



## SJ-R1

### State-of-the Art Report TOWARDS EXTENDED FIELD SURVEYS AND ASSESSMENTS IN AN EARTHQUAKE

Yutaka OHTA<sup>1</sup> and Yoshimasa KOBAYASHI<sup>2</sup>

- 1 Department of Architectural Engineering, Hokkaido University,  
Kita-ku, Sapporo, JAPAN
- 2 Geophysical Institute, Kyoto University,  
Sakyo-ku, Kyoto, JAPAN

#### SUMMARY

The submitted 14 papers to the Special Theme Session (SJ) entitled "Survey Methods and Quantitative Evaluation of Earthquake Damage" were summarized in a broader scope of earthquake disasters than has been traditionally recognized. In regard with this, the various approaches to develop field surveys and associated assessments were proposed from direct-physical disasters to indirect socio-economic impacts.

#### INTRODUCTION

A Special Theme Session ( SJ ) in the 9th World Conference, entitled " Survey Methods and Quantitative Evaluation of Earthquake Damage", was coordinated so as to have a systematic understanding of the currently existing data-collection schemes for earthquake disasters, especially in concentration of non-instrumental data, and regarded data processings and analyses, and of exploring better ways toward the future.

As has long been recognized, an occurrence of a significant earthquake gives us an unexpected opportunity of collecting variety of field data of the earthquake impacts on the human societies and the profound analyses of the collected data may contribute considerably to the earthquake engineering and earthquake disaster protection developments. In this belief, numbers of and various of field surveys have been conducted immediately after an earthquake takes place, and statistic and/or advanced analyses from various points have been attempted. However, the covered range in view of the existing major field surveys is, as far as we understand, too much concerned with the disaster aspects which may occur during and/or immediately after an earthquake, or, in another word, too biased on direct physical damages.

Incidentally, earthquake disasters are not only the phenomena triggered directly under the seismic shakings but also the phenomena which may continue as long as several years or more depending on the suffered situation of an attacked area, and all the phenomena are mutually correlated and even causal. From this point of view we first make clear in this report a new scope of the

"earthquake disasters" in a broader sense than those understood, then based on this new view we summarize the submitted 14 papers to this Session, and in parallel we prepare various proposals for the extended survey schemes and assessments toward the future developments.

#### A NEW SCOPE OF EARTHQUAKE DISASTERS

Due to the dominance of physical damages to man-made structures, major efforts in earthquake have been made at improving the structural safety from mechanical point. But, as is easily understood all the phenomena from the earthquake onset to the final stage of household and/or areal recovery from the suffered states are a really linked and causal events. Human casualties and succeeding disasters as spreading fires and social degradation etc are strongly affected by what kinds of disasters occur immediately after an earthquake and by how they occur in regard with the social settings of the area. In this report, therefore, we first attempt a brief description of a new scope to be covered in regard with a word of "earthquake disasters" in a broader sense than those recognized.

Suppose we deal with the seismic risk in a social body - whatever it is -, in the first of all we should keep in mind of the seismic input events as important items to evaluate. Some of major items are earthquake-generating process, earthquake wave propagating-process and regional-to-local amplification effects and so on. As for the output events, on the other hand, there are two major aspects; damaging and impacting processes, and responding and restoring processes. The former ones are further classified into several sub-aspects of Primary disasters ( = damage to nature and man-made structures ), Secondary disasters ( = human casualties and fire breaks and spreads ), and Tertiary disasters ( = deterioration of daily lives and regional activities etc ). Likewise, the latter ones are also divided as Emergency responses ( = rescue, fire fighting, evacuation, supplies of subsistence for daily lives ), and Restoration activities ( = medical cares, structural repair or reconstruction and socio-economic recoveries etc ). If we see these aspects from time sequential point, the primary disasters are the events which occur in the time range of sec-min, the secondary disasters and emergency responses as well, are the events in min-to-week, and, tertiary disasters are the events to continue as long as week-to-year. The restoration activities are also the events belonging to the longest time span. What we should observe in regard with the earthquake disasters are broad in the coverage of items and long in the time span.

Among these, however, the instrumentally observable items are very much limited as some part of seismic inputs and most of the others rely on the data collection by means of non-instrumental methods. And even the seismic inputs can obtain in a very limited number compared with that to be requested and in most of developing countries we cannot expect almost no instrumental data. In consideration of such background we want to see a more way of getting seismic input data other than by instruments, together with data collection by non-instrumental methods. Then, the principal items to cover in this report are; mostly on Seismic Intensity as input event, and as output events Damage to Nature and Man-made Structures, Human Behavior and Casualty, Effects on Daily and Social Lives and Emergency Response Activity and so forth. These will be

discussed in parallel with the line-up of sub-themes prepared in our SJ Session as "Earthquake intensity", "Effects on natural environment and property damage" and "Human behavior and casualty".

#### SEISMIC INTENSITY

In the past era when no modern seismology initiated, "Seismic Intensity" had been known as a useful concept to evaluate the seismic severity of a given area where an earthquake attacks and therefore various scales from region to region were developed, and even now it is considered as the fundamentals in earthquake-related fields. Despite of modernization of seismic instrumentation in developed countries, as well-designed strong motion seismometers, the field surveys on areal distribution of seismic intensities are still important. In developing countries it is nothing to say that the observed seismic intensity data can be non competitive for every purpose in Seismology-to-Earthquake Engineering. In response to such significance there are not a few regarded papers being presented in this Conference. We selected 4 papers for this Session. Those are simply summerized in the followings.

Zegarra, L., Bariola, J., Tinman, M., Malpartida, C., Becerra, J., and Samanez, R., "Evaluation of the April 5, 1986 Earthquake in Cusco, Peru"(not presented).

Seismic intensity and building inspection surveys were conducted in Cusco city, Peru, for a shallow, near-distant 1986 earthquake with M 5.4. The intensity survey by a questionnaire method in a size of around 4,000 made clear microzoning characteristic ranging V-VII in MM scale. The inspection was made for damaged 95 adobe buildings for collecting data about location, use, material, walls and floors, type of footings, and damage details. This is to obtain a closer relation of architectural and structural characteristics to damage features, and better reconstruction and repair findings.

Kagami, H., Okada, S., and Ohta, Y., "Versatile Application of Dense and Precision Seismic Intensity Data by an Advanced Questionnaire Survey".

Based on a dense and precision seismic intensity survey by a questionnaire method, recent 30 earthquakes were investigated for various objectives. This series of surveys unveiled versatile application capability of seismic intensity data. Some applications in engineering seimology are for seismic source, propagation path effects and microzoning characteristics. As for applications to earthquake engineering and earthquake protection problems, it is to use the seismic intensity data as a dominant index to damaging features to man-made structures, impacting effects on the societies, and emergency countermeasures by local governments etc.

Astroza, M. and Monge, J., "Effect of Geology and Soils on Damage. Central Chile Eathquake of March 3, 1985".

Based on the field survey of damage to one-story adobe and masonry dwellings in 1985 Chile earthquake with M = 7.8, isoseismals and seismic microzoning characteristics were elucidated. And such characteristics were found in highly correlative relation with areal and local soil conditions, as the fundamental data for assisting a future city planning.

Veneziano D. and Heidari, M., "Earthquake Intensity Fields: Anisotropy, Nonhomogeneity, Variability, and Local Anomalies"(not

presented).

Based on MSK intensity data in north-eastern Italy various earthquake intensity attenuation characters were reexamined, and anisotropy and nonhomogeneity were found to be effective by one intensity unit. Variation of attenuation rates among events is rather large. Local anomalies are also large as one intensity range, which is beyond the simple interpretation by geological or morphological settings.

As is seen above, the objectives of field determination of seismic intensities are different from paper to paper as seismic source-regional effects, microzoning characteristics and other various applications as key index. Correspondingly, the survey methods are also different. But the major ones are the field inspection of structural and other damages, questionnaire and/or interview methods. The common character to which every author stresses is to conduct a high dense survey. As demonstrated by Kagami et al a well designed high-dense questionnaire survey brings significant data on seismic intensity by which most fundamental problems in Seismology as well as Earthquake Engineering can be developed in cooperation of advanced data processings. Simply, we may say that seismic intensity is determined by a survey of limited items of human perception, damage to nature and man-made structure, but effective as a major factor for the evaluation not only direct but also indirect disasters and emergency responses as well.

For better use of seismic intensity data, however, there are more subjects to study. Some of them are 1) further establishment of objective determination at a site, 2) elucidation of physical background of intensity, 3) more understanding of the relation between direct and indirect disasters, 4) comparison among existing intensity scales for international standard scale, and 5) development of intensity definition itself from one-value to multi-value parameter in regard with "earthquake wave period" dependency.

#### DAMAGE TO NATURE

Major earthquake damage items to nature would be "Landslide" and ground failure mostly due to "Liquefaction". In our Session, however, there is only one paper which discusses landslides. It is the one by Harp et al and summerized as follows.

Harp, E. L., "Earthquake-induced Landslide Maps as a Quantitative Data Base"(not presented).

In insisting on outstanding necessity of completed and detailed map inventory of the landslides, this paper searches actual and probable way of accumulating such data. According to this, a map with 1:40,000-50,000 scale is demanded for the correlation analysis of landslides to geological, topographical and other natural conditions. And convenient methods of landslide mapping are primarily that by use of the air-photos, and, to be more precise, that by field inspection. Along this understanding several examples were to be demonstrated for 2 Californian earthquakes. Eventual objective is to construct " landslide hazard maps", and the success of it depend mostly on how to disclose the relations between landslides and seismic parameters.

It is our regret that this paper was not presented at the Session. But, it says a very fundamental point for a systematic collection and following analyses of landslide. Even apart from this

paper the present situation is still in descriptive expression as "large" or "small" scale landslide. A more advanced method of expressing them in a quantitative way is strongly desired. For that, as insisted by Harp, it should be made to prepare a complete and detailed map inventory of the landslides.

As for Liquefaction, there was no paper for the presentation in this Session. But it is true that this item as the major cause of ground failure under seismic shaking is important in the scope of field survey. The present situation is, as far as we understand, similar to that for the landslide problem as mostly due to the air-photo viewing and field inspection. So, the data are generally descriptive and their damage degrees are based on the categoric classification. Our desire is to develop first an objective field survey method by which ground failure severity can be well itemized, and then to compile the mapped inventory for the liquefaction phenomena in cooperation with the other seismic parameters of seismic intensity and surrounding damage features to man-made structures. There is a proposal on the Liquefaction Scale by a Japanese researcher as classifying into 5 major ranks in account of the liquefied state at a given site and its effect on the near-by area, which may give the useful guidelines for the better evaluation of liquefaction phenomena. To specify the ground failure by the liquefaction, an introduction of the quantity of [liquefied degree x suffered area] might be one possible way.

#### DAMAGE TO STRUCTURES

Under this subject we would very much like to cover not only the damage to structures but also damage to non-structural elements and associated indoor distortion. Submitted with the damage to structure itself are 3 papers as summarized in the followings.

Tiedemann, H., "Lessons from the Mexican Earthquake of 1985: Quantitative Evaluation of Damage and Damage Parameters". This paper deals with seismic performance dependency on the mechanical and geometrical characters, based on the questionnaire survey for the 5 or more storied buildings in the 1985 Mexican earthquake. The founded are the strong dependency of geometrical characters on MDR (mean damage ratio), as asymmetrical buildings are weaker than symmetrical ones, which suggests the more attention to the design details.

Elnashai, A. S., Pilakoutas, K., Ledbetter, S. and Bommer, J., "Comparison of Structural Damage from Two Recent Earthquakes". In the belief that field observations provide the most definite method of assessing structural performance and the effectiveness of design codes and recommendations, 2 earthquakes of 1986 Kalamata and San Salvador were surveyed forming separate investigation teams. Comparison of damaged data made clear that poor construction and workmanship are responsible for a high percentage of damage, and thus suggests the earthquake-resistant to be made more on providing adequate ductility and energy dissipation capacity, which are most important for the drastic mitigation of casualties as dominated in the 1986 San Salvador earthquake.

Umemura, H., Murakami, M., Okada, T., Ohkubo, M., Otani, S., Taniguchi, K. and Hiraishi, H., "Post-Earthquake Inspection and Evaluation of Earthquake Damage in Reinforced Concrete Buildings".

From the understanding that quick inspection of building damage features is of fundamental importance for optimal emergency responses and restoration processes, three types of field survey guidelines were developed. Those are quick inspection mostly for immediate separation of dangerous and safe buildings, first level evaluation for more classification of building damages, and second level evaluation for getting fundamental data towards strengthening design details. An application for Mexico city made clear the effectiveness of these guidelines.

These papers are interesting in view not only from field survey developments in traditional earthquake engineering but also from succeeding disaster mitigation as well. The popular methods are field inspection, interview and questionnaire surveys with the variety of objectives for knowing seismic performance of the building itself and of the non-structural elements and indoor spaces. The available period is, depending on the survey objective and detail, usually hours-several weeks later than the earthquake attack. Tiedemann et al stress the importance of more attention to the configurational characters of a structure, Elnashai et al appeal more ductility for the existing brittle and weak-resistant buildings, and Umemura et al propose a step-wise survey methods of structural damage so as good for the emergency responses and forthcoming restoration works.

Incidentally the most important point is, at the field survey, how to define and describe the damage degree of structure, and, at the assessment, how to evaluate the structural performance in a good way for a functional form. For the damage grading there are at least 2 well-known manners. The one is the definition which classifies the structural damage into several categories of [no damage], [partial damage], [heavy damage], and [collapse]. This has a merit that the field determination is easy with a demerit that the definition is descriptive, discrete and therefore subjective. The other one is, developed from the necessity in the earthquake insurance field, the definition of counting the [partition rate of repair cost] so as to score in a range of [ 0.0 - 1.0 ]. This seems quantitative and therefore better than the previous one, but the actual process breaking down the damage state into monetary value is not straight forward as expected, and even weighted too much on economy. There might be also 2 probable ways for developing the definition of damages. Those are as follows; The first one is to introduce a more minute classification for [collapse] state, since the covered range by a word "collapse" is too wide compared to the associated disasters as human casualties. This is also the way which we can implement even from now. The second one more advanced is to attempt a functional expression as

Damage to structure = F [ Mechanical, Economical and Functional ],

that is, to introduce a definition by means of a combination of 3 characteristic damage indexes ranging [ 0.0 - 1.0 ]. In the existing definition, these 3 different characteristic damage aspects are not separated nor well recognized, especially for the functional deterioration of the indoor spaces. The last index is most important at the evaluation of casualty risks. If this kind of definition would be available, the more information for the total performance of a structure against an earthquake would be obtained. But, for this attainment the more advancement and systematization in the field survey should be in practice. All the papers presented in this

Session are also effective from this point of view.

Based on the opinions by the present and past papers the most appropriate description of seismic performance, in terms of vulnerability characteristic, is to formulate in a functional form so that all the concerned factors are well combined. A probable example is to express as

Structural Vulnerability Function = F [ Seismic input parameter; Mechanical strength, Ductility, Configurational factors, auxiliary elements].

If this will be expressed in a well correlated manner with the previous damage function which describes the degree to structures, it must be of special usefulness.

A paper by Evans et al is only the one in this Session which treats damage to a non-structural element. A summary is as follows.

Evans, D. and Kennet, E., "Glass Damage in the 19 September 1985 Mexico Earthquake"(not presented).

An intensive survey for glass damage in the structures was attempted to elucidate first the damage statics and then its mechanism in regard with damages of structure-in-total and structural elements. This was made for exploring recommendations toward glass damage mitigation, but this kind of survey is certain to provide important information for reducing human casualties in and around a building.

They concentrates their attention to the grass damage to get the general features and to elucidate various causes in regard with structural behavior in an earthquake. We consider similar kinds of surveys and following assessments should be more prevailed especially for disclosing the fundamental effect on human casualties. Likewise, a phenomenon of indoor space distortion due to falling down, overturning and scattering of household contents as well due to structural deformation under seismic shaking is the object to be made much more weightedly and far beyond the very limited experience until now. According to our preliminary surveys, this is considered the most significant factor which controls injury occurrence.

#### HUMAN BEHAVIOR AND CASUALTY

Despite that everyone knows the human casualty as the most severe earthquake disaster, the accumulation of past studies for this subject is rather small in number. This may partially be due to that no well established way of field surveys and succeeding assessments have been developed. In these years, fortunately, regarded studies are gradually increasing, and in this Session 3 papers are presented. Followings are their summaries.

Durkin, M. E. and Ohashi, H., "Casualties, Survival, and Entrapment in Heavily Damaged Buildings".

In a selection of 3 buildidngs in different damage features from heavily damaged, to somehow collapsed and to totally collapsed, human behavior and resultant casualty was intensively surveyed, and found the strong correlation of casualties on the damage details as most and extremely severe in the "pancaked" building. Also casualty, survival and entrapment details were investigated in regards with

where occupants were and how they behaved in an earthquake.

Mochizuki, T., Kosaka, S. and Hayasaka, S., "Human Behavior and Casualties in the Epicentral Region of a Large Earthquake". By conducting questionnaire and interview surveys the details of human behavior and casualty occurrence were made clear for the most devastated 1948 Fukui earthquake in Japan. Surveyed items are behavioral deterioration under the severest intensity, casualty rates and their controlling factors, and found sex, age etc most influential. Because of injury mostly of legs, many injured people were brought to deaths under spreading fires.

Shiono K. and Kosaka, S., "Injuries in Earthquakes: Consideration of Local Social Characteristics in the Construction of Estimation Schemes".

For the purpose of selecting major factors affecting injury, and interview survey in a size of 50 injured and medically-cared people was made in Noshiro city at the 1983 Central Japan Sea earthquake. They finally proposed relation of "probability of injury" in a certain unit area is expressed as a function of dwelling size, building density, aged inhabitant density.

Since this subject is the one belonging to the human sciences there is as yet no good way of observing instrumentally what people behaves in an earthquake, the most popular survey methods are those by questionnaire and interview, although in a special case the direct field inspection is effective. To be specified is that a well-considered questionnaire method is available even for a past earthquake by several tens of years. Mochizuki et al's paper is a good example. Surveys under this subject aim at elucidating behavioral patterns and major factors on casualties, and the principal mechanism findings. Most effort is expected on the derivation of better empirical casualty equations by which leading opinions for optimal countermeasures can be productive.

Commonly understood matters through the above papers are first the importance of structural performance in view of its indoor space safety dependency and also the importance of human's attribute dependency on casualty occurrence. Durkin et al insists that a delicate difference of collapsing of a structure brings the significant discrimination to casualties and following rescue survices. This requires a more minute classification of damage states from "heavy damage" to "pancake collapse", which is in parallel with our aforesaid proposal for a better definition of structural damages. Two papers by Mochizuki et al and Shiono et al examine the dependency of human's attribute factors on casualties as well as damages to surrounding areas. Considering such findings a probable casualty equation can be written as

Casualty rate = F [ Major factor, Supplementary factors ],

hence "Major factor" is the structural vulnerability (damage degree), to be determined in a functional form mentioned before, and some of important "Supplementary factors" are building type, indoor and outdoor space factor, occupant's attributes (sex, age, disability, protection capability etc), and earthquake occurrence time and so forth. A more effort is desired to develop this kind of systematic casualty equations in parallel with the more accumulation of field data on casualties.

## EMERGENCY RESPONSES AND EFFECT ON DAILY AND SOCIAL LIVES

Except for Kagami et al's paper in which emergency response activities as HQ setup, mobilization, communication of information and subsistence supplies are well correlated with seismic intensities, no paper in this Session is concerned with emergency responses. A more definite effort should be made for this problem. As for the effect on people's daily and social lives we could have one paper by Shiono. It is summarized as follows.

Shiono, K., "A Method for Evaluating the Difficulty posed on Residents' Daily Living Activities by the Interruption of Life-line Services".

In order to develop a new scale for measuring the influence of people's daily life due to the interruption of life-line systems, a pilot test was carried out in Noshiro city for the 1983 Central Japan Sea earthquake. Surveyed was made in a size of 1,000 households by a questionnaire method, picking up several items of cooking, washing, bathing and etc, and attempted to evaluate the difficulty by [degree of restriction] times [time length].

Judging that most of existing studies under this subject have considered engineering damages to lifeline facilities and evaluated restoring processes as a total of an area, his way of study is innovative in attempting to assess in quantitative manner the various effects of lifeline interruptions on the household living activity. Similar studies but the ones extended to the other objects than lifeline system are urgently and strongly recommended.

## CONCLUDING REMARKS

Incorporated with the new scope of "Earthquake Disasters and Regarding Problems", we have made a state-of-the-art report on the survey methods and assessments in an earthquake. What we found are 1)recent development in this research field is significant in both developing and developed countries, 2)covered disaster range and regarded items have been enlarging abruptly from physical and engineering ones to those associated with social impacts, but 3)such new trend in survey and assessment studies is still far insufficient, if taking into account that all the earthquake phenomena are just causal and seamless. Dominant defects are for the items in secondary and tertiary disasters, that is, for the damaging and restoring aspects which may occur later than the occurrence instance of an earthquake.

As mentioned in the beginning we concentrated our attention on the survey methods for non-instrumental data. This is based on our belief that the more development in this way is certain to help us the profound understanding of earthquake disaster phenomena in a broader sense. But it is also our belief that more reference of those data with instrumental data is of fundamental importance. From this point of view there might be 2 separate ways. One is to conduct the verification with instrumental data as much as possible. The best trial would be a comparison of seismic intensity with strong motion record. This is a way to develop the worldwide standard seismic intensity scale, as well. The other one is to develop a more objective (and hopefully instrumental) method for the item which apparently seems difficult in the adoption of instrumental field

survey. Kawashima et al's paper is attractive in this sense. Their paper encourages us to explore more items which may adapt to the instrumental measurements, as is summarized in the following.

Kawashima, K., Obinata, N. and Kanoh, T., "Damage Features of Sewage Pipes caused by the Nihon-Kai-Chubu Earthquake of 1983". This paper introduces a new instrumental tool for the damage detection to water sewage piping system, by applying a small TV camera, showing an actual survey for a length of 13 km. And by use of such field data the damages to the piping system were well classified as the one for pipe itself and the other for joint part between pipes, and statistical analyses were also conducted to know the damaging details.

As for the actual evaluation of obtained data through various survey methods, there are in general various steps. The first step is probably to conduct some how a statistical analysis to know the general trend, to attempt an elucidation of controlling factors and/or causing factors on the event under consideration, then to develop an empirical and, if circumstances permit, theoretical model, and, in final step, to explore better countermeasures based on these series of findings. All of these steps are to be made of effective use of modern computers, so there is no more difficulties. But, we should keep in mind that the certainty and reliability of the findings through such advanced data processings depend essentially on the quality of original data. That is, the better field surveys only can give us the opportunity of the better assessments.

What we want to add in closing this paper is that events to be considered in an earthquake are many compared to the number of items commonly surveyed and assessed, and that our efforts should be made for the unknown items to be in table in the descriptive manner as a first step and to be in the quantitative manner for the items which have been expressed descriptively, so as to widen our understanding of earthquake-related phenomena and to upgrade existing earthquake protection measures.

Finally, we would very much like to express our sincere thanks to all of the authors of papers and the participants in the Session, from whom we learned so many things.