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Lessons Learnt from the 512 Wenchuan Earthquake: Perception of Seismic Risks

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Abstract

On May 12, 2008, a devastating earthquake occurred in Sichuan Province of China depriving tens of thousands of lives and destroying homes of millions of people. In this article, the seismotectonic background and the seismicity of the regions are first introduced. The seismic hazard levels specified in the Chinese Code for Seismic Design of Buildings, GB 50011 – 2001, and issues concerning the perception of earthquake risks and the extensive damage to buildings in the affected regions are discussed.

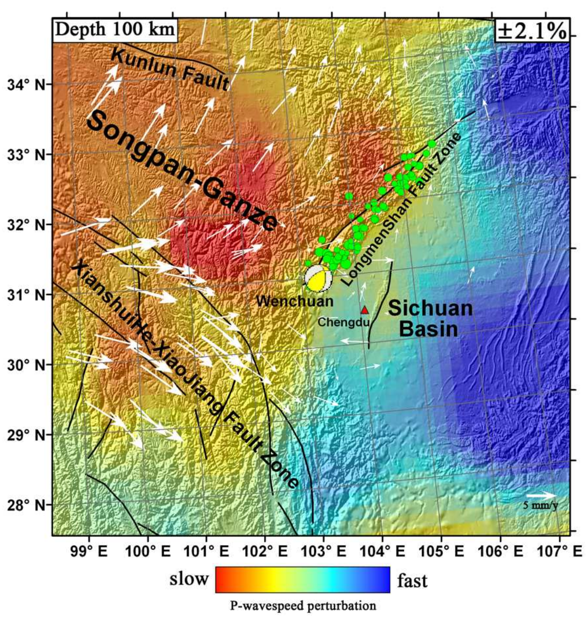
Keywords: Wenchuan Earthquake, Sichuan, China, seismic, hazard, risk, intensity

1. BRIEF BACKGROUND OF THE 512 WENCHUAN EARTHQUAKE

At 06:28:01.42 UTC on May 12, 2008, a devastating earthquake occurred at the Wenchuan County in the Sichuan Province of China. On the moment magnitude scale, the earthquake was of Mw = 7.9 according to reports from the United States Geological Survey (USGS). On the surface wave magnitude scale, the earthquake was of Ms = 8.0 according to reports from the China Earthquake Administration (CEA). The epicentre of the earthquake was 80 km west-northwest of the provincial capital city of Chengdu (refer Figure 1(a)). The fault ruptured at a depth of about 19 km. There were over 200 aftershocks with magnitudes greater than 4.0 and 8 aftershocks with magnitude greater than 6.0 occurred in the area afterwards. The strongest aftershock was measured at Ms 6.4. Official sources reported 69,225 dead, 17,939 missing, and 379,640 injured and at least 5 million homeless, rendering this event of May the 12th (often referred as the "512 event") the 19th deadliest earthquake of all times. The highest intensity level recorded from the earthquake was XI on both the European Macroseismic Scale 1998 (EMS–98) (Grünthal, 1998) and the Modified Mercalli Intensity (MMI) Scale. The unexpected heavy rainfall in the rural and mountainous area at the time of the earthquake accentuated the scale of the disaster and posed additional challenges to the rescuers.

On the continental scale, the earthquake was resulted from the northward convergence of the Indian Plate with the Eurasian Plate with a velocity of about 50 mm per year. The convergence of the two plates resulted in the uplifting of the Asian highlands. The quake which occurred along the Longmenshan Fault Zone on the northwestern margin of the Sichuan Basin (Figure 1a), was resulted from movements along the northeast striking reverse fault (Figure 1b). This fault zone had experienced destructive earthquakes previously. The notable example was the M7.5 quake which occurred in 1933 and had a death toll of 9,300.

The 512 Wenchuan Earthquake, which was the strongest earthquake to hit China since 1949, was even stronger than the Tangshan Earthquake of 1976 which had a death toll of 242,400. The Wenchuan Earthquake actually released much greater energy than the Tangshan Earthquake which was of Ms = 7.8 (whilst Mw values of 7.5-7.6 have been suggested in the literature). The affected area of the Wenchuan Earthquake was also much wider than that of the Tangshan Earthquake.



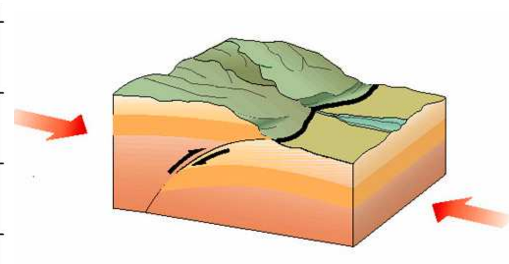


Figure 1.
(left) Location of the 512 Wenchuan earthquake (downloaded from http://earthquake.usgs.gov/).
(top right) The northeast striking reverse fault mechanism of the Wenchuan earthquake (downloaded from www.tectonics.caltech.edu/).

2. A WIDELY-FELT EARTHQUAKE

The earthquake was felt as far away as Hong Kong (1,450 km), Beijing (1,500 km) and Shanghai (1,700 km), as well as in neighbouring countries, including Vietnam and Pakistan (over 3000 km). Buildings in the distant affected cities were reported to have swayed noticeably during the event. The exceptionally good wave transmission properties of the earthquake over very long distances can be explained by the quality of the earth crusts in Central China as revealed in the Q-factor contour map of Figure 2 (produced by Jin and Aki, 1988). The epicentre of the main shock of the Wenchuan Earthquake is shown by the “star” symbol whereas Beijing and Hong Kong were shown by the symbols of “solid circle” and “hollow circle” respectively.

The 512 earthquake was felt in Hong Kong. Earlier in 2006 Hong Kong had experienced two tremors: the first was generated from a small magnitude (M3.5) near-field earthquake from the Dangan Island which was at a distance of about 36 km and the second was generated from a M7.1 earthquake in Taiwan which is some 670 km away. All three tremors were recorded in Hong Kong with intensity levels ranging between III and IV.

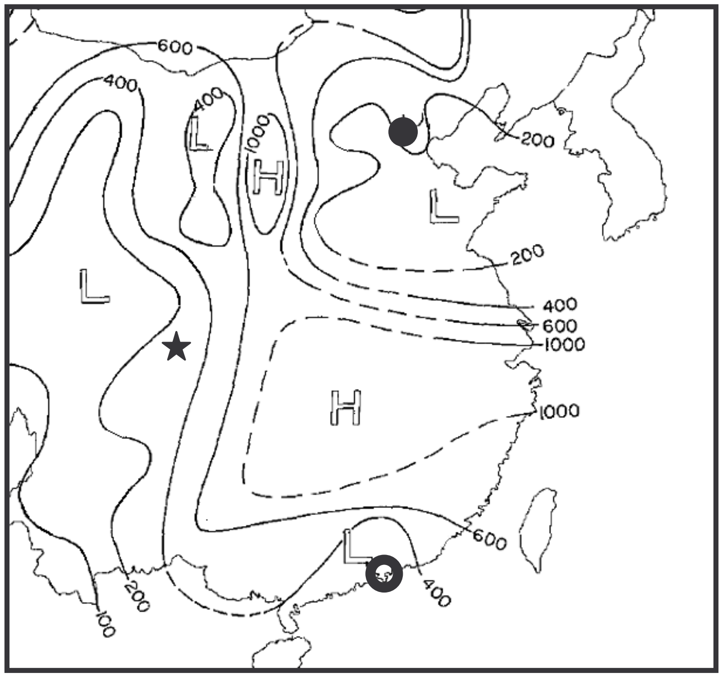


Figure 2. Crustal quality (Q) factor contour map of Eastern China (Jin and Aki, 1988). (The epicentre of the main shock of the Wenchuan Earthquake is shown by the “star” symbol whereas Beijing and Hong Kong were shown by the symbols of “solid circle” and “hollow circle” respectively.)

The ground motion time histories of the three earthquakes (Figure 3) were simulated by stochastic simulations of the seismological models using program GENQKE (Lam et al., 2000). The choice of the Q values and other seismological parameters which were specific to the travel paths of the three earthquakes, was decided after considering information provided by the relevant literature: Jin and Aki (1988), Lam et al. (2002), Mak et al. (2005) and Chandler et al. (2005, 2006a, 2006b).

The simulated accelerograms feature very different duration, amplitude and frequency contents. Ground motions simulated for the Dangan Island earthquake are of short duration, high frequency contents, and high acceleration amplitude. In contrasts, ground motions simulated for the Wenchuan Earthquake in the very far-field features long duration, low frequency contents, and low peak ground acceleration (PGA). The level of PGA in the Wenchuan Earthquake simulations is an order of magnitude lower than that of the Dangan Island earthquake simulations. Ground motions simulated for the Taiwan earthquake is intermediate in properties between the other two simulations.

The overall amplitude of the acceleration time series (Figure 3) and their respective calculated response spectra (Figure 4) were of the same order of magnitude, which is consistent with the fact that the intensity levels recorded from the three earthquakes were the same. However, the spectral contents from the individual simulations were distinctly different (Figure 4).

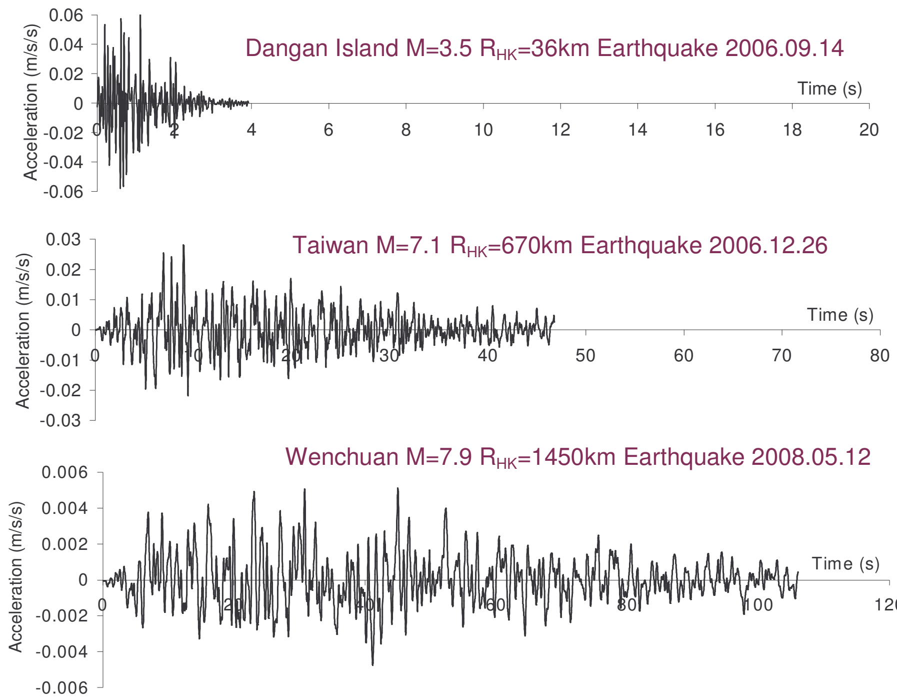


Figure 3. The ground motion time histories of the three earthquakes simulated by stochastic simulations of the seismological models using GENQKE.

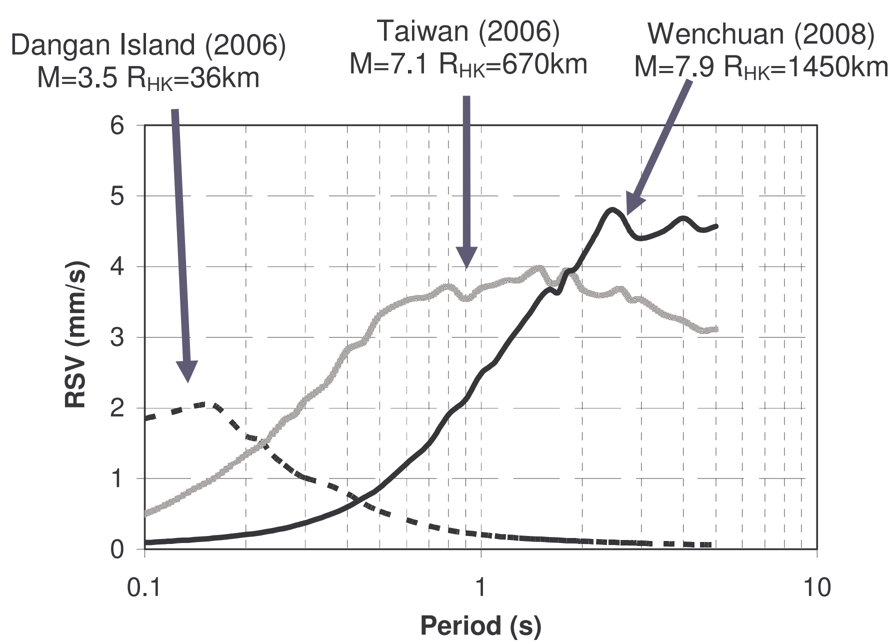


Figure 4. The response spectra of the simulated ground motion time histories of the three earthquakes.

3. "ALLOWABLE" COLLAPSES OF BUILDINGS

Following from the earthquake catastrophe of May the 12th, 2008, there were intense debates on the dubious construction quality of the building structures, particularly that of school buildings. Whilst the focus of the debate was mainly on inadequate supervision of the construction of the buildings, few queried the adequacy of the authorized design standards or the design earthquake hazard levels of the affected regions.

The seismic design specified in the Chinese Code for Seismic Design of Buildings (GB 50011 – 2001) is based on three earthquake design levels as is the case for many major earthquake codes of practices. The design levels are namely minor (frequent) earthquake (probability of exceedance (PE) = 63%/50 years, return period (RP) = 50 years); moderate earthquake (PE = 10%/50 years, RP = 475 years) and major (rare) earthquake (PE = 2-3%/50 years, RP ~ 2,000 years). The ratio of PGA of the three design levels is approximately 1:3:6. The hazard level shown on the zoning map (GB 18306 – 2001 – A1) (Figure 5) is based on the hazard with RP of 475 years (PE = 10%/50 years). The intensity levels and their corresponding PGA are listed in Table 1. It is noted that seismic intensity levels of VII and VIII have two sub-divisions. For the sake of clarity, the two higher intensity levels (i.e. PGA = 0.15g and 0.30g) are classified hereafter as intensity levels VII-VIII and VIII-IX respectively, noting that the amplitudes of the corresponding PGA were exactly midway between the adjacent reference PGA levels.

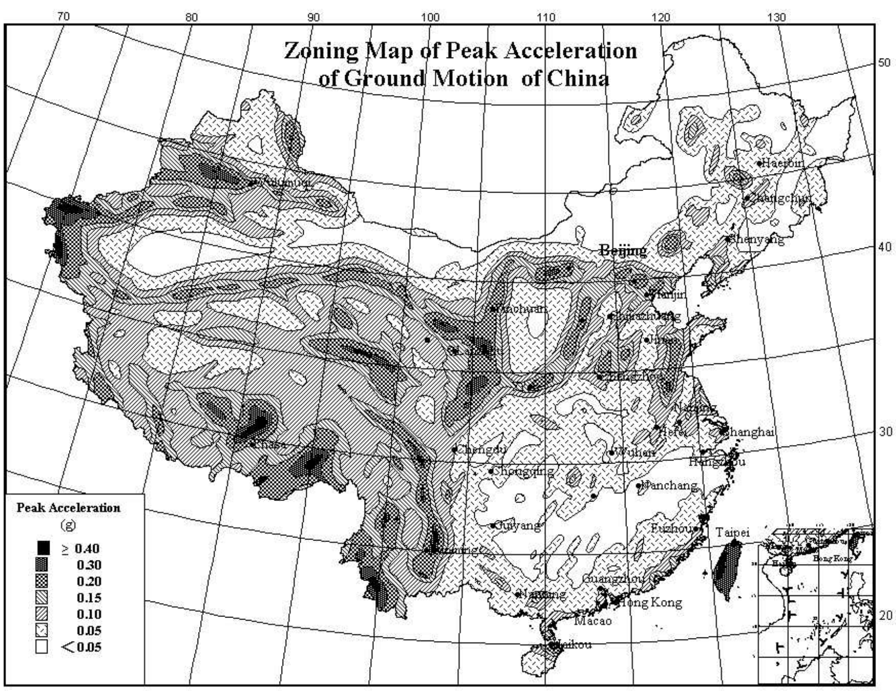


Figure 5. Seismic zoning map of peak ground acceleration (PGA) of China (RP = 475 years; PE = 10%/50 years) (GB 18306 – 2001 – A1).

Table 1. The earthquake design intensity levels and their corresponding PGA.

Intensity Level	---	VI	VII	VII-VIII	VIII	VIII-IX	IX
PGA (g)	< 0.05	0.05	0.10	0.15	0.20	0.30	> 0.40

On the other hand, the design procedure consists of two phases: (i) the first phase involves the section design of the structural elements (strength), and a deformation check by elastic analysis based on the Minor Earthquake Design Level; and (ii) the second phase involves a structural deformation (collapse) check by elasto-plastic analysis based on the Major Earthquake Design Level. Note, the Phase Two (collapse limit state) check is not compulsory for all buildings, but only for buildings possessing a weak storey feature, buildings located on soft soil sites, buildings located in regions of a higher intensity level, taller buildings, or important buildings (Class A and part of Class B). Normal (Class C) structures/buildings would not need to be subject to Phase Two design checks. Design checks in Phase One are basically checks for yield strength coupled with checks on the elastic drift (effectively a stiffness requirement), and are based on the 50-year RP earthquake.

For regions with high death tolls in the 512 earthquake (which include Deyang, Mianyang, Guangyuan), the design earthquake intensity level is typically VI for a RP of 500 years. There are other severely-affected regions (such as Chengdu, Beichuan, Mianzhu) which have a design earthquake intensity level of VII. The immediate epicentral areas (including Wenchuan and Dujiangyan) too has a design earthquake intensity level of VII only. For the capital city of Chengdu, the PGA level used for Phase One design checks would only be around 0.035g and a peak spectral acceleration level of 0.08g. Note, 0.035g is less than 10% of the PGA that probably occurred in the 512 earthquake.

In theory, buildings which have been undergone Phase Two design based on a design intensity level of VII are expected to be sufficiently robust to withstand ground shaking of up to intensity VIII. However, there were areas which reported intensity much higher than VIII. Thus, the chance of survival of the majority of buildings in areas of high intensity of ground shaking could only count on various intrinsic conservatisms embodied in the design assumptions. In other words, even if all the buildings were constructed strictly in accordance with the regulations, many would have suffered severe damage in the event.

4. SEISMIC HAZARD OF SICHUAN PROVINCE

It is generally agreed that the sheer magnitude of the event was the main cause of the high death toll and extensive damage, but it does seem that the regional seismic hazard in the affected regions has been grossly underestimated on the seismic hazard map of China. A 500-year PGA of 0.05-0.10g for most, if not all, of the affected regions seems anomalous given that 8 earthquakes with magnitudes greater than 7 have occurred in the area and its vicinity over the past century.

Figure 6 shows the epicentres of all the major historical earthquakes of magnitude > 6 that have occurred during the period 780 B.C. to 1994 A.D. in China. The location of the 512 Wenchuan Earthquake is annotated by the "star" symbol in the figure. It is obvious that high seismicity can be observed along the North-East Seismic Belt at the central part of China, where major earthquakes with magnitude greater than 7 have occurred relatively frequently. It is interesting to note that the level of seismic hazard specified by the Chinese code for Hong Kong is VII – VIII, which is even higher than those specified for most regions in the Sichuan Province. However, the level of seismicity of the South China region as a whole (where Hong Kong is located), is noticeably lower than other regions within China as is shown in the map of Figure 6.

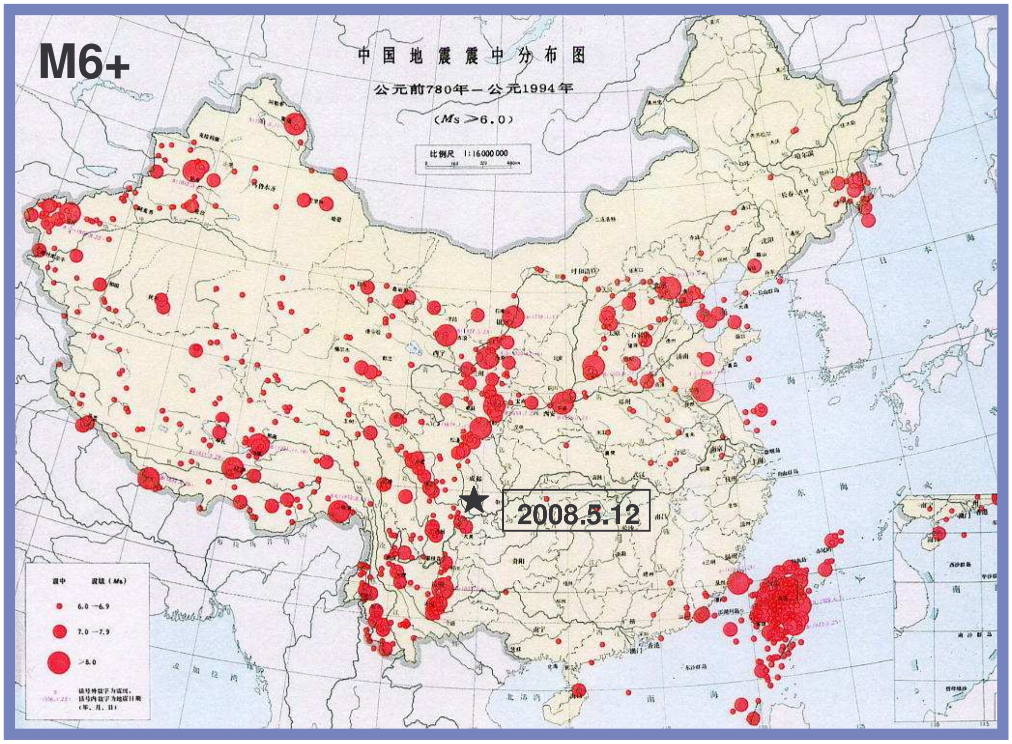


Figure 6. Earthquake events with magnitudes greater than 6 occurred in the period 780 B.C. to 1994 A.D. in China. (Note: the "star" symbol annotates the location of the 512 Wenchuan Earthquake.)

One may question whether the seismic hazard levels calculated by CEA have understated the actual level of seismicity (although acknowledging that the seismic hazard levels were calculated by the standard probabilistic seismic hazard assessment procedure, as reported in Gao (2003)). Overall, there are good consistencies between the seismic zoning map produced by CEA (Figure 7 – left) and that produced by the Global Seismic Hazard Assessment Program (GSHAP) (Figure 7 – right). The good agreement between the two models is probably of no coincidence, as they should have used the same data and methodologies, and there is strong representation from China in the committee of GSHAP.

The speaker believes that the seismic hazard levels of the affected regions as specified in the Chinese code could have been under-estimated significantly, as this offers explanations to the extensive collapse of buildings in the affected regions. The understated seismicity could have been attributed to the following causes: (1) the maximum considered earthquake (MCE) levels of the regions have been under-estimated; (2) the seismic hazard of the whole China was computed based on only two ground motion attenuation models: one representing Eastern China and the other representing Western China. It is well-acknowledged that the attenuation behaviour of earthquakes can be highly dependent on local geological conditions.

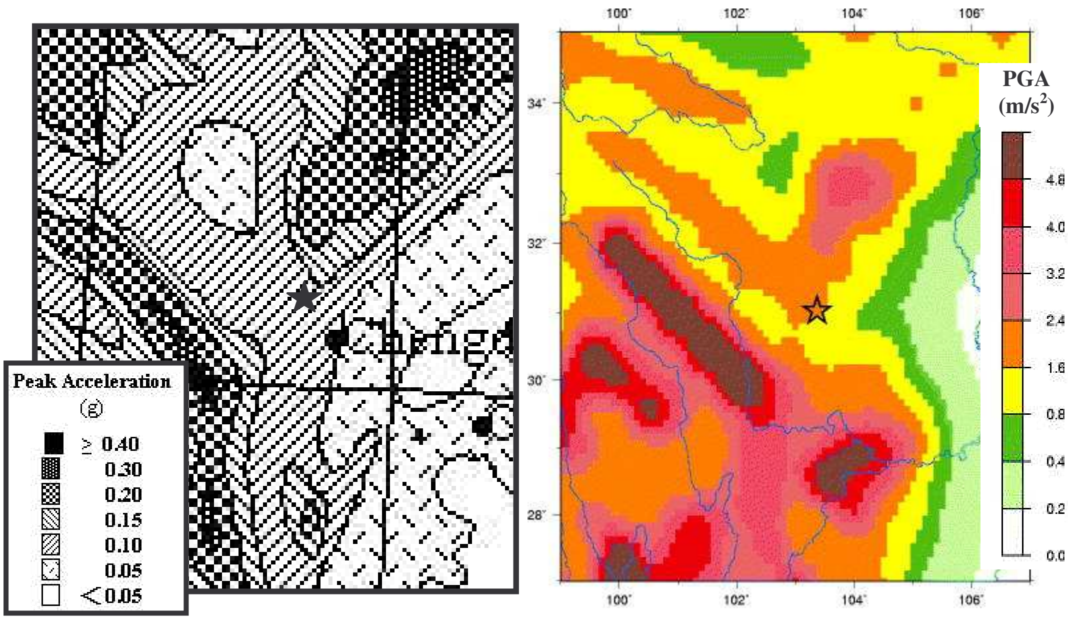


Figure 7. Comparison between the zoning maps produced by China Earthquake Administration (CEA) (left) and that produced by the Global Seismic Hazard Assessment Program (GSHAP) (right).

It is recommended that the earthquake hazard levels of the Sichuan Province should be re-assessed for the future revisions of the seismic design code for China. In the long run, the re-assessment of the ground motion attenuation characteristics which in turn controls the level of the seismic hazard should ideally be carried out for the whole China.

In order to develop a more accurate ground motion attenuation model for the affected regions, strong motion records collected from the 512 earthquake event must be readily available to researchers at the international level. However, not all of the recorded strong ground motion data are as yet available. Some of the records that have been uploaded on the web have been found to have substandard quality and this might be due to the limitations of the recording instruments.

5. LOW-PROBABILITY HIGH-CONSEQUENCE EARTHQUAKE

The rupture of the M8 Wenchuan Earthquake represents the release of slowly building tectonic stresses generated by the convergence of crustal material from the Tibetan Plateau to the west with the strong crust of the Sichuan Basin and Southeastern China. Although the rate of slip along the eastern margin is low, at about 1 – 3 mm/yr, this region has the potential to generate large magnitude events due to accumulation over long time periods. According to a geodetic observation, the Wenchuan Earthquake may have released energy accumulated over 1000 – 3000 years (Kato et al., 2008). Thus, the earthquake has filled a certain “seismic gap” where previously the seismicity has been considered “low-to-moderate” due to the absence of seismic activities in the recorded history. The 512 earthquake is a good case to demonstrate how unreliable and misleading are the contours shown on the “precise” zoning maps.

Magnitude-recurrence relationship (or commonly referred to as Gutenberg-Richter relationship) is an essential ingredient in the probabilistic seismic hazard assessment procedure which is based on the conventional Cornell-McGuire approach. However, it is well-known that there are great uncertainties with predictions in the large magnitude (low probability) range. It is a problem for both the low-to-moderate and the high seismic regions.

Figure 8 (as reproduced from Adams and Atkinson, 2003) shows that the typical exponential magnitude-recurrence curve are not very consistent with the recurrence trends of recorded historical earthquakes. It is noteworthy that the actual data indicate a higher recurrence rate at magnitude greater than around 5. In the case of Vancouver where earthquake records are relatively abundant, experienced seismologists have been involved with the modelling of the recurrence rates for achieving a more accurate magnitude-recurrence relationship for low probability predictions. However, for other regions where earthquake catalogues are limited in the time span of coverage, the computed seismic hazards are prone to errors and there might have been under-estimations of the rate of recurrences.

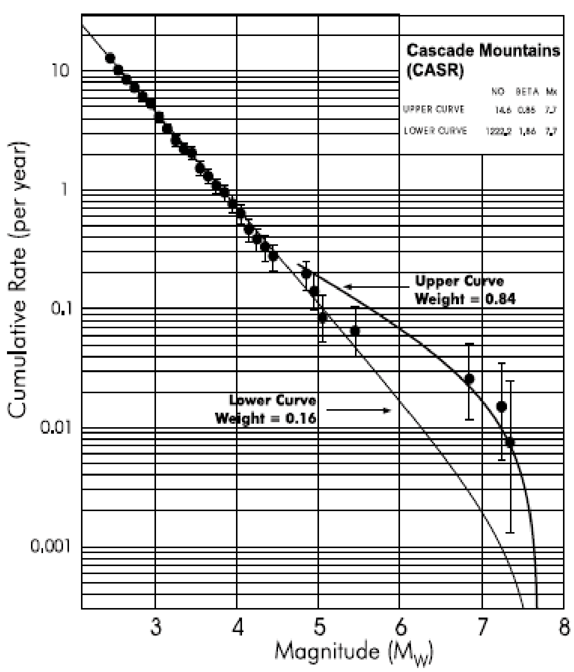


Figure 8.
Magnitude–recurrence curves for crustal earthquakes near Vancouver (reproduced from Adams and Atkinson, 2003).

It is recommended to make the resolution of the zoning maps lower, i.e. do not try to distinguish areas too precisely (grid area being too small), which may give a false sense of accuracy. The preferred approach may well be the “broad-brush” approach in which a more uniform disposition of seismic activities is modelled from information on the regional tectonic settings and geological conditions, and where necessary supplemented by local knowledge. Nevertheless, the preciseness of the seismic zoning should be left until a site-specific hazard assessment, commonly referred to as micro-zonation (in which potential soil site effects have been incorporated). Such consideration is particularly important for low-to-moderate seismic regions, where the historical earthquake records cannot provide an adequate, and accurate, projections for the occurrence of low-probability high-consequence earthquakes.

The "broad-brush" approach as described would probably have more sympathizers in Australia. The phenomenon of "seismic migration" in Australia was discovered by reconciling neo-tectonic data with historical seismic recurrence data (refer Leonard and Clarke, 2006). It was found that Western Australia was more active in this century than in past centuries, whereas very different trends have been observed elsewhere in Australia. This means that contours shown in seismic hazard maps which are based on the occurrences of historical events can be misleading. In other words, what has happened in the past is not necessarily a good indicator of what will happen in the immediate and near future. It is therefore recommended that more attention should be paid on neo-tectonics and paleoseismology, and not relying entirely on modelling in accordance with occurrence data derived from archives of historical events given that we are dealing with a natural phenomenon which has a much longer cycle time than our recorded history, and this is particularly so in stable inner-continental regions.

In summary, the attenuation models used for the generation of the seismic zoning map as well as the (spatial) model of the disposition of seismic activities need to be reviewed across the whole of China. The potential faults and the corresponding maximum credible magnitude that can be generated by the faults need to be identified. The level of seismic hazard can be represented by earthquake scenarios of magnitude-distance combinations, and not solely PGA nor peak ground velocity (PGV). The recommended approach should also be deemed appropriate for other low-to-moderate seismic regions.

6. BENCHMARK RETURN PERIOD FOR ZONING MAP

For the seismic zoning map in the Chinese seismic code (Figure 5), the benchmark RP for specifying seismic hazard is at the Moderate Earthquake Level (RP = 500 years). It is noted that for countries like Canada and the United States which have both interplate and intraplate seismic regions, the benchmark RP has been shifted to 2,500 years to provide a more uniform risks of collapse across the country. It is because the slopes of the hazard curves vary considerably in different parts of the country (due to different seismo-tectonic environment and source characteristics). It is indeed a relatively subtle, and yet important, issue.

Adams and Atkinson (2003) demonstrated such change in the 2005 Canadian code in Figure 9. The shapes (and especially the rate of change) of the hazard curves vary considerably in different parts of Canada. For a high seismic region like Vancouver, multiplying the hazard parameter (spectral acceleration (SA) in this case) by a factor of two would correspond to a RP of 2,400 years (~ 2% in 50 years). However, for a moderate seismic region like Montreal, the same multiplication factor would correspond to a RP of 1,600 years (~ 3% in 50 years) only. The probability of failures in the collapse limit state is then higher in moderate seismic regions compared to high seismic regions with extreme events (of very low probability of recurrence). Hence, shifting the benchmark from RP = 500 years to RP = 2,500 years can provide a more uniform margin of protection of structures against collapse.

Although this issue has been well acknowledged all around the world, it is not easy to be implemented in many countries lacking adequately long histories of recorded earthquake catalogues. For example in China, the low probability hazard cannot be reliably assessed in those regions of low-to-moderate seismic activities. For this reason a RP of 500 years is still used as reference with the preparation of seismic zoning map for the sake of unifying the zoning map methodology for the whole country. Scaling factor is then used for making predictions for events of longer return periods.

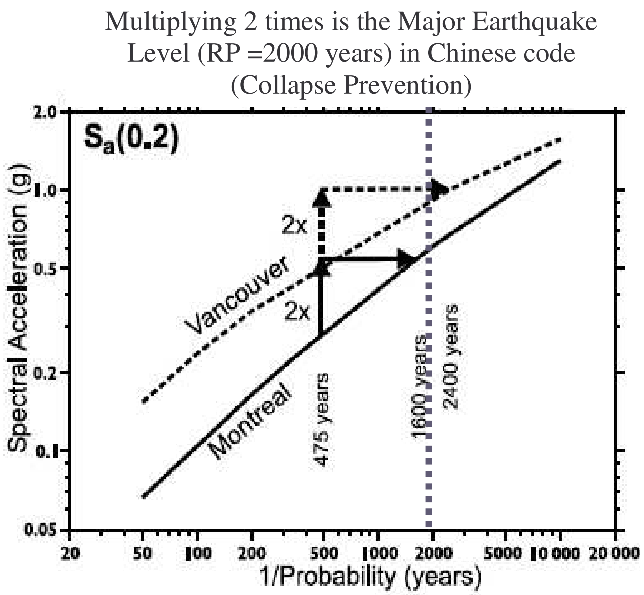


Figure 9.
The different shapes of the hazard curves in different parts of Canada (reproduced from Adams and Atkinson, 2003).

7. COLLAPSE OF SCHOOL BUILDINGS

Shortly after the 512 earthquake, the extensive collapse of school buildings were once a hot topic of intense media coverage and heated debate within China as well as in other countries. It is estimated that around 10,000 schoolchildren were killed by the earthquake. Due to the one-child policy of the Chinese government, many families have lost their only child, rendering thousands of parents protesting around the province. Local officials and builders have been accused over the alleged poor control of the construction quality of school buildings which have been blamed for their severe damage in the earthquake.

Schools play an essential role in every society. They are not only places for students to learn and for teachers to teach, they are also used for social gathering and entertainments, and so forth. Moreover, school buildings can play a very important role in responding to and recovering from natural disasters, including earthquake, hurricane or tsunami. Schools can serve as emergency shelters for the local community. In addition, in most communities, school attendance is compulsory, thus it is a moral obligation of the government to provide a safe environment for students.

Undoubtedly, earthquake prone regions need earthquake-resistant schools. However, it has been observed that schools built worldwide routinely collapse in earthquakes due to (1) avoidable errors in design and construction, (2) existing laws and regulations are not sufficiently enforced (OECD, 2004). When schools are closed due to earthquake damage, education is hindered and emergency shelters would become unavailable.

In fact, there is another national standard in China that takes into account the level of importance of different classes of buildings, namely, "Standard for Classification of Seismic Protection of Building Constructions" (GB 50223 – 2004). Buildings should be classified as Earthquake Resistance Class A, B, C or D according to their function. Class A includes important buildings that may cause serious disaster during an earthquake. Class B are buildings the function of which could not be interrupted or immediate repair following an earthquake is required. Class C includes all other buildings that are not within Class A, B or D, and finally secondary (less important) earthquake resistant buildings are of Class D.

The following is a quote from Section 6 of the Public and Residential buildings; Clause 6.0.8: Among educational buildings, low-rise kindergarten schools (with more than 200 students) and primary school buildings (with more than 600 students) should be of Class B. It is stated in the specification that extra protection should be provided to kindergarten and primary school students who have relatively lower self-rescue ability. However, this clause has only been enforced since 2004. Thus, most of the existing school buildings were only designed as Class C buildings (GB 50223 – 95). Note, not all school buildings are of Class B, even if they were built after 2004.

It is recommended to amend the current standard of building classification (GB 50223 – 2004), in order to improve the constructional standards at all levels (in terms of the age of students in the school) and scales (in terms of the number of students in the school), irrespective of whether the school is located in urban or rural areas.

8. SHOULD WE DESIGN FOR LOWER PROBABILITY EARTHQUAKES?

Certainly, the 512 Wenchuan Earthquake can be considered as very low probability (beyond RP of 2,000 years) and its potential had probably been ignored in seismic design. However, nobody could deny that the consequence of a major earthquake disaster is really unbearable to any society nowadays. The situation of low recurrence rate may be similar to the Kobe earthquake in Japan in 1995, where no recorded damaging event had ever struck in the preceding 1,000 years. These events lead us to doubt whether designing for no collapse at RP of 2,000 years is adequate or not.

For example, if we are going to design a school building in the Dujiangyan city in Sichuan, the basic design intensity level (RP = 500 years) is VII (corresponding to a design PGA of 0.10g). For a school building of Class B, the design intensity level should be upgraded from VII to VIII (which corresponds to a design PGA of 0.20g). This somehow implies that the design probability level corresponds to a RP of around 2,000 years. For such important buildings, Phase Two elasto-plastic analysis for collapse check might have to be conducted, and consequently collapse prevention of the building could be guaranteed up to a ground shaking level of intensity IX. Assuming that there is no additional reserve in the seismic resistant capacity of the building, its chance of survival in the earthquake could be in doubt should the intensity level exceed IX. In the 512 Wenchuan Earthquake, the intensity level of ground shaking went up to X and XI around the epicentral areas. In areas where the design intensity level is only VI, school buildings are only expected to survive up to intensity VIII shaking even if the construction is in full compliance with the code requirements.

It is very natural for people to ask if the stipulated level of earthquake protection of buildings is adequate or not. Should we shift the collapse prevention level up to a limit which corresponds to a RP of 5,000 years or even 10,000 years?

Written in the foreword of the Chinese seismic code GB 50011 – 2001, this latest edition was revised based on latest research findings and past experiences, and importantly the code writers have considered the current economical conditions and what can be achieved in practice. It is understood that the level of protection (safety) of buildings can be compromised by economical considerations (cost). It is therefore acknowledged that the actual level of protection varies between nations, and is a function of the predicted seismic activity and importantly the demographic (economical) conditions of the community.

For a developing country, a high level of protection is probably a "luxury". However, for a developed country or city like Australia and Hong Kong, where resources are comparatively abundant, why don't we provide a higher level of protection for our community? Increasing the earthquake resistant provisions from intensity VIII to IX, say, may increase the construction (plus design) costs by 20%, which will be reflected in the property price by an increase of 1–5% only, such change is probably less than the normal fluctuation of the property market in a month. If assuming the recurrence probability between one intensity level is around five times, a slight increase in the property price by a few percent can reduce the risk by five times. In a design life of 50 years, the risk of collapse, and the associated loss of lives, will decrease from 1% to 0.2%, say.

Lastly, there are two more interesting issues about the perception of earthquake risk that require more understanding and investigations, and are briefly discussed in the following sections.

9. HOW FAR IS "RARE" TO "WORST"?

Is it sufficient if a building is guaranteed no collapse in an event of RP 2,500 years? This RP is corresponding to 2% probability of exceedance in 50 years. Such event is commonly referred to as a rare (or major) event amongst seismologists and earthquake engineers, and the term "rare" has also been adopted in code provisions, including the Chinese seismic code. However, many design engineers have been regarding the rare event as the worst case scenario. This poses a scientific question that "how much is the difference between a 'rare' earthquake (or ground motion) and the 'worst' or 'maximum credible' or 'upper bound' earthquake (or ground motion)".

Citing an example of the latest seismic hazard assessment for Hong Kong (Tsang and Chandler, 2006) (refer Figure 10), the PGV estimated on rock sites at RP of 2,475 years is around 80 mm/s, but then it goes up to around 120 mm/s at RP of 10,000 years. The worst case scenario can actually go up to around 250 mm/s or even higher.

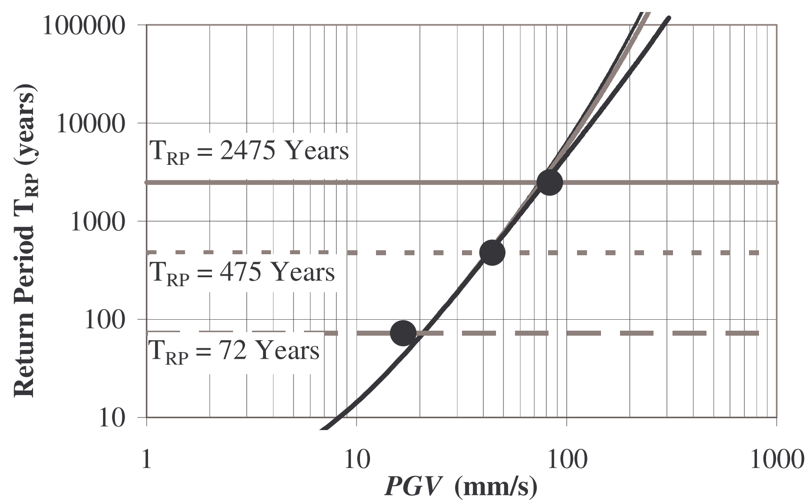


Figure 10. Seismic hazard curves for rock sites in Hong Kong (Tsang and Chandler, 2006). (The three curves were computed based on different proposal of worst case earthquake scenarios; and the three "solid circles" were the results from another recent hazard assessment for Hong Kong.)

10. THE NEXT BIG ONE??

Sadly, both the 1976 Tangshan (M7.6) and 2008 Wenchuan (M8.0) Earthquakes are low probability events, and with a recurrence interval in the order of thousands of years. Despite these repeated events occurring every few decades, many people still consider an event with a recurrence interval of 2,000 years is a rare event or even the worst-case scenario. Is that "rare" event really that rare?

The following example shows a number game that can be played: If the M8 Wenchuan Earthquake has a probability of exceedance of 1% in 50 years (RP = 4,975 years) within a particular region of China. This seems to be a very rare event which people tend to ignore. The probability of having such a rare event in 30 regions (with similar seismotectonic environment), within the same country, will become 26% in 50 years in collective terms. Now, is that 1% still a small number? For one region, it bears a risk of 1% in 50 years, but the risk can become 26% in 50 years in collective terms for the whole country (which comprises 30 such regions). Is the calculated probability of 26% still so "low" that one can ignore?

Put it another way, the occurrence of the 1976 Tangshan Earthquake may be quite rare, with a recurrence interval of 1,000 years (say), but the occurrence probability of a similar earthquake in the whole country would increase by 30 times, which means a recurrence interval of around 32 years. 1976 + 32 = 2008 and it is the Wenchuan Earthquake this year. **When and where will be the next big one in China?**

11. CLOSING REMARKS

Usually, the major problem may not be related to the technical aspects, such as the probabilistic seismic hazard assessment methodology. The perception of earthquake risk (or probability) of the general public as well as the policy makers counts. Before the 1976 Tangshan Earthquake, the design intensity level in Tangshan was VI, even lower than that in Chengdu Sichuan (VII) and Hong Kong (VII-VIII) as specified in the current seismic code, and it was revised to VIII after the earthquake. Actually, similar situation was found in the Wenchuan Earthquake, in which many places seeing building collapsing have been identified with design intensity levels of VI and VII only. The design intensity levels have recently been revised to VII and VIII.

This does not only happen to China. After the 2003 Boumerdes (M6.7) earthquake near Algiers, engineers raised a similar question, saying that they built according to the specified design code, based on a moderate seismic hazard and yet the ground motions were much higher than expected.

Both Australia and Hong Kong are at present considered to be non-seismically active. Ironically, before May the 12th this year, Eastern Sichuan would have been considered as non-seismically active too. In fact, slow moving faults in China that have suffered major earthquakes within the past few centuries have very low probabilities of a repeat earthquake in the immediate future. As with Tangshan before 1976, it is now recognised that the highest hazard is likely to be on faults without historical fault rupture (Grossi et al., 2006).

Lastly, certain facts concerning the 1995 Kobe Earthquake is cited as conclusion (Chandler, 1997). Before 1995, there was no recorded damaging event that had struck Kobe for 1000 years, and Kobe had been considered as having very low risks of being affected by a damaging event. In January 17, 1995, a M6.8 earthquake struck Kobe causing a death toll of 6,000, and injuring over 35,000 people. Some 56,000 buildings were totally destroyed and 110,000 buildings were severely damaged. The important lessons learnt from this earthquake are: (1) An unexpected level of damage can happen even in a developed country. (2) The earthquake did not only take away thousands of lives, it also caused the highest ever direct economic losses. (3) The event of Kobe posed concerns about the urgency worldwide to replace or strengthen older (pre-1971), and much more vulnerable, buildings.

Memories are short, and action is required sooner rather than later to prevent a repeat in other earthquake-threatened cities.

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