AN INTRODUCTORY NOTE ON EARTHQUAKE DAMAGE AND MEASURES

Iware MATSUDA

Abstract A phase of earthquake disaster was divided into four stages. Outlines of each stage were given along with some examples. Also, a variety of measures to counter an earthquake disaster explained in line with its phase. It is emphasized that comprehensive measures are indispensable to mitigate earthquake damage.

1. Introduction

Natural disaster caused by for example, a heavy rain, an earthquake or an eruption of a volcano is regarded as such a phenomenon that the normal daily life is seriously disrupted. This extreme geophysical event is called an inducement of natural disaster. Human beings, their properties and other man-made structures which are likely to be damaged by natural disaster are called a subject of damage (Matsuda, 1978).

Although the mechanism of occurrence and the extent of damage of natural disaster are decided by a magnitude of its cause, they are often influenced by the latent weakness hidden in the physical conditions of land and the social conditions of the subjects of damage. If we can define these latent weakness as the causative factors of damage, they are classified into two kinds, namely physical and social. A physical causative factor is derived from physical characteristics of land on which human society has been established. A social causative factor is characterized by the conditions of the subjects of damage and is closely related to land use.

Supposing that a residential area being composed of many wooden houses has been developed on a flood plain without considering the physical conditions, this area is apt to suffer from flood and earthquake disaster. A physical causative factor of flood disaster is low and flat features of a flood plain and that of earthquake disaster is existence of soft soils. A social causative factor is existence of wooden houses and the poor measures to counter a flood or an earthquake.

These causative factors are latent in normal conditions and daily human life goes ordinarily. But when an inducement of natural disaster, for example a heavy rain, hits this area, the latent causative factors become actual. As a result, the subjects of damage, wooden houses, residents, *etc.*, suffer from a flood. Such a phenomenon is called as the first stage of disaster.

Once a natural disaster occurred, its damage works upon other causative factors and the disaster moves to the second stage. In this case, damage caused during the first stage induces the second stage of disaster. Then, the damage of second stage triggers the third stage of disaster. For example, a heavy rain collapses a slope. Debris supplied from the collapsed slope fall down and crush a house on the foot of the slope. A householder living there is killed and his family is forced to suffer from the difficulty of living. Like that, the first stage of disaster develops into the second, and the chain reactions continue in succession. As a disaster develops, its aspect transforms and its influence to the subjects of damage changes on the basis of mainly social causative factors. Though we usually use the term, natural disaster, we have to examine not only its physical characteristics but also social ones.

Distinctive features of natural disaster mentioned above, conspicuously appear in earthquake disaster, especially when it occurs in a big city. Many kinds of man-made structures have been built up and large numbers of people commute to work in large cities. Daily life of citizens totally depends on various facilities such as those for energy supply, water supply, transportation, *etc.* There are multifarious and large quantity of causative factors of earthquake disaster in large cities.

Accordingly, measures for earthquake disaster in a big city have to consider its various aspects. Earthquake resistant structure has to be recognized as one of the measures to mitigate earthquake damage and the comprehensive measures have to be adopted (White and Haas, 1975).

Figure 1 shows a flow of earthquake disaster and related factors such as an inducement, causative factors, measures taken before and after occurrence of an earthquake and fundamental research oppotunities. Each factor and their relationships will be explained and necessity of studies on comprehensive measures will be emphasized in this paper.

2. Context of Earthquake Disaster

An inducement of earthquake disaster is slippage of an earthquake fault. Its dimension (length, wideth, strike, dip angle, depth, slip type, *etc.*) and epicentral distance are well known for having much influences on an extent of damage.

Also, time of occurrence is very important because the conditions of the subjects of damage are always changing. The Great Kanto Earthquake of 1923 occurred at about noon when fires were used for cooking meals in most of homes and restaurants. This is one of the reasons why 183 fires broke out all at once and brought about the catastroph to Tokyo (Imperial Earthquake Investigation Committee, 1925). The Mikawa Earthquake of 1945 collapsed 7,221 dwelling houses and killed 2,306 residents by crushing them under the collapsed houses. That means 3.1 collapsed houses killed one resident. This high ratio derived from the fact that the earthquake occurred at night and most of residents were sleeping (Matsuda, 1983 a).

A season is an important factor like occurrence time of an earthquake. The land slide caused at Nakagi by the Izuhanto-oki Earthquake of 1974 buried 16 inns and crushed 27 people to death. If this earthquake did not occur on May 9th but in mid summer, much more casualties should have been caused, because the southern part of the Izu Peninsula is

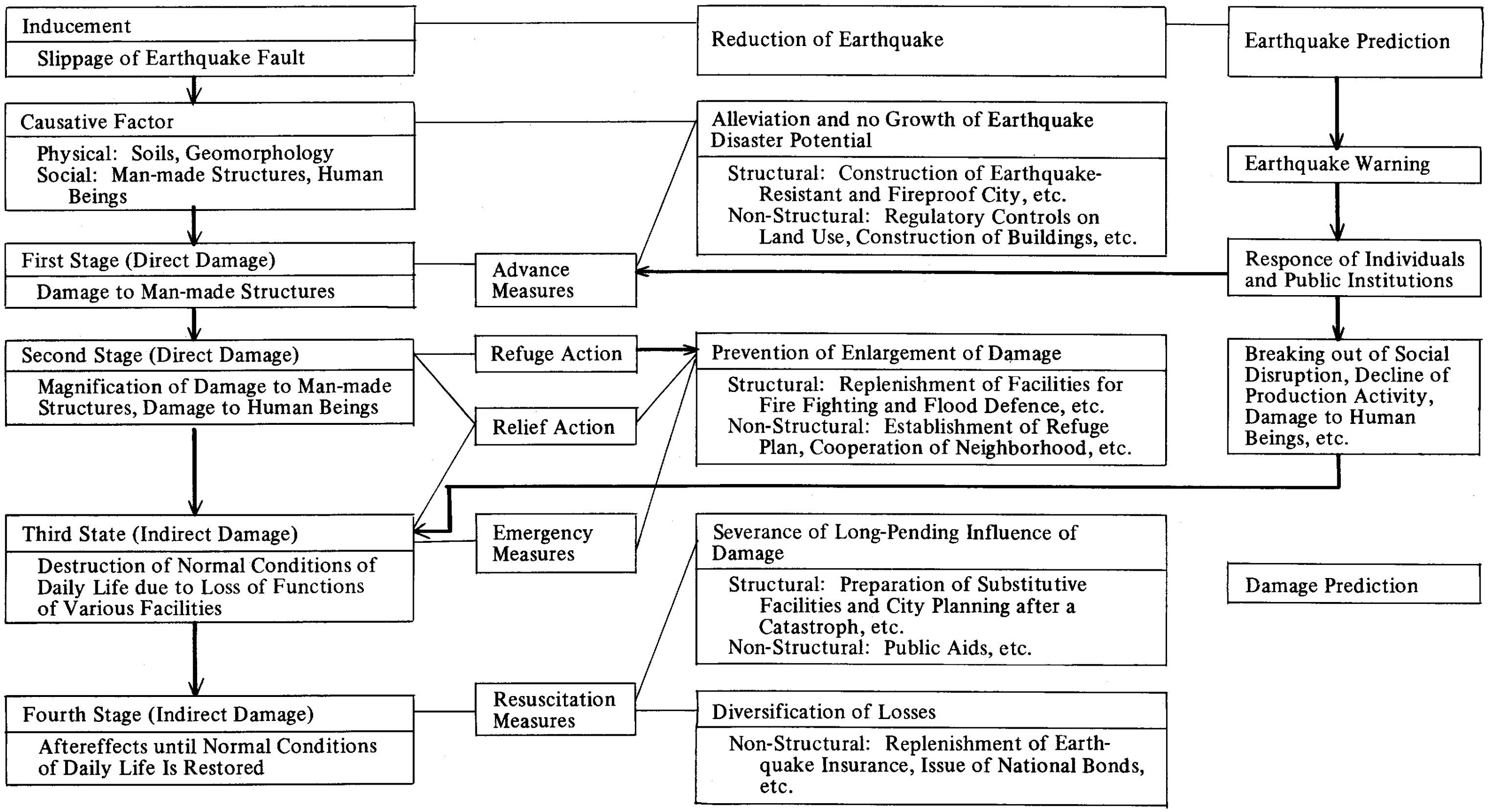

Fig. 1 Relationships between earthquake damage and measures
Solid lines show relationships between stages of earthquake and measures coping with them.
Arrows follow the development of earthquake disaster.
Solid lines connecting between damage prediction and other factors are omitted because damage prediction relates most of other factors.

wellknown for a good seabathing place and a great number of people come together in summer season (Matsuda and Tamura, 1974). Usually about 50 guests stay at each inn in this season. The outbreak ratio of fire from kerosene stoves being in use reached 1.32% in time of the Tokachi-oki Earthquake of 1968 in Towada City, Aomori Prefecture. If this ratio was applied to Tokyo being hit by a big earthquake in winter, the number of fires breaking out all at once was thought to reach near 30,000 (Nakano and Matsuda, 1980).

Causative factors

Seismic waves generated by slippage of an earthquake fault attenuate during propagation. However, when they enter into a soft soil layer near the ground surface from a hard basal rock layer, they are amplified. This amplified seismic waves give damage to man-made structures on the ground surface. Soil engineering properties, thickness and distribution of soft soils are an essential physical causative factor of earthquake disaster.

Seismic waves often break soils themselves by triggering liquefaction or a slope collapse. In time of the Niigata Earthquake of 1964, liquefaction of loose sandy soils gave serious damage to reinforced concrete buildings, river banks, bridges, *etc.* (Tajime and Mochizuki, 1965). Since then, measures to counter liquefaction have been considered to be one of the important problems concerning earthquake damage. Damage to wooden houses of the Nihonkai-chubu Earthquake of 1983 was mostly due to liquefaction of fine sandy deposits composing sand dunes or being used for filled up materials (Matsuda, 1983 b). Rock fragments and debris supplied from a collapsed slope often hit a house or a car and crush people to death. With the exception of being drowned by a tsunami, most of casualties due to earthquakes for these ten years have been caused by collapse of slopes (Mochizuki, *et al.*, 1982).

Materials composing soils of urban area are not only Holocene or Pleistcene deposits but also artificial fills, especially in a reclaimed land and residential estate. Damage to wooden houses in the residential estate where has been newly developed in the hill land was conspicuous in the Miyagiken-oki Earthquake and damage concentrated on the cut-and-fill boundaries (Maruyama, 1980).

A social causative factor of earthquake disaster derives from man-made structures, human activities done through them (land use in a broad sense) and human beings themselves. As mentioned before, a social causative factor comprises the conditions of the subjects of damage. It, however, must be mentioned that functions of man-made structures are the subjects of damage, too.

First and second stages

Damage of the first stage of earthquake disaster is the direct damage to man-made structures and is brought about within several minutes after earthquake occurrence. Its direct inducements are seismic waves and liquefaction or collapse of slopes. An extent of the damage of the first stage is determined by the characteristics of soils and earthquake-proof abilities of man-made structures. Recently, much progress has been made in the study of earthquake resistant construction, construction techniques have been much improved and the Building Standards Act has been amended. Accordingly, earthquake-proof abilities of man-made structures have been much improved. As a result, a state of their damage has become to be different from the past. But it can be pointed out that new problems are born whenever an earthquake occurred.

Damage during the second stage is brought about from several minutes after earthquake occurrence to two or three weeks. It can be typified by two respects, the magnification of damage to man-made structures and the occurrence of casualties. Main inducements of the damage of the second stage are fire, flood and collapse of man-made structures.

The fire breaking out in Tokyo and Yokohama Cities due to the Great Kanto Earthquake brought about the catastrophs to these cities. Especially, in Tokyo, about 370,000 houses were lost in the fires and about 60,000 people were burnt to death. A fire breaking out from a collapsed house did not occur for these twenty years. However, 290 houses were burnt by the spreading fires from the oil tank in time of the Niigata earthquake of 1964. A large number of fires breaking out simultaneously are likely to be beyound the fire fighting abilities. The way how to prevent breaking out of many fires during an earthquake is most important measures to mitigate the damage of the second stage, especially damage to human beings.

The Niigata Earthquake of 1964 brought about typical flood disaster in Niigata City. The land below sea level has been formed along the lower reach of the Shinano River by land subsidence due to over withdrawal of ground water for producing natural gas. Because river banks were destroyed by liquefaction, river water rushed into the land below sea level and a small inlet leading to the sea was formed.

Land below high tide level covers an area of about 125 km^2 in Tokyo Lowland among which an area of about 68 km^2 is below mean sea level (Nakano and Matsuda, 1976). If the banks along the Rivers of Ara and Sumida are broken by liquefaction of loose sandy deltaic deposits, occurrence of serious damage is expected in Tokyo Lowland. A large number of population, production facilities, buildings, *etc.* certainly suffer from inundation. Especially, it is anxious that river water rushes into tunnels of an underground railway.

A large volume of debris supplied by land slide often dam up a river and make a lake. In such a disaster, not only the upper reaches are inundated but also the lower reach is apt to be swept away by a flash flood triggered by dam break. The big land slide due to the Zenkoji Earthquake of 1847 supplied so large volume of debris that 90 m high dam was formed and backwater reached some 40 km upstream of the river. After 19 days, this dam collapsed by itself and a broad area along the downstream was swept away (Usami, 1975). Such a type of earthquake disaster has been recorded in several parts of Japan.

Many people were crushed under the collapsed houses in time of the Mikawa Earthquake of 1945. The author reexamined the dead of this earthquake in the area of present-day Nishio City, Aichi Prefecture. As a result, two characteristics were emerged on the death ratio. One is that the death ratios of male residents in the twenties, thirties and fourties were 14–18%, but 27–34% in case of female residents. The other is that the death ratio of more than fifty year-old residents exceeded 35% irrespective of sex.

Occurrence of panic is a serious problem in a big city where a large number of unspecified people often come together to a narrow place such as a theater, a base ball stadium, a junction station during rush hours, *etc.* If a panic occurs, human beings may injure themselves. It is necessary to study how many, where and when persons are likely to gather and how they respond to an earthquake.

In addition, other causes to harm human beings must be mentioned, such as diffusion of poisonous gasses, chroline gas and ammonia gas, and radio-active contamination, *etc.*

Third and fourth stages

When various facilities sustaining daily life were broken or burnt, they lose their functions and daily life are hindered. For example, destruction of so-called life lines such as facilities for supplying gas, water and electricity causes residents inconvenience. Facilities for electricity supply will be restored within several days. However, if liquefaction gave damage to buried pipe lines for supplying gas or water, it takes many days to restore them. In case of the Niigata Earthquake of 1964, 45 days and 189 days were necessary to restore the damaged pipe lines for water and gas supply, respectively (Nakabayashi, 1978).

Insolvency due to destruction of factories and unemployment following it are possible to occur. If fires break out on a large scale in the densely inhabited metropolitan area, a large number of people may lose their home and may not be able to live there. Accordingly, they may be forced to leave a place of work.

Such indirect damage as caused by loss of functions of various facilities for sustaining normal conditions of daily life are classified into the third stage which are likely to continue or to occur for several months after an earthquake.

The fourth stage of disaster is various aftereffects of the first, second and third stages. It continues until daily life is completely restored. However, some kinds of damage such as loss of human life can not be restored and their effects torment a damaged family for a long time.

Very few studies are done on these problems. Researches on indirect damage were just begun after the Miyagiken-oki Earthquake. Approach to these problems is very difficult because city life depends upon many kinds of the complicated facilities.

3. Measures to Mitigate Earthquake Damage

Earthquake-resistant structure is the most common measure to mitigate earthquake damage. It, however, is one of the measures to an earthquake, because as mentioned in the previous chapter, the aspects of earthquake disaster transform as time goes by and it is necessary to take measures coping with stages and aspects of earthquake disaster. These measures are composed of (1) advance measures which are performed in daily life, (2) refuge and relief actions which are begun soon after occurrence of an earthquake and are continued for two or three days, (3) emergency measures being taken for several weeks and (4) resuscitation measures until daily life is restored.

The measures for direct damage during the first and second stages are to alleviate the hazard potential of existing properties and to ensure no growth of it. Construction of earthquake-resistant and fireproof city is important. In addition to these structural measures, non-structural ones such as regulatory controls on land use and on construction of buildings have to be adopted. The most pertinent strategy to these measures is seismic microzoning. It delineates an area into several homogenious zones on the basis of soil conditions which are the most important physical causative factor making the extent of earthquake damage different (Gaus and Sherif, 1972). These non-structural measures are apt to be kept out of acceptance because they restrict a private right. However, some non-structural measures have produced the intended effects, for example, designation of a fire zone has proceeded construction of fireproof buildings in a city and danger of fire has diminished. On the other hand, residential areas being composed of two-storied wooden houses are developed on the flood plains in Tokyo Metropolitan Area. Hazard potential is growing there and regulatory controls are necessary.

During the second and third stages, the enlargement of damage has to be prevented. Replenishment of facilities for fire fighting and flood defence is necessary. Moreover, the establishment of a refuge plan and the cooperation of neighborhood to counter fires are indispensable to diminish damage to human beings. Though one of the advance measures, daily preparedness for earthquake disaster through education or public relations is important. However, we see many places that may trap and kill people in an earthquake in the present-day city such as underground shopping complexes, multi-purpose buildings, densely built-up wooden houses, *etc.*

The purpose of measures being taken during the third and fourth stages of disaster are to sever long-pending influence of damage and diversify losses. A portable cylinder containing liquid propane gas was very useful as a substitute for the facilities for gas supply. The preparation of substitutive facilities is valid for severing long-pending influence of damage. To make public aid more effective, city planning after a catastrophic disaster must be prepared. If such planning has been done, restoration works can be efficiently performed and the normal daily life can be quickly restored. Replenishment of earthquake insurance is a valid measures for diversification of losses. If circumstances require, an issue of national bonds can be adopted for a measure to raise funds for giving assistance to damaged families in order to disperse losses. These measures, however, have not been considered in Japan.

Addition to the measures mentioned above, an earthquake warning on the basis of exact earthquake prediction may become a very powerful measure. If it became possible to issue an earthquake warning containing three basic factors, that is, when, where and what magnitude, a variety of measures can be prepared before a quake and the extent of damage must be largely diminished. On the other hand, there is the possibility that an earthquake warning provokes social disruption, stops production activities, *etc.* The special act for countering the coming large earthquake of the Suruga Bay was issued in 1978. On the basis of this act, an earthquake warning has been able to be issued. It, however, is now under review how the earthquake warning is to be announced and how individuals and public institutions should react to the warning.

As for an earthquake prediction, earthquake reduction possibly becomes a measure for an inducement of earthquake disaster. Earthquake reduction means to release the energy in small steps by bringing about many small earthquakes instead of one or a few big earthquakes. It, however, is difficult to make this measure practicable because of the deficiency of technical knowledge and its effectiveness is thought to be doubtful by seismologists.

Though the author enumerated various measures to counter an earthquake, he wishes to emphasize that a comprehensive measures is indispensable in order to mitigate earthquake damage and that it must be studied how the measures mentioned above have to be configurated to make them most effective. For accomplishing these purposes, damage prediction is needed. But its methodology has not been established. Though some results of damage prediction have been published, they are nothing but partial prediction of damage which is likely to occur during the first and second stages. Under existing circumstance of progress in study of measures to counter an major earthquake, the problem how to configulate measures is in the dark. The goal is far off.

The author wishes to dedicate this paper to Professor Takamasa Nakano in commemoration of his retirement from Tokyo Metropolitan University. He has always adviced and encouraged the author in the Department of Geography and has guided the research group for earthquake damage mitigation in the Center for Urban Studies in which the author holds the additional post.

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(* in Japanese, ** in Japanese with English abstract)