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THE SOLE COURSE OF MITIGATING EARTHQUAKE RISK

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SUMMARY

Earthquake disaster is a kind of catastrophic event occurring without warning so that the sole preventive course is to keep alertness and preparedness for it. The term "preparedness" used here is in a broad sense to mean all the measures that could be taken before its occurrence. Three links are discussed here, namely, assessment of earthquake hazard, provision of seismic resistance for all kinds of engineering constructions and post-earthquake relief and rehabilitation. It is hoped that a worldwide preparedness against earthquake could be effected through the IDNDR sponsored by the United Nations.

INTRODUCTION

Almost two thousand years ago in ancient China, there was a story told by a high official to the emperor for hint to his rule. The story is as follows: In a family's kitchen, the smoke stack erected straightly up and the firewood piled close to the stove. Some one advised the owner that the stack should be bent somewhat and the firewood should be removed away in order to prevent fire but the owner neglected this advice at all. One day, fire eventually broke out and the house was burned. The neighbors all came to help putting out the fire and many of them got their heads and faces burned. The next day, the owner held a big dinner party for expressing his gratitude to the neighbors and put those getting burned in honorable seats but no invitation was extended to the one who had given him advice before the event. Some one remarked to the host, "Is it fair that the one who gave you advice in advance gets no credit at all but those getting burned are all honored? And if you were listening to him, there wouldn't be such an accident". The owner then waked and added one more seat to his guest list. A sarcastic idiom formed after the story: "The one who gave the advice of bending the stack and removing the firewood got no credit but those with burned faces were respected as honorable guests". Since then, this idiom prevailed for thousands of years till now. It hints that preventive measures are vital for catastrophic events but easily overlooked by the people.

Earthquake is a major natural disaster. According to statistics, there were two and half million lives, regardless of the tremendous property loss, lost due to earthquakes over the world since the beginning of this century, which should rank on the top of all natural disasters. However, with the present developed technology, it could be greatly mitigated. The handicap exists in the unawareness and negligence of the public on one hand and in the vast investment required by preventive measures on the other hand. Owing to the randomness of earthquake occurrence in time and space and the gaps between successive big events being long and wide, the people are used to the psychology of escaping it by luck, so they are not prepared for it at peaceful

time until hurted by an incidental attack, and after the hurt heeled, they came back to paralysis again. Things were so repeated that earthquake remains a nightmare to us. It is now the time to awake the people over the world to consider the problem seriously and keep alert and prepared for it constantly. The story mentioned above is quite inspiring.

There are three most important links that we should take into consideration for preparedness against earthquakes:

1. Assessment of seismic hazard;
2. Provision of suitable seismic resistance for all kinds of engineering constructions;
3. Post-earthquake relief and rehabilitation.

If these links are fully observed by the people, earthquake disasters could be mitigated to a degree acceptable by the society. In the following, each link will be further discussed.

ASSESSMENT OF SEISMIC HAZARD

Assessment of seismic hazard is the foundation of earthquake engineering. If you know nothing about the potential hazard, your preparedness would have no target to aim at. On the other hand, if you know exactly the place and severity of the hazard, there would be no problem to provide safety to the public by the application of the present engineering knowledge. The most bitter lesson learned from the 1976 Tangshan earthquake is under-estimate of the hazard so that the city is practically undefended during the earthquake. It should be pointed out that seismic hazard in the sense of engineering is somewhat different from what is meant by in the sense of earthquake prediction. In engineering, it is only required to make an appropriate appraisal of the hazard potential over an area or at certain critical sites in a fairly long period while in earthquake prediction, the goal is set at predicting the time, location and magnitude of future events. The latter task is much more difficult than the former. Both are communicative but with difference between, however, hazard assessment may be regarded as a robust long-term prediction.

Many approaches to the assessment of seismic hazard have been developed but none of them found entirely satisfactory. The earlist attempt is to find the upper bound of hazard for the sake of safety. This is not an easy job because upper bound is meaningful only if related to certain time period, for engineering constructions all have lifetimes. It is difficult to imply certain time period in the sense of upper bound. Later on, considering the randomness of earthquake occurrence, the probabilistic approach was developed. But the theory of probability is founded on large number of facts; with short and incomplete earthquake catalogs, especially for high magnitudes, probabilistic estimates are not reliable. As the science of earthquake prediction developed, people has begun to make hazard assessment on the basis of earthquake prediction. But earthquake prediction is still at a young stage. With all kinds of precursors, the short-term prediction can not assure success, needless to say for earthquakes of many years later. After all these attempts, the engineers realize that in seimsic hazard assessment, there are full of uncertainties and resort to intelligent means of decision making, such as expert systems, fuzzy mathematics etc. But these methods do not deepen the knowledge of seismic hazard. Therefore, there is still much to be done for bringing the art of hazard assessment to satisfaction.

Moreover, the engineers are not satisfied with assessment of qualitative nature but are more interested in the prospective ground motion which varies with source mechanism, propagation path, local geological features, topography of the ground and soil conditions etc. Studies of the effects of these factors led to rapid development of strong-motion seismology whose main task is addressed to prediction of ground shaking, particularly for near-field of large earthquakes, say, within several tens of kilometers from the epicenter of an earthquake with magnitude greater than 6. This requires a truly interdiscipline approach with geologists, seismologists and earthquake

engineers all involved and working on subjects of wide spectrum from modelling of crack propagation to subsoil behavior. Many advances in physical understanding of earthquake source mechanism and seismic wave propagation have been made in the past 20 years; with the help of computer facilities, mathematical modelling of source and path are available and furnishing a ground for further refinement. For engineering use, the prediction of ground motion depends more on semi-empirical means which could absorb research results flexibly and provide an ensemble of design accelerograms to account for various sorts of uncertainties. It should be stressed that the method of integrating results predicted from various aspects is also important and the result should be identified by practical application to actual sites.

In general, hazard assessment is laid on two bases. One is past facts, i.e. the history of seismic activity, including strong-motion records. If you have a long and complete record of historical earthquakes, then, by inference from it, you can make a fairly good assessment of future activity. The other base is the physical mechanism of earthquake occurrence which involves the tectonic formation and movements, the stress fields, the gravity anomaly and other geophysical features. If you master all these factors and their relationships with earthquake occurrence, it would be possible to make hazard assessment on a physical basis. Unfortunately, we neither have adequate data of past facts nor well understand the mechanism of earthquake occurrence. Therefore, both bases should be broadened and deepened by extensive researches. For instance, exhaustive search of historical earthquakes, exploration of paleo-seismic activity, expansion of strong-motion network etc. are good for expanding the data base. On the other hand, identification of active faults and seismic gaps, measurements of tectonic movements and stresses, modelling of seismic behavior etc. would help our understanding of the physical process of earthquake occurrence. Reliable scientific hazard assessment shall not be feasible until these two bases are well developed. In practice, the sole way out is to integrate knowledges of both bases and make decision by human or artificial intelligence. The process can be conducted on double tracks. For general applications such as urban and rural planning, ordinary earthquake resistant design or as a target for preparedness, the traditional way of seismic zonation which delineates the active seismic areas in a macroscopic manner and designates them by grades or max. probable intensity is still appropriate. The ground motion characteristics required by engineering design can be inferred from intensity rating and soil condition. Another track is for critical projects where all kinds of field investigation are possible so that we can make microscopic studies to identify the potential sources and rely more on the physical base for hazard assessment. It is believed that if keeping on these two tracks with constant supply of knowledge from research works on aforementioned bases, hazard assessment could be brought to our satisfaction. It should be stressed that to achieve this objective, mutual understanding and close cooperation of seismologists, geologists, geophysicists and earthquake engineers are vital; without their concerted effort, the success of the task would be in vain.

PROVISION OF SUITABLE SEISMIC RESISTANCE FOR ENGINEERING CONSTRUCTIONS

The word "suitable" here refers to being adaptable to the assessed hazard, being acceptable by the national economy and being attainable by the present state of science and technology. Its implication varies from time to time. Provision of suitable earthquake resistance for engineering construction is the main part of earthquake engineering. Its development could be roughly divided into several stages. In the beginning stage, it was attemped to match the conception of statics with earthquake experience, e.g. for certain period it prevailed the concept that engineering costructions could be safe against earthquake if designed with 10% gravity as its lateral seismic load. In the next stage, with the development of structural dynamics and the corresponding computing and experimental facilities, the engineers make endeavor to control the dynamic response under earthquake excitation within elastic range and the total stresses not to exceed the allowable. In the further next stage, it was deemed as uneconomical and conservative to demand engineering works remaining in elastic range under a load of such randomness like earthquake and that the reserved strength in the non-elastic

range should be utilized. Developed with this thought are the concept of designing structures not to exceed certain deformation instead of stress limit and the non-linear dynamic analysis and experimentation beyond elastic range.

Now, it is the time to ask what the next step should be? In China, there prevails a saying, "No damage during a minor earthquake; being restorable after a moderate earthquake; and no collapse during a major earthquake". I used to hold it up as the goal to be pursued by earthquake resistant design. These words on one hand give consideration to the uncertainty of the assessed hazard which could be a minor, a moderate or a major event; and on the other hand gives consideration to the reality of national economy and provides different preparedness for different intensities of the shake. This saying is reasonable and comparatively complete and could serve as the criterion of design, especially for developing countries. In technology, "no damage for minor events" could be realized by limiting the structure within elastic range. "restorable for moderate events" could be achieved by keeping the dynamic deformation not to exceed certain threshold. Although there remains a lot of work to be done towards these goals, but the enormous literature available have paved the throughfares to them.

The most less-studied subject is "no collapse during a major event" due to a number of difficulties. In the first place, the mechanism of collapse has numerous versions and is different for different types of structures; secondly, the dynamic properties of the structure are unstable on the verge of collapse. It is hardly to conceive that the problem could be solely solved by structural analysis. It might be tackled by the art of design or in other words, by conceptual design. For instance, for multi-story buildings, people once got the idea of making the first story flexible to reduce the seismic load but converse to this idea, many cases indicated that it led to collapse of buildings. This is an example of failure resulted from a wrong design concept. On the other hand, an example of successful design based on a right concept may be mentioned. In high-rise building design, there was an idea to erect the building like a vertical shaft on the ground for earthquake resistance. Many buildings have been built that way and proved to be effective by their performance during earthquakes. As another example, the writer has proposed the concept of "second defense". It was inspired by the performance of the adobe houses in rural area during the 1975 Haicheng earthquake in China. In the epicentral area, many houses of this kind were seriously damaged with all the adobe walls collapsed but the tile roof supported by a slender, weak and unbraced wooden frame which is built inside the adobe walls were still standing all right. The writer names the adobe walls as the first defense, its collapse dissipates the energy of the strong phase of the shake and the wooden frame remains as the second defense to stand the tail phase. Following this concept, reinforced concrete frames with infilled walls would be regarded as a good design against collapse. The above examples illustrate that there is ample ground in the design art for improving the earthquake resistance with little added cost.

So far we are talking about design of new structures but it is known that existing structures are more vulnerable to earthquake because many of them are non-engineered or not well maintained. As we are confronted by a golden age of world peace and rapid economic development, it would be wise to take this opportunity to evaluate the earthquake resistance of existing structures against the potential hazard and make the decision on which should be strengthened or rebuilt or demolished. This is an important phase of preparedness and should be done in the quiescent period of seismic activity. Technically, the evaluation and strengthening problem is more difficult than design because the structure is existing, any change is not at the engineer's disposal and the construction details and material properties are not clear. It depends more upon the experience and expert's knowledge. The current method of expert system may serve as an approach to it.

For preparedness against earthquake, engineering constructions may be classified into three categories. The first category consists of the critical structures which either

involve heavy investment or their failure might bring serious consequences, or their security should be guaranteed for certain reasons. The second category covers the ordinary structures in daily use and constitutes the major part of engineering constructions. The third category refers to unimportant constructions. Different degrees of preparedness should be provided for different categories to minimize the burden on the economy of the society. Constructions of the first category generally are well engineered and designed on a conservative basis. Those of the second category are generally controlled by design codes while those of the third category are frequently non-engineered. Care should be paid in demarcating the second and the third categories. For instance, residences in rural area should belong to the second category but are often built of adobe or brick masonry and non-engineered and treated as the third category, especially in developing countries. This is not right. In China, the 1966 Xingtai earthquake and the 1970 Tonghai earthquake both occurred in rural area with a casualty of more than 10,000 dead, and in history, the 1556 Great earthquake in Shanxi Province caused a casualty amounting 800,000 dead. These painful lessons reveal us that preparedness in rural area should not be overlooked. Another thing that I wish to point out, is nowadays, most of the people are staying in multi-story or high-rise buildings. During an earthquake, they have no way to escape and easily lose their senses and take ridiculous action. In China, we had the experience that people jumped out through windows and fell dead on ground during moderate quakes. It could be imagined that if there occurs somewhere that a high-rise building collapsed in an earthquake, the whole society will be disturbed and become unrest. So it is required to assure the people of the safety of their residence. Things like that require us to think about for preparedness against earthquake. In the coming decades, it is expected that most cities and rural areas will be under drastic reconstruction, especially in developing countries; comprehensive planning works are indispensable. Overall consideration of preparedness against earthquake threats should not be neglected in the planning.

POST-EARTHQUAKE RELIEF AND REHABILITATION

The process of relief and rehabilitation after an earthquake disaster generally consists of three phase, namely, rescuing of lives; restoration of normal life and rehabilitation or reconstruction of the community. In the process there are full of difficulties and hardships to be overcome.

Taking the 1976 Tangshan Earthquake in China for instance, the earthquake broke out before dawn; in seconds of time Tangshan as a city of million people darkened up and became a silent dead city with numerous dead in bloodshed, numerous wounded helplessly lying down and numerous survivors paralyzed by the shock and waiting for help. All the communications with outside world were cut off and all the transportation lines were blocked by debris and failure of bridges and embankments. The Government at Beijing was awaked by the monitoring service that an earthquake occurred somewhere in that area but could not locate it precisely at Tangshan until four hours after the event. Hundred thousand troops and medical teams were then ordered to rush to the quaked site by all kinds of transportations and the first batch of arrival was 24 hours after the shock. In such a rush, they were by no means well equipped with facilities. For rescuing lives they had to remove heavy debris by bare hands and stood hungry, thirsty and sleepiness through days and nights. It was a luck that no secondary disaster happened; if it did, the hardship would be multiplied. But the danger was existing, e.g. a reservoir located 15 km, north of the city was filled to its capacity of 36 million cu. m. of water. The bottom of the reservior is 15 m. higher than the city proper. The dam was damaged seriously with full of cracks over the body. Had the dam failed, the city would be in a pool of water, efforts of rescuing lives would be totally in vain.

The total casualty during Tangshan Earthquake was estimated at 400,000 with 240,000 dead and 160,000 seriously wounded. It was reported that only 12245 were saved by rescuing action. There were also many lives detected underneath jumbles of debris but the rescuer found no way of access to them and watched their voice

until it became silent. The last one rescued from the ruins was on the 13th and last from the coal mine was on the 15th day after the quake. Thousands of wounded were transported by air to big cities far away for medical care. These concluded the first phase post-quake relief.

The second phase commences after the first or in parallel with it. The task in this phase is to restore normal life to the community. Taking Tangshan Earthquake as an example again, the work was proceeding as follows:

1. Restoration of the transportation routes

There were 6 main highways through Tangshan, through rush-repair, all reopened to traffic in a week. The railway got through in two weeks but regained the original traffic capacity three months later. Before the recovery of highways and railways, transportation was mainly by air. In the busiest day, there were flights once every two minites taking off from a small airport.

2. Prevention of epidemic

The dead bodies were buried in deep pits and medicines for sterilization were sprayed from air by planes. As a result, the dysentery prevailing after the quake was under control and the rate of contiguous diseases of the next year had been controlled lower than the previous year.

3. Restoration of daily life

After the quake, the people are exposed to open air under the summer sunlight and had no clothes, no drink, no food and no place to rest. Urgent needs were supplied from all directions to release the hardship. Building of temporary huts started about a week after the quake. In three months, almost every family got two rooms and the living condition were gradually brought up. It was followed by the resumption of commercial activities supplying the daily needs. It took about a year for restoring the city in shape.

4. The resumption of industrial production

Tangshan is an industrial city. There are many big industries around the city. After the quake, they were engaging in resumption of production without loss of time. The biggest industry is coal mine. The original daily production had been recovered by a year later.

The third phase is rehabilitation or reconstruction of the destructed areas which varies from case to case and can not be narrowed down to a single pattern. In the case of Tangshan, the whole city was demolished, the problem became rebuilding of the whole city. The project were carried out in three parts, namely, rebuilding of the city proper, recovering of the east mining district and opening a new industrial district on the northwest of the city. The project commenced in 1978 and practically accomplished in 1985. The total rebuilt floor area amounts to almost 20 million sq. m. and the investment to two and half billion yuans. The investment were furnished by the Central Government and collected from related industrial enterprises. The guideline of rebuilding is to facilitate production, to offer convenience to the community, to protect the environment and to contribute to the welfare of the people. The design and construcion work were shared by eleven provinces and the national army under unified planning. The main experience of success may be summarized as: keeping up the spirit of self-reliance to reduce the burden on national economy; accepting help from the whole nation but under unified planning; standardizing the design and construction methods; rebuilding at first the outskirt and then the city proper so that people can move to new residences without disturbing the order of life; and finally, the construction of the network of major roads and streets going ahead of other constructions.

What mentioned above is to illustrate how the people suffered post an earthquake disaster, using Tangshan as an example. Now, the tragedy has passed twelve years but there remain many things for us to think about. I used to ask myself:

1. Had the government and the community well prepared for the event with the relief measures all planned, could more lives be saved and suffering much reduced?

2. Should another similar shock occur again somewhere else, could we rule out the repetition of the Tangshan tragedy and have a much better situation to deal with?

My answer to the first question is positive but to the second question is negative because although all understand that preparedness could reduce the disaster greately, but no enough real effort has been devoted to it yet. For promoting the preparedness, I would like to recommend some measures which seems feasible to take:

1. Establish safely-designed rescuing centers in highly active seismic areas, equipped with all kinds of tools, goods and materials necessary for rescuing action and offering training course on rescuing technique. Since earthquake is not a constant threat, these centers may be utilized for other emergent uses.

2. Charge the responsibility of rescuing action formally to the national army because the army has a tradition of strict discipline, prompt action, loyalty to the people and the spirit of self sacrifice and also being well equipped with transportaion facilities.

3. Well protect the communication facilities so that the epicentral area will not be isolated from the outside world during and after the quake.

4. Insure traffic routes unblocked and quick resumption of blocked traffic routes. Make plans in advance for calling transportation facilities during emergency.

5. Provide refuges for the wounded and homeless survivors in urban and rural planning. The need of refuges is critical in bad weather like extremly hot, bitter cold or heavy raining. Safely built public buildings, such as schools, theaters, auditoriums etc. may be utilized for this purpose.

6. Develop insurance business to cover earthquake losses. Insurance, in reality, is a means of collecting resources from the community for supporting the victims.

I believe, much more efficient countermeasures to reduce the suffering of the people post earthquake will be proposed if the problem were exposed to the public.

APPEAL TO IDNDR

In 1984, on the occasion of the Eighth World Conference on Earthquake Engineering, Dr. Frank Press made the proposal of establishing an International Decade of Natural Hazard Reduction to call all nations join their forces to reduce the consequences of the natural hazard and set the time at the final decade of this century. The proposal was accepted by the United Nations in a resolution passed on Dec. 11, 1987 and designated as International Decade of Natural Disaster Reduction (IDNDR).

Earthquake is a major natural disaster, it deserves special attention of IDNDR, and the technology has been well developed to meet the goals set by IDNDR. It is my hope that through the activities of this Decade, world preparedness for earthquake disasters especially for big events could be enhanced and a comprehensive knowledge base could be built up by concerted efforts of the world experts and specialists. As a part of the content, I would like to make the following suggestions:

1. Make a collection of national seismic maps and based upon them, compose a world seismic map to facilitate mutual understanding of the hazard potential between

nations and to erase the national boundaries of earthquake disasters.

2. Compose a world history of earthquake disasters for promoting exchange of experience.

3. Formulate unified recommendations for earthquake resistant design and evaluation by integrating knowledge of world experts for general reference so that national aseismic codes could be laid on the basis of world state of the art.

4. Install a worldwide network of strong-motion observation and post-earthquake investigation system so that measures taken in preparedness could be checked by practice.

5. Promote legislation and insurance business for preparedness against earthquakes.

6. Establish an international post-earthquake disaster relief program.

7. One of the goals of IDNDR is to disseminate the existing and new information related to measures for mitigation of natural disasters. Earthquake is the hot spot among the natural disasters. It is saying that knowledge is accumulating by geometrical series while that we can accept is only by arithmetic series. In order to overcome this handicap it is suggested to build a huge integrated knowledge bank by utilizing the modern computer technology for facilitating its dissemination.

It is believed, through the concerted efforts of the government, the community and experts in various related fields, reduction of earthquake disasters could be achieved in the foreseeable future.