation

It is decided to build several networks in the mainland in the coming 5 years, i.e. 1100 stationary stations in 21 fixed networks, 370 stationary stations in 5 urban city arrays, and several arrays of special purposes, such as attenuation, site effect, active faults, and some movable arrays. All observation accelerographs will be the digital wideband modern type. Site conditions will be provided for all stations. The total number of stations will be nearly 1800, with an average covering of 1 per 600 km^2. We started to observe the strong earthquake motion in 1962 when a reservoir earthquake of M=6.1 occurred and damaged the Xinfengjiang dam close-by. That region was considered as of low seismic activity before the building of the dam, very similar to the Koyna dam in India. The Xinfengjiang dam was designed for 0.05g and a long horizontal crack occurred at the sharply turning section near the top of this concrete buttress dam. But not many records were obtained near this dam and the earthquakes gradually stopped. IEM (Inst. of Engineering Mechanics) and others in China have tried to measure the strong earthquakes in China for nearly 40 years, part of the results has been published. Records processed were roughly 1500 traces at end of 1990 and nearly half of them were from IEM [11]. There is a big project of strong motion observation just started for the next few years to allocate a few thousands of the modern digital instruments over the China mainland. Since the main land of China is big and the strong earthquakes are scattered over vast regions, the accumulation of strong ground motion records will certainly be slow.

(1) Existing stations
There are now on the mainland of China about 400 stations with standard triaxial accelerographs, on free field or on structures. There are mostly stationary and scattered in some cities and many types of structures and ground. Records obtained are mostly of peak acceleration less than 0.5g, and a large part if they were from strong after shocks. I had this kind of experience myself, in the aftershocks of the 1966 Xingtai earthquake and 1970 Tonghai earthquake and the maximum peak accelerations reached nearly 0.6g. Detailed records were published at IEM.

(2) A new project [2]

There is a new project in CEA, the China Earthquake Administration, to allocate during the coming 5 years starting from 2002 with roughly 2000 stations with modern digital strong motion instruments on the mainland, as show in Fig. 6. It includes 1160 stationary stations and 200 mobile stations, and 200 with other purposes. All together, there will be 12 arrays with special purposes: 1 array for across active fault, 2 for ground motion attenuation (one on the west China and one on the east), two for site effect, one for topographic, 4 for buildings of typical types, one on long-span bridge and one for large dam. In addition, there will be 80 sets of strong motion accelerographs for mobile stations in Beijing, and 40 sets each in the southwest, northwest and southeast regions. There will be a national strong motion observation center in Beijing, and three regional centers at other regions mentioned above.

It is planned to spend roughly 3600 millions Chinese Yuan to complete this project in 2007.

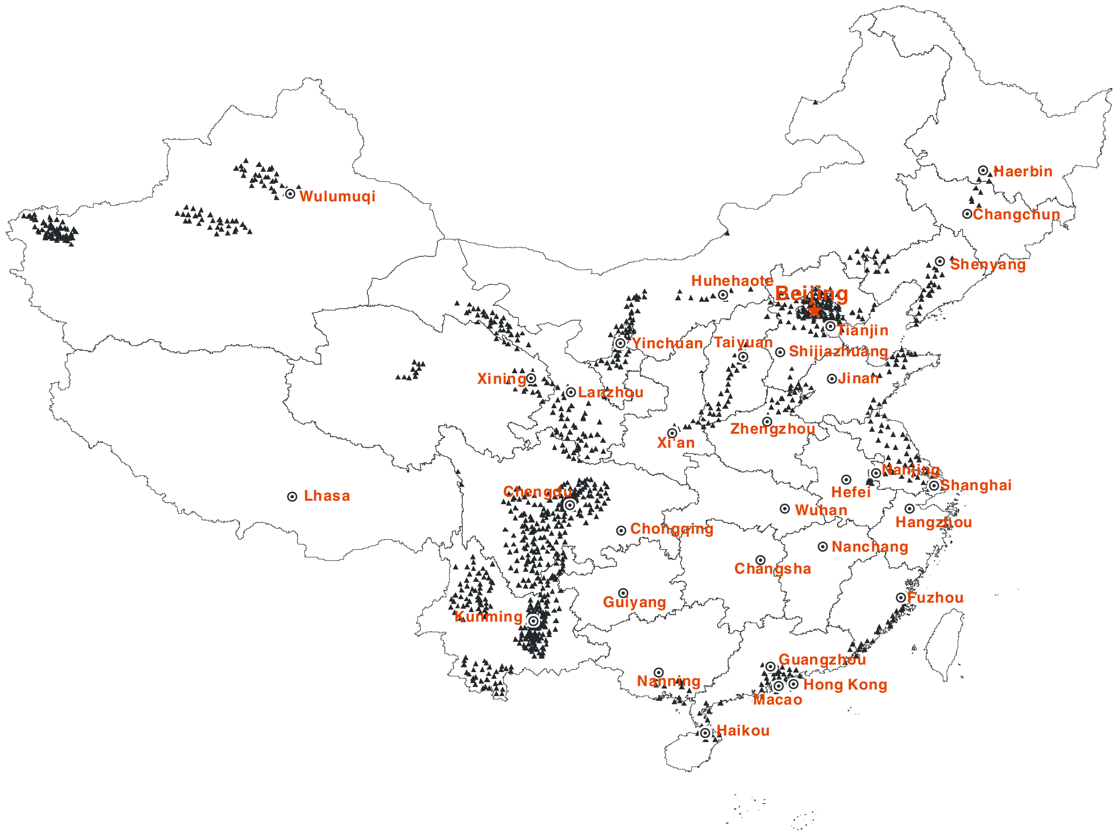

Fig. 6 Stations to be completed before 2008

2.9 Joint effort of seismologists and engineers

For better and fast achievements in ground motion assessment in earthquake engineering, it is a "must" for seismologists and engineers to work jointly and closely, and engineers should be more initiative in working together with the seismologists because it is for the safety of structures, and because the engineers know what are needed. At the creation stage of earthquake engineering, some engineers from Europe visited the strong-shaken area right after the occurrence of strong earthquakes, and created the terms of Intensity and some others, and invented ground motion measurement instruments to record the motion for the purpose of motion itself not for the determination of the focus or source mechanism of the quake. The main interest of seismologist is the mechanism and the occurrence of earthquakes and the main interest of engineers is how the ground or the construction vibrates because that is closely related to damage of structures. The ground motion properties are functions of fault rupture properties, not only a single quantity magnitude, but also many others, such as rupture dimensions, beginning and rupture sequence, rupture propagating direction. And the most important thing is when and where the earthquake will occur. The engineers know what they need to design their structures. Close and cooperative relationship between seismologists and engineers is always important for a smooth relay to develop the science of engineering seismology.

There is a group of seismologists and engineers in the Institute of Geophysics under CEA, having worked closely together for roughly 10 years. They worked together to complete the third and the fourth seismic zonation maps of China in 1990 and 2001 respectively. The third one was in terms of intensity, and the fourth one in terms of ground motion parameters, the acceleration and the characteristic period, which is the proportional to the ratio of ground motion velocity and acceleration. They worked together also for several other topics, such as seismic hazard assessment for various important engineering projects, such as the Three Gorges Dam site. They are still working together and with others, under the leadership of the CEA, on the following topics: engineering seismology, such as evaluation of ground motion of an engineering project, a city, a region, and the whole nation; safety assessment of existing structures, including single important structures or a whole city; and loss estimation of a region or a city. One unique development in this group is the close joint work of seismology and engineering. For example, the consideration of wide spectra from 0.1 sec. up to 20 sec. is simple and straight foreword, but it is a joint achievement of seismologists and engineers.

3. SEISMIC DESIGN OF STRUCTURES

In China, there are separate seismic design codes for various kinds of structures, such as buildings, industrial structures, highways, railways, dams, hydraulic structures, pipelines, etc. Since the buildings are the most common man-made structure and the first one to consider the earthquake action in design, it will be the major one to be discussed in this paper.

The first seismic design code adopted in China was drafted in 1959 and it included all kinds of structures. It followed closely that of the former Soviet Union code, but it was soon replaced by our 1964 Code. These two codes were only draft codes but they have been followed at their times, because no other code was available in China. The 1964 code was considered as a formal one of our own, but because it was completed just before the so-called “cultural revolution” and it was not officially approved, but the main ideas were followed in the later codes. A short introduction of the features of the 1964 seismic design code will be given at the beginning of this section and then go into some details of our current codes.

3.1 The former earthquake design codes in China

The 1964 code was only a draft code because the so-called “cultural revolution” stopped its official application, but the later codes followed its principles and main specifications, which are briefly outlined in the following.

First of all, the 1964 code was for buildings only; our first code was the 1959 code, which included all kings of structures.

Secondly, intensity defined by the macro-seismic intensity scale was still used as an index for the strength of ground shaking, as that used in 1959. However, as shown in Table 1, the values of peak acceleration for given intensities are greatly changed, roughly three times of those used in the 1959 code, and remained nearly the same in the later codes. Because a constructional coefficient $C=1/3$ approximately was adopted at the same time to consider the energy-absorbing effect of nonlinear deformation of the structure during strong shaking, so that Ck remained nearly the same.

Thirdly, site effect was correctly considered by modifying the shape of design code. Before 1964, all seismic design codes in the world adopted a design spectrum of the same shape for all site conditions; in many cases, a constant coefficient was specified to take care of the effect of site condition. As far as the Author knows, in the early 1960’s, there were quite different understandings in this aspect. The Soviet Union investigators adopted formally in their design code that structures on softer sites were required to be designed for higher seismic forces, plus or minus one intensity grade respectively for softer or stiffer sites comparing to moderate site. One intensity grade increase means 100% increase in seismic design load, as specified in the formal design code, because the damage is higher on softer sites. In Japan, strong belief was that damage of structures on softer site might be lower because softer sites would absorb more energy of vibration. In USA, many authorities believed that softer sites may amplify the weaker vibration but may reduce the strong vibration because the soft soils were considered highly non-linear, and it would be better then not to consider this effect at all. When we were revising our 1959 code, detailed investigations were carried out on this problem. Damage data from past strong earthquakes over the world were collected and analyzed [12, 13]. Though we agreed that damage was in general, higher on very soft sites, but the main reason was the additional ground failure of soft grounds. We found, both in theory and strong motion data from real earthquakes, together with similar results obtained by leading scholars in USA and Japan, at nearly the same time, that the frequency content of ground motion was amplified mainly in the long period side of stronger motion. Fig.2 showed part of the results obtained at that time from the accelerograms obtained in USA. Japan and US specifications adopted similar specifications in their seismic design codes roughly 10 or 20 years later. Needless to say, the number of strong motion records now available is much increased now and this conclusion is certainly true. For example, Prof. Seed of USA obtained similar spectra from much more real records of strong earthquake motions roughly 10 years later [14], and the conclusions are similar.

3.2 Current seismic design codes in China [15]

In China, there are three ranks or levels of seismic design codes, namely, the national level, the ministry level, and the city level. There are also other legal codes, not for design but also safety related, such as standard for seismic evaluation of buildings, technical code for seismic safety evaluation of engineering sites, the leading structural code is that for buildings and its current edition is completed a couple of years ago. Its fundamental targets are still a three-level protection as adopted since the 1989 code, but the design spectrum adopted in our current building code was changed as shown in Fig.6. Since this new code was worked out nearly at the same as the 2001 edition of our new zonation map, there are better connections in the following aspects. Firstly, the ranges of design peak acceleration for higher intensity regions were considered too much, such as 0.2g for intensity VIII and 0.4g for intensity IX, there was then a requirement from the designers to subdivide this interval. The revision in the new zonation map in 2001 subdivides the intensity zones VII and VIII into two sub-zones each. Actually, the term Intensity

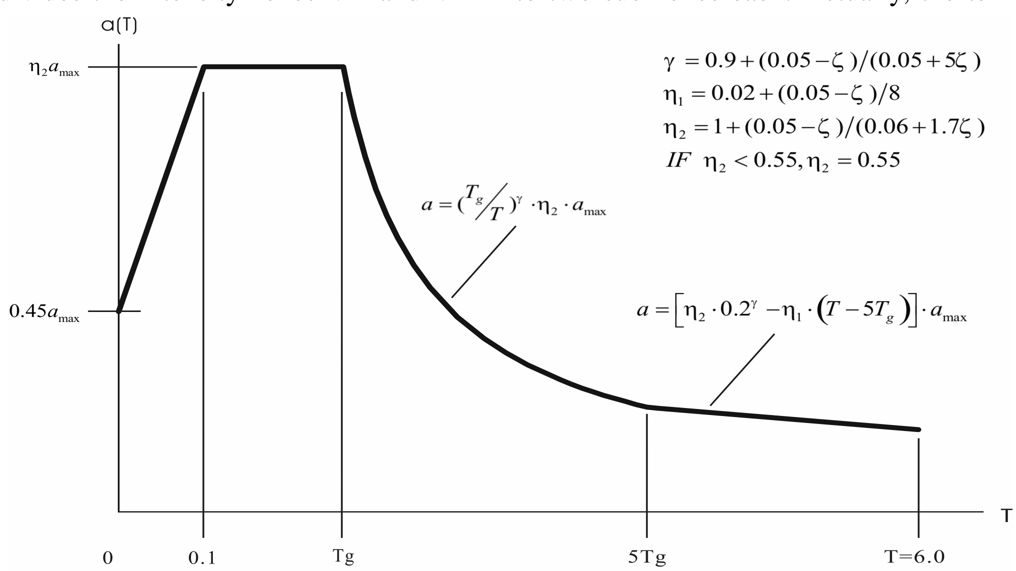

Fig. 6 Design Response Spectrum

defined by intensity scale was given up because many seismologists and engineers believe that it is not easy for them to provide adequate definition of the 12-grade division in terms of qualitative statement of damage or behavior of objects or buildings after a strong earthquake, and no body would try to make such a refined sub-division. That is why both sides, the design engineers and the engineering seismologists, worked out a modification together. But the cooperation is not perfect yet at this stage, so that the design spectra in the 2001 code are still somewhat different from the one of a simple combination of acceleration and velocity. Author hopes that both our zonation map and design code would be able to reach a common agreement on the specification of design and zonation on the shape of design spectra up to a longer period, say 10 sec., acceptable for the designers and to the engineering seismologists.

3.3 Seismic design principle

Seismic design started in China in the 1950s. At the beginning, the formal Soviet Union codes were adopted, and our first draft code was almost a copy of theirs. In our1964 draft code, some important changes were made and applied already, but it was not a formal one because the so-called Cultural Revolution stopped almost all technical works, including this draft code. The design principles for these codes were an elastic design for seismic intensities of IX and below. The two-stage or three-stage design principle for a small intensity of roughly 60% in 50 years with almost no damage, a moderate intensity of10% in 50 years with heavy damage but still repairable, and 2% in 50 years with no collapse. That is the one used now.

(1) The present practice

Structural response was the first topic studied in the field of earthquake engineering in the world and also in China. The specific first topic is the earthquake damage and the result was the terms earthquake intensity and the intensity scale. Intensity was firstly studied not by seismologists, but by engineers. It is clear that structural behavior during strong earthquakes is both the beginning and the purpose of the study of earthquake engineering. If all structures were safe against strong earthquakes, that might be the end of this branch of science.

To prevent losses due to strong earthquake is practically a problem of safety and economics. The engineers know how to construct structures strong enough for the highest possible earthquakes, but the present problem is to construct them economically. Strong earthquakes of magnitude of 5 and up will cause damage to structures of weak resistance, such as adobe houses and other masonry structures, and these kinds of damage will then to cause injury or death of human lives. The problem of structural responses during strong earthquakes remains one of the most important subjects in earthquake engineering field.

There are at least two principles on the level of protection of the seismic design target in the design code, the minimum protection principle and the over-all design principle. A representative one of minimum design is used in USA and some other countries. In their codes, it is clearly stated that the requirements given in the code are minimum requirements to protect the publics of the society from possible damage level selected in the code and the owner of the structure may construct it stronger than required to suit his own requirement of higher security. This requirement is preferred in the States perhaps because most of the buildings are private properties there. China code is a representative of the second kind, perhaps because most of the buildings are public properties, especially many years ago. Though it is not openly stated in our codes that our codes are not minimum requirement, but it is obvious so to us that it should not be over-designed.

Seismic design is quite different from design against other loads, such as the so-called live load, loads due to goods, contents, cars or trains, which can be predicted with good accuracy through statistics collected for the past years. Strong earthquakes, in China mainland at least, occurred with very large uncertainty, so large that accurate prediction of the occurrence of a strong earthquake, say of magnitude 7 in a region of 50 km radius within the future 50 or 100 years, is still not possible; we therefore are forced to consider future strong earthquakes with a probabilistic sense, i.e. to give a probability to our assessment of seismicity in our zonation map.

Actually, a few years before the changes in the methodology of our zonation map from deterministic approach to probabilistic one, the probabilistic assessment of seismicity has been applied in China at the beginning of 80s for the ground motion evaluation of the dam site of Er-tan in the Southwestern China.

Since 1990, both our seismic intensity zonation map and seismic building codes were revised from deterministic to probabilistic.

Most of the current seismic design codes in the world require in general a three-stage protection. For example, in China it requires to consider three stages, i.e., no repair of the structure is required for a weaker ground motion of 65% probability of exceedance in 50 years, reparable for a moderate motion of 10% in 50 years, and no collapse to save human lives for a strong earthquake of probability of 1-2% in 50 years in the region. The small and the strong earthquake motions are to be designed and the moderate one is considered then satisfied automatically, because the construction coefficient c=1/3 was adopted. In our 1964 design code, a design acceleration of k=a/g has been considered as the moderate design acceleration, and a constructional coefficient c=1/3 roughly was taken as the design acceleration for an elastic analysis, and a coefficient of 4-6 time of the small one was required for the strong one.

(2) Performance-based seismic design

Professor J.P. Moehle mentioned [16] that, a key feature is the definition of performance metrics that are relevant to decision making for seismic risk mitigation. In concept, these metrics consist of estimates of losses due to earthquakes, including direct losses (repair and restoration costs) and loss in its functionality (or downtime). The objectives of PEER performance-based earthquake engineering methodology under development are (1) to facilitate the decision making on cost-effective risk management of the built environment….., (2) to facilitate the implementation of performance-based design and evaluation …., and (3) to provide a foundation on which code-writing bodies can base the development of transparent performance- based provisions." Professor H. Krawinkler [17] suggested a framework of performance assessment approach, which consists of five links as follows: seismic hazard (input ground motion), engineering demands (structural analysis), damage measures, decision variables (loss), and performance targets. Words in the parentheses are the terms I added.

In my opinion, in earthquake engineering problems, there are two sides and three levels as follows. The two sides are the enemy--society (earthquake--society) and three levels are the minimum (or no repair required), the moderate (or repairable), and sever (or pending to collapse or total failure). For earthquake problem, two sides are not changed in almost all suggestions, though the second item may change from society to structures to include more items, such as indirect economic loss in the society; but three levels are changing at different levels of development of this branch of science. For example, what we consider now is only the direct loss, but in the consequence-based principle, it includes the indirect economic losses not only in a city but also in the whole world [18], if the earthquake is very strong and the damaged structure is of high importance, such as the World Trade Center damaged in the 9.11 catastrophe. The history of the past half Century in earthquake engineering design study shows that the content of society changed from buildings or structures, to direct and indirect loss; and the level of damage changed from allowable or elastic limit, non-elastic and collapse, to multi-level control; and they are all related to its own probabilistic definition to consider the huge variances involved in each item mentioned above.

As far as the author is concerned, the present Chinese seismic building code is performance-based, at least, an initial version. It stated clearly three or two levels of design: a first level with a weak earthquake ground motion level of probability of exceedance of 60% in 50 years to come together with an elastic design for the strength of the structure; and a high level of ground motion with probability of exceedance of 1~2 % in 50 years to come together with a limit design for the deformation of the structure. A moderate level of ground motion of 10% probability of exceedance in 50 years is considered nearly satisfied automatically. Briefly speaking, three design motion levels of 60, 10 and 1~2% in 50 years of exceedance, together with three design limits of elastic, yield and collapse design. The weak point in our current design requirement is that the structural analysis is not really a detailed dynamic non-linear one yet.

(3) Possible future advance -- Consequence-based design principle [18]

To me, the most important addition of the consequence-based design principle over the performance one is the consideration of the induced indirect economic losses. Design principle may be analyzed in a diagram in Fig. 7 and its explanations are followed. The important addition comparing with the performance-based principle is the addition of consideration of the possible indirect influence on the societies involved. For some structures, such as an ambulance or telecommunication station, if collapsed, its indirect loss in a small town will be much less than that in a modernized metropolitan area, not only because of more buildings there but, more importantly, because of the multiple connections of the damaged structure to other activities in the society or even in other countries, especially the living, business, trade, political, or military connections. Structure is man-made and is one of the most important items that are related closely with loss. Engineers know their structures quite well, much better than they know earthquakes. I like to emphasis that, in addition to the specific structural loss, the society effect induced by the damaged important structure should also be considered. Since a structure is always in a society, one structural damage will then influence its society. For example, the damage of a factory will loss its supply to the society and also reduces its requirement of the raw materials or service, which may then in turn influence other links. On the opposite side, it may stimulate or increase the production of some other business, for example, loss of houses may stimulate the construction business. These cases are generally referred to as indirect loss or effect and they are mostly economic losses. As far as I can remember, that the indirect loss in some cases, especially for a large earthquake occurred in a developed area, such as the 1997 Kobe earthquake in Japan, the indirect loss was nearly the same as the direct one or even more.

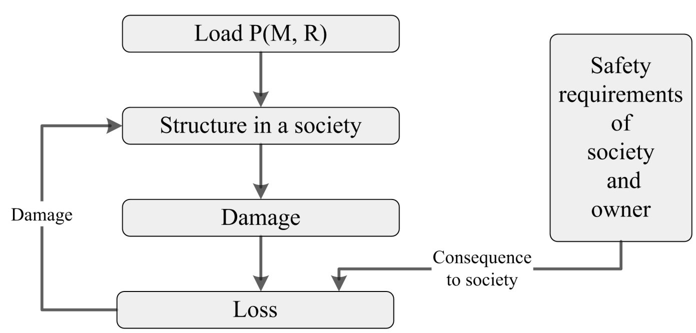

Fig.7. Earthquake design principles

I like to mention here that there are currently two different design policies in the world. In USA and many other countries, a minimum level is specified in the code and the individual owners are allowed to adopt a design with a higher level of safety for one's own structure. Since almost all structures in China were nationally owned, and the China codes are naturally the only level required. But now, there are many privately owned buildings, especially in modern cities, such as Beijing, people spend a large amount of money to decorate the inside of their houses. The price of better inner decoration usually costs them 10% increase or even more. It would be quite possible for them to spend 5% more to provide them a much better safety of their lives and houses in regions of high seismicity, such as Beijing.

3.4 Other types of structures

In addition to buildings, there are other structures. High dam is a typical and important one and will discuss briefly in the following.

China is now in a stage of fast development and the development of our hydraulic power resource is of course of high importance. Hydraulic resources are rich in the western mountain regions of China, where unfortunately strong earthquakes are also rich. Among all kind of structures, the earthquake safety of high dams, long-span bridges, long pipelines, and transportation systems is of high importance. According to reliable statistics, only 5.2% potential power resources in China are developed. Their earthquake safety problem is then of high importance. As Professor H.Q. Chen mentioned [19], the following problems are of high importance.

(1) Ground motion assessment of dam sites and reservoir-induced earthquakes

An effective peak acceleration is adopted for design, which is defined as $S(T=0.2, \zeta=0.05)/2.5$. On the basis of a mixed method of probabilistic and deterministic approaches of seismic hazard assessment, to select a maximum possible design earthquake for the given earthquake-geologic condition of the specific site and then a reasonable site-related design spectrum. Scenario earthquake may also be considered. In case of deep soil sites, site investigation should be carried out to find the soil condition there through in situ investigation and sampling and its effect on design spectrum should be considered to evaluate the site spectrum.

(2) Earthquake analysis and experimental verification of high arch dams

A numerical analytic model has been developed to study the dynamic interaction of dam-water-foundation interaction, considering the horizontal joints, non-uniform input ground motion, energy radiation to the foundation, valley formation and geologic and tectonic effects near dam site. Nearly 20 years field study with USA on three arch dams in China has been completed.

(3) Studies on key earthquake engineering problems in water transportation crossing the Yangzi River

Two possible selections were studied to bring water from south to north of the Yangzi River, where a peak ground acceleration of 0.16g was considered for rock site for a probability of exceedance of 0.05g in 50 years. There are two possibilities considered, over crossing by aqueduct and under crossing by tunnel over a length of more than 3 km, and the key factor is the earthquake safety problem, which brings many innovative problems.

3.5 Other possible considerations

Some additional possible considerations for further improvement of seismic design in my mind are listed in the following.

Firstly, all quantities in Fig.7 are probabilistic. The earthquake load or ground motion is given or estimated in terms of probability P(M,R), where M represents the magnitude of earthquake possible in a region and the distance R is close enough to have effect on the structure. There are at least two problems related to the magnitude M. Firstly, It is a very rough quantity, error of 0.3 or 0.5 is very common which is clear from the magnitude determinations from records of stations over the world after a strong earthquake. It means that the variation of acceleration may be twice, which is too much for engineering purpose. That is one of the reasons to introduce probabilistic approach in engineering seismicity problems.

Secondly, different possible combinations of R and M should be considered for each structure. For example, for structures of very long span bridges or very tall structures, such as suspension bridge and high-rise building, ground motion of long periods, say longer than 3 or 6 sec., from earthquakes of large magnitude at a long distance away may cause serious damage to the structure, even though the peak acceleration may be very low, lower than the ordinarily considered.

Thirdly, the design spectra specified in the present codes are usually not long enough for the long-period side. Reason of this shortage comes from the presently available records, which are recorded mostly by the old types of accelerographs, which give dependable records only for waves of periods less than 3 seconds at most. Since it will take time for the newly available digital instruments to record enough records from strong earthquakes, the author has suggested a reasonable and easy way to extend the spectra to periods up to 10 or even 20 sec. through the definition of the earthquake magnitude, a necessary quantity in any attenuation law, as mentioned in Sect.2.5 [7].

4. STRUCTURAL RESPONSES TO STRONG EARTHQUAKES

The top-most important problem in earthquake engineering should be the structural response to strong earthquakes, because structural response is the reaction of structure to earthquake shakes and then a natural index of the safety of the structures. It is not over-emphasized if one says that all works done in the 13 world conferences on earthquake engineering are for one aim, that aim should be structural response.

4.1 Theoretical and experimental studies of structural responses

Earthquake engineering studies started from the analyses of damaged structures in strong earthquake shaken fields, followed by theoretic and experimental studies in laboratory, and instrumental observations in field waiting for strong earthquakes to come. China was and still is a third-world country, and strong earthquakes are scattered, except in Taiwan. Problems studied include strong-earthquake observation, shaking table tests, and large-scale computational facilities among others. Though we started researches in this field roughly fifty years ago, but with serious interruptions in mainland of China. As far as I know, the main institutes are as follows: IEM in earthquake engineering in general; Institute of Buildings (IOB) of Ministry of Constructions; Institute of Hydraulic Structures (IHS), mostly dams; Building Engineering Department (BED) and State Key Laboratory for Disaster Reduction (SKLDR) of Tongji University (TGU); Beijing Polytechnic University (BTU); Harbin Institute of Technology (HIT); Tsinghua University (THU); Dalian University of Technology (DLUT); Tianjin University (YJU); Guangzhou University (GZU), Wuhan University of Technology (WHUT); Hong Kong University (HKU), etc. All together, there are roughly a few thousands of researchers involved on structural part of the problem. Because of economic conditions and other reasons, China is lagged behind in experimental investigations.

4.2 Replacement and strengthening of weak buildings

It has long been realized that adobe and masonry buildings are the most vulnerable buildings against strong earthquakes and it has been proved again and again, such as the recent strong earthquakes in the northwestern part of China, and also in Bam of Iran in December 2003. Though we know that a simple wooden frame will be of great help to prevent collapse, but that is still not easy because of lack of supply of timbers or economic problems or the custom. A well designed and constructed masonry house may stand a shake of intensity VI or VII without collapse, but good construction quality and details must be guaranteed. For very long unsupported brick walls, intermediate constructional columns will provide supports in-between. I am glad to mention that, masonry buildings are not allowed to build anymore now in Beijing City, but there are still many of them remain and it may take many years to replace them. If China can be constantly improved in her economic condition, this problem can be solved sooner.

Strengthening of weak structures has being started a few tens of years ago for very important buildings in Beijing. Many existing structures, residential and industrial buildings, were re-evaluated and many of them strengthened; and some of them were proven to be successful, such as buildings in a large factory, strengthened after the 1975 Haicheng earthquake, suffered much less damage than those in another nearby factory during the 1976 Tangshan earthquake [20(p.598)]. Extensive re-evaluation and strengthening of existing structures in strong earthquake prone regions, especially in cities such as Beijing have been carried out. It is really difficult to strengthen all the dangerous buildings because strong earthquake is always rare and nobody can predict it with certainty.

For many masonry buildings in large cities, such as Beijing, simple strengthening by adding R.C. ties, horizontally and vertically around the outside walls, can be seen in Beijing. Test results support this idea because they provide lateral support or confinement for the plain brick walls and thus provide some confinement and thus ductility to the brick walls.

4.3 Isolation and structural control

Isolation and control are well-studied subjects in the field of earthquake engineering in the world and also in China. It was started early in the 60s at IEM but serious studies started only in the recent decade in the world and in China. Back in the 60s, a team at IEM studied this problem and constructed a plain brick building in Beijing with a thin layer of fine sand near the bottom of all walls. Unfortunately or fortunately, no strong earthquakes occurred there at all. The only real buildings constructed with testing base-isolation purpose and experienced the shake of a moderate earthquake in China [21, 22] were constructed in Guangzhou City under the study conducted by Prof. Fulin Zhou of the GZU. Prof. Zhou told me that, under his advices, several buildings and structures have been provided with some kind of roller bearings. A small earthquake attacked some one there at mid-night and the people inside the building with base-isolation had almost no aware of the shake, but in contrast, people inside a similar ordinary building nearby with no isolation, constructed to compare the effect of the isolated one, were awaken and some of them run out of the house. There are other buildings constructed with base isolation systems but no experience of strong earthquakes yet. Our new (2001) seismic code for buildings includes also a separate chapter for base isolation. The first book <Vibration Control of Engineering Structures> written in Chinese by Prof. Zhou F.L. was published in 1997 [21, 22].

4.4 Works at IEM and others

IEM was founded in 1953 in Harbin and the first director, and the director for 30 years, was Professor Hui-xian LIU. When I joined IEM in 1955, IEM was named as Institute of Civil Engineering and Architecture, an institute under Academia Sinica. In the beginning of 1970s, its name changed to IEM and was shifted gradually to the leadership of CEA (China Earthquake Administration), and earthquake engineering studies has been the main research topic.

IEM was and still is the main institute working on earthquake engineering problems. In the middle of 1980s, there were the following laboratories: strong motion observation, engineering seismology, industrial and residential buildings, lifeline engineering, shock and vibration, soil dynamics, vibration laboratory, instrumentation, computers and related problems, information, and other divisions. There were roughly 500 personals for many years but now limited to roughly 300. Four collections of papers on earthquake engineering were published in 1962, 1965, 1977, and 1981 respectively; and the national journal <Earthquake engineering and engineering vibration>, four issues a year, was started in 1981, an international journal of the same name was started in 2002 with the help of Professor George Lee.

IEM works on shaking-table tests of small-scale models of various structures, including tall buildings, such as the Shenzhen Post and telecommunication building [23], with the main building of 51 stories.

Because of the limitation of shaking table size, tests were usually small scales models of very tall structures or long-span bridges. IEM works on also popular problems of performance-based design principles, such as detailing of performance index, protection targets, and optimization of design parameters

In addition to works done at IEM, there are several other groups working in the field of vibration isolation and control too, such as the group in the State key laboratory for disaster reduction in civil engineering of the Tongji University in Shanghai [24], the civil engineering college of the Southeastern University in Nanjing, and the Harbin Institute of Technology and the Hong Kong Polytechnic University [25]. Theoretical, experimental and practical applications have been conducted together with wind resistance problems. But we are still lack of experience from strong earthquakes to verify the long-term effectiveness of this kind of structures.

5. DISASTER EVALUATION AND MITIGATION

5.1 Disaster evaluation after strong earthquakes

It is a universal practice to have some kind of disaster evaluation carried out right after a strong earthquake to evaluate the economic loss as well as life loss. The level of evaluation varies from single buildings to a group of sample buildings, from each village to sample villages; but the results are usually the total loss of counties or each intensity zone. Purpose of the evaluation is to have a general idea of loss, to allocate the scale of scale of relief from the government or other sources, including the immediate helps of medical care, housing, food and others. For seismological and engineering purposes, there will be teams of seismologists to study the possible trend of strong earthquakes immediate after a major quake in the near future, and engineers to evaluate the losses and draw conclusions or suggestions on the rebuilding of the damaged buildings and other engineering structures, if needed, and to allocate ground motion instruments to measure the strong ground motions from strong aftershocks. For example, author spent more than one year in the shaken area of the 1970 Tonghai earthquake with a team of 5-10 technicians in average.

5.2 Disaster prediction before strong earthquake

Works of disaster prediction before strong earthquakes started a few decades ago in China. After some strong earthquakes in the 70s, some city governments wanted to know what would be the loss if a strong earthquake occurred there. Loss estimation and micro-zonations were done for quite a few cities and districts. Until the beginning of 90s, a modernized way of disaster prediction with application of GIS (geographic information system) was started for the first time in China, by a group of engineers and seismologists, in Urumqi City in the northwestern part of China [26]. After that, nearly the same work has been done for quite a few cities and regions in the eastern part of China.

Author was responsible for the job for Urumqi City. Though it is important to carry out this kind of prediction for earthquake-prone regions, I strongly felt that there is a big problem in this kind of work. China was and still is a developing country, and we are trying hard to modernize our country. Though we tried real hard, but to develop a developing country of more than 1200 million persons is certainly a difficult and time-lasting task. It is good to see the fast-moving improvement of modernization of our country, and the adobe, stone, and plain brick buildings will be limited and soon replaced by better constructional materials, such as reinforced concrete, especially in large cities. But on the other hand, modernization and expansion of small cities into moderate or large cities will introduce better constructions, such as buildings of reinforced concrete or buildings of reinforced masonry walls and better lateral supports. Efforts will be made to strengthen some structures into better ones. An important problem as then the structures in many cities will be quickly changed. Door to door inspection of the changes or the fast renewal of the GIS maps will be a big task. GPS and RS together with GIS are perhaps the best possible solution.

I am glad to report here that CEA, the China Earthquake Administration or the formal China Seismological Bureau, is planning to start an important project to study some easy and cheap types of buildings for rural countries and small towns in China [27].

5.3 Disaster mitigation and related regulations

(1) Experience from strong earthquakes

As far as the author knows, works on disaster evaluation and mitigation started some years later when a series of strong earthquakes attacked several densely populated regions many years ago, such as those north of our capital region, such as the 1966 Xingtai earthquake of M=7.2, the 1975 Haicheng of M=7.3, and the 1976 Tangshan of M=7.8. One followed the other brought heavy casualties to the densely populated regions. This process leads to a routine process now of three steps and three purposes, i.e. to observe the aftershocks to judge if there will be strong earthquakes to come, to observe to damages from epicenter to areas of intensities less than intensity VI or no damage to access the loss or intensity distribution and thus the final total loss of lives and property, to estimate the total loss with the local government to decide if additional helps are needed and how much it would be.

The China Seismological Bureau, founded in the early 70s, took this problem seriously and works in the direction of disaster mitigation became an important branch of its concern. A series of important policies were undertaken and are discussed briefly in the following in this section. By the way, it is perhaps the right place to mention that the English translation of the China Seismological Bureau (CSB) is just formally changed to China Earthquake Administration (CED) a few days ago. It is clear, at least to me, that its duty is then enlarged from prediction and engineering to include also protection and disaster release.

It is well known that strong ground motion may be different for different geological background. China is a large country, and the geological background of the western mountain region is quite different from that of the eastern region. It is therefore necessary to try hard to obtain enough strong motion records in several regions in China, for example, west mountain regions and east plain regions. It is good that Taiwan region is covered with dense arrays of new digital accelerographs and sets of good records have been obtained. We have now in the China mainland about only 300 strong motion stations. The average coverage of the China mainland is only 0.3 stations per 10 thousand km^2, very low compared with Japan's 132 or USA's 5.3.

(2) Disaster management

Disaster management needs ever-lasting and successful preparedness of governmental action, with help from various societal bodies, before and after strong earthquakes. The modern GIS management of earthquake disasters started near the middle of 1990s in Urumqi City. Before this work, many researches had been done for regions in cities and regions in China. This kind of investigation takes usually a few years for one city and usually carried out by a research team of personals from some research institution together help from local institutions, such as university, research institution, and the local construction department of the city. Before the Urumqi case, the final report was usually a big volume of paper work, and now always with GIS or ARC/INFO software. The Author's experience is that with only this kind of software, the information from this kind of software is always out-of-date, because the mainland of China is now in a fast developing stage in many cities, such as Beijing, so fast that the renewed society information is always lagged behind, especially the removal or replacement of buildings of made of weak materials, such as adobe and plain masonry dwellings. The earthquake resistance of each important structure is usually estimated on the basis of field inspection, but only samples are inspected for ordinary houses.

The important point here is that the disaster management is the responsibility of the local government. The topics of this issue should include the following stages.

Before strong earthquake:

(i) Long-term prediction, say 50 or 100 years, for seismic design or retrofitting of structures.

(ii) Enforcement of codes and requirements of seismic design and re-evaluation of the adequacy of earthquake resistance capacity of existing structures and retrofitting and preparation of other related documentations, and insurance. Invention of new types of earthquake resisting structures, such as the actively controlled structures and structures with new controlling mechanism or smart materials, is needed for very important structures.

(iii) Assessment of the adequacy of the strength of the existing weak buildings; if not, replace them as soon as possible, especially in important regions, such as the developed regions.

After a strong earthquake:

(i) Rescuing lives and valuables

(ii) Evaluating the damaged existing buildings

(iii) Restoring normal society, such as reconstruction

In the first two stages, seismic design of structures is the main topic of interest, for which ground motion for structural design purpose is estimated on the basis of seismicity and ground motion attenuation law, and conception design is emphasized on the basis of both theoretical requirement of integrity and symmetry and experimental analysis. Though damage assessment and retrofitting were and remain important subjects of interest, but a systematical consideration of disaster management became not only an academic step but also a governmental effort, due to the lessons we learned from the great losses of life and property from strong earthquakes in the last two decades in China, and also the influence of the international effort of the International Decade for Natural Disaster Reduction at the end of last Millennium.

(3) Laws and regulations

In China, there are at least three levels of laws, the nation, the ministry, and the city. The national law of the People's Republic of China on the protecting against and of mitigating earthquake disasters was adopted at the meeting of the Standing Committee of the National People's Congress of the People's Republic of China in 1997 and came into force in 1998. In this law, there are 7 chapters as follows:

Chapter I General Provisions
Chapter II Earthquake Monitoring and Prediction
Chapter III Protection against Earthquake Disasters
Chapter IV Measures for Earthquake Emergencies
Chapter V Post-earthquake Relief and Reconstruction
Chapter VI Legal Liability
Chapter VII Supplementary Provisions

In Chapter III of this law, it classifies constructions into three classes, namely, major project, project related to serious secondary disasters, and others. For the first two classes, seismic safety evaluation should be carried out and structures should be design accordingly. A national standard code for seismic safety evaluation of engineering sites GB 17741-1999" was implemented for this purpose. For the third class, structures may be designed for earthquake actions according to the result specified in the ground motion parameter zoning maps, issued by the China Earthquake Administration (CEA), the former English translation being China Seismological Bureau.

It should be mentioned here that since 1982, Taiwan had launched three five-year research programs on earthquake hazard (risk or disaster) mitigation. At that time, earthquake disaster strategies in Taiwan separated into three major categories: pre-disaster measures to construct safe structures, emergency measures after an earthquake aimed at life safety, and post disaster management for restoration (Loh, 2001). In 1997, with help from RMS (Risk Management Solutions, Inc.) in USA, following HAZUS97 in USA, an earthquake loss estimation methodology HAZ-Taiwan was developed. Now GIS base maps are available for each county in Taiwan.

A series of provincial or municipal laws or acts have been issued to implement the national law. For example, the Beijing City passed a municipal law of earthquake disaster mitigation in the beginning of 2002. And there is a code for earthquake disaster evaluation [26, 27] to be issued soon as a national document to guide this important phase of disaster management.

(4) Vulnerability and loss estimation of large cities [26]

In recent years, GIS (geographic information system) has been applied as a necessary and powerful tool to the seismic zonation and damage and loss estimation of large cities, in the 90s in China. Our main experience is that for ordinary structures, group investigation of their present condition and evaluation of their vulnerability matrices may be applied together with individual investigation and study for important structures. The most difficult theoretical problem is the estimation of future seismicity of the region; the most difficult practical problem is the investigation of the social exposures, i.e. the investigation of the number and current state of strength of the structures and estimation of their vulnerability matrices, which is extremely so because China is in a state of fast developing, which means fast addition and renewing of the exposures. It is considered necessary to apply the new techniques such as RS (remote sensing system) and GPS (global positioning system) for this purpose to keep our societal exposures updated.

The most important motive is the requirement of a safe society to guarantee the fast building-up of our country to provide at least same economic safety against earthquake as Japanese and American for more than one billion people in the world. A richer China through the effort of last 10 years of hard work provides a possibility of this effort and the achievements of some developed countries provide us good examples.

It should be mentioned that the progress in China is in a stage of the world current frontier of earthquake engineering and disaster mitigation management, which is benefited by the achievements in other countries in the world, such as the United States of America and Japan. The engineering seismology is perhaps our strong branch, and the earthquake disaster management and application of active control and new intelligent materials are our weak branches. As a strong-earthquake prone country, it is our duty to protect our people from our earthquake enemy attacks and we, the scientists are responsible together with our government, would feel guilty if we did not do our best.

It should be emphasized here that new construction motive in China requires new research. The western part of China is a strong earthquake prone region, and it is well known now that heavy construction works are being and will be carried out in this part of China in the next scores of years. There is big task in front of us to construct the Western China with safe constructions.

6. CONCLUSIONS

A brief overview of the development of the earthquake engineering science in China in the past half century is presented here first. The mainland of China is still in her developing stage, the speed of development is quick in understanding, but is slow in practical construction. Most of the residential buildings are made of timber in USA and Japan, but most of houses in China are made of plain masonry materials, brick in city and adobe or mud in rural countries. Strong earthquakes are rare even in earthquake-prone areas and no strong earthquakes in 50 or 100 years will lessen the attention of residents. If seems to the author that a combination of a strong realization of safety requirement against strong earthquakes and some typical simple houses of enough earthquakes resistance are necessary to solve this problem.

The review covers four parts as follows: seismic hazard assessment, seismic design of structures, structural response to strong earthquake, and disaster evaluation and mitigation. The emphasis is given to the first part, because it is the part that I am familiar with and it is the part that has been emphasized in China. There are two groups of people work in this area in China, one from CEA, the China Earthquake Administration, and another in other branches, including universities. There are several research institutes under CEA, working in this area, mostly on engineering seismology and disaster mitigation. The part of structure analysis in CEA is chiefly under IEM in Harbin.

There are at least two main tasks before us. Firstly, it is important to find some kinds of materials locally available to build houses in rural countries to prevent collapse to save human lives. Secondly, in large cities, it is urgent to replace those old masonry building and buildings better buildings with reinforced concrete and steel to maintain a functional society in case of earthquakes of magnitude of 6-7.

China is still a developing country. There are many buildings made of adobe or plain bricks, i.e. no reinforcements in the load-bearing brick walls. It is well realized that they are not earthquake resistant, but people keep on build buildings the same way, either because they cannot afford to use better materials, such as wood or reinforced concrete, or because the terrible experience is forgotten after 50 years because strong earthquakes were usually happen again in the same region more than 100 years or so later. Author thinks that this situation may remain for years until people are richer. I just hope, with constant advice, the situation may be improved, if we can think of some cheap and easy ways to build houses with enough strength or ductility or redundancy to extend the collapsing process a few minutes or longer so that people inside may have enough time to escape. The cheaper and better earthquake-resisting houses should be made of materials that are cheap and locally available, such as timber or bamboo houses in Southern mountain areas of China. I am glad that, as I reported, that CEA is ready to start a large research program to study this problem soon.

REFERENCES

1. Law of the People's Republic of China on Protecting against and Mitigating Earthquake Disasters," China Seismological Bureau, 1998.
2. China Space Civil Building Engineering Design and Research Institute and China Earthquake Administration, "Preliminary Plan of China Strong Motion Network", November, 2003.
3. Loh CH and Tsay CY. "Responses of the Earthquake Engineering Research Community to the Chi-Chi (Taiwan) Earthquake." Earthquake Spectra, Vol.17 (4).
4. Hu YX, Liu SC, Dong W. Earthquake Engineering." E & FN SPON, Chapman & Hall, 1996: 83-97
5. Hu YX, Huo J. "Regress ional principle and relationship between earthquake intensity and acceleration." Proceedings of 9th World Conference on Earthquake Engineering, Tokyo-Kyoto, Japan, paper no. 3-2-19, 1988; v.II, 379-84.
6. Hu YX. "Strengthen the link between engineering and seismology." Earthquake Engineering frontiers in the new millennium, ed. by BF Spencer, Jr. and YX Hu, Beijing, China. A.A. Balkema Publishers, 2001: 103-08.

7. Yu YX, Hu YX. “A combine method to establish attenuation relation of long-period response spectrum attenuation relation of long-period response spectrum.” Proceedings of earthquake engineering frontiers in the new millennium, Beijing, China, 2001; 177-82.
8. Hu YX. “New seismic zonation map of China.” Six International Conference on Seismic Zonation (6ICSZ), Palm Spring, California, USA: EERI, 2000; 113.
9. Hu YX. (Chief editor) “Seismic Zonation Maps of Ground Motion Parameters”, GB 18306- 2001, Beijing, China (in Chinese), 2001.
10. Hu YX, Chen HY. “Probabilistic analysis of uncertainties in seismic hazard assessment.” Structural safety, 1992; 11(2):245-53.
11. Xie LL, Peng KZ, Yu XJ. “30 Years of the Strong-motion Observation in China”, Research Progress of Earthquake Engineering in China, Seismological Press, 1992 (in Chinese).
12. Chen DS. “Design response spectra for building code”, Collections of research reports on earthquake engineering, (Chief ed. H.X. Liu), Institute of Engineering Mechanics, Science Press, Beijing. 1977; 2: 73-94 (in Chinese).
13. Zhou, XY. “Effect of Soil Condition on Earthquake Loads on buildings”, Collections of research reports on earthquake engineering, (Chief ed. H.X. Liu), Institute of Engineering Mechanics, Science Press, Beijing. 1965; 2:27-43 (in Chinese).
14. Seed, H.B. et al. “Site Dependent Spectra for Earthquake-resistant Design”, BSSA, 1976; 66(1): 221-243.
15. Code for seismic design of buildings, GB 50011—2001, China building industry publisher, Beijing, China, 2001 (in Chinese).
16. Moehle, J.P.L. “Framework for Developing Performance-Based Earthquake Engineering”, Proceedings 3, International Conference on Advances and New Challenges in Earthquake Engineering Research (ICANCEER), Hong Kong Volume, ed. J.M. Ko and Y.L. Xu, Hong Kong, 2002; 67.
17. Krawinkler, H., (2002), “General Approach to Seismic Performance Assessment”, Proceedings 3, Int. Conference On Advances and New Challenges in Earthquake Engineering Research (ICANCEER), Hong Kong Volume, ed. J.M. Ko and Y.L. Xu, Hong Kong, 173-80.
18. Hu YX. “Application of consequence-based design criteria in regions of moderate seismicity.” Proceedings of international workshop on earthquake engineering for regions of moderate seismicity, Hong Kong, China, 7-8 December, 1998; Earthquake Engineering and Engineering Vibration, 2(1), 35-38, 2003.
19. Chen HQ. “Some key technical problems on earthquake resistance of important hydraulic structures in the development of the western China and transportation of water from south to north.” Earthquake Engineering and disaster mitigation in the new millennium, Chief ed. Wang QR. and Qi XZ, 2002, 25-7.
20. Sun JM, Zhou XY, Gao XW, Liu JB. “Aseismic Engineering.” China Building Publishers, Beijing, 2000, p.598 (in Chinese).
21. Zhou FL. “Vibration Control of Engineering Structures.” Seismological Press, 1997 (in Chinese).
22. Zhou FL, Gao XY, Xu ZG, Liu WG, Tan P. “Progress of application and R&D for seismic isolation and passive energy dissipation for civil and industrial structures in P.R. China.” 7th Intern. Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control of Vibrations of Structures, Assisi, Italy, October 2-5, 2001.
23. Zhang MZ, Meng QL, Chen HM, Guo X, Pei Q. “Test of a model of a high-rise residential building in Hong Kong on earthquake simulation shaking table.” Earthquake engineering and disaster mitigation of the new millennium, Wang Qi (ed.), Seismological Press, Beijing, 2002; 620-7.
24. Lu XL, Zhao B. “resent advances in structural control research and application in China mainland.” Earthquake engineering and engineering vibration, Science Press, Beijing, 2003: 2 (1); 117-32
25. Xu YL, Ko KT, Chau SS, Wong YL. “Research of earthquake engineering in Hong Kong: current status and future challenge”. Earthquake Engineering frontiers in the new millennium, ed. by BF Spencer, Jr. and YX Hu, Beijing, China. A.A. Balkema Publishers, 2001: 77-99.

26. Institute of Geophysics, “Technical Report of Earthquake Damage Prediction of Urumqi City and the Information System of Disaster Reduction and Counter Measures.” V.1-10, 1996 (in Chinese).
27. Code for earthquake disaster evaluation and its information management system (to be approved).