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Microzonation and disaster mitigation

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ABSTRACT: This paper presents four aspects of microzonation: estimation of ground shaking intensity, primary disaster, secondary disaster, and disaster mitigation strategy. The section about estimation of ground shaking intensity describes recent procedures, methods, and actual examples for modeling seismic sources, estimating earthquake ground shaking, and evaluating effects of local geology. The sections about primary and secondary disasters describe damage to structures (buildings, bridges, *etc.*), ground failures (landslides, rock falls, and liquefaction), fires following an earthquake, damage to lifelines (electric power, water, gas, *etc.*), environmental contamination, and social impacts. The last section introduces several examples of actual disaster mitigation strategy including a system for disaster response.

1 INTRODUCTION

The goal of microzonation is to mitigate the damage and loss due to earthquakes by the most efficient ways. In order to achieve this goal, it is a must to estimate the ground shaking intensity in an area we focus on and to predict the disaster pattern reflecting the specific characteristics of the area. Then, the most efficient strategy must be planned and executed for disaster mitigation. The estimation of the disaster pattern is sometimes called 'microzonation,' but recently it is called 'microzoning.' The microzonation introduced here includes all the aspects mentioned above.

Figure 1 shows the flow chart of microzonation. This paper presents the basic concept of the estimation of the ground shaking and some examples of the primary disaster, the secondary disaster, and the disaster mitigation strategy. In this paper, microzonation will be performed in an area such as a city (Ohsaki, 1972).

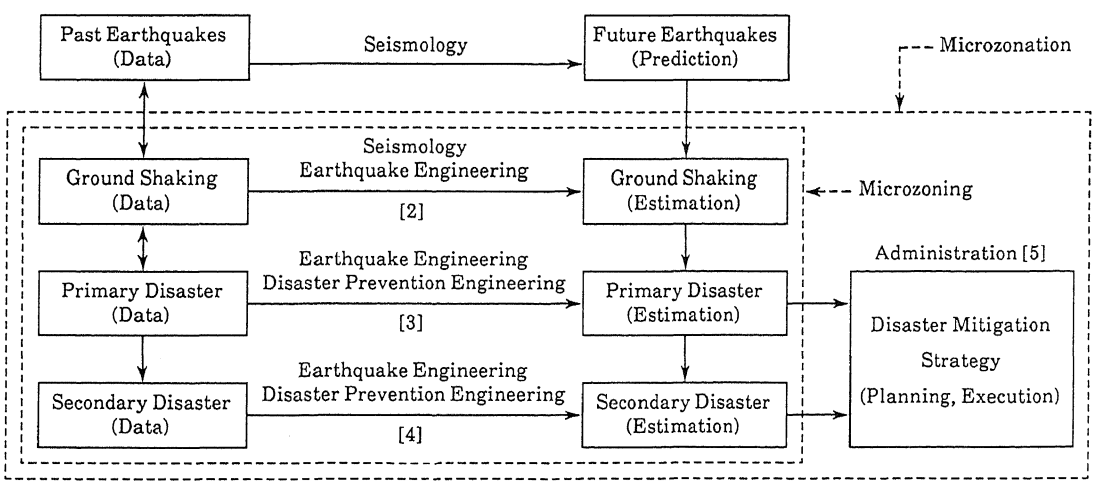

Figure 1. Flow chart of microzonation (The numbers in [ ] indicate the sections in this paper.)

2 ESTIMATION OF GROUND SHAKING INTENSITY

2.1 Modeling seismic sources

Seismic sources for microzonation in a planning area are modeled based on the information on a seismo-tectonic structure, highly active faults, and historical earthquakes in the region extending a few hundred kilometers around the planning area. Basically, there are two approaches to model seismic sources, depending on the quality and quantity of the information.

In a region where the causative link between the occurrence of significant earthquakes and particular faults is not clear, the input motion intensity is estimated by a statistical seismic hazard analysis based on the data of historical earthquakes. In this approach, the earthquakes are assumed to occur randomly in space and in time and the input motion intensity is calculated by attenuation formulas. The eastern U.S.A. may correspond to this case.

In a region where significant historical earthquakes are clearly associated with particular faults, such as the western U.S.A. as shown in Figure 2 (Bertero, 1991), the next significant earthquakes can be predicted, as shown in Figure 3 (U.S. Geological Survey, 1989), based on the knowledge of the past earthquakes and the long-term geological slip rate of the faults. Recently, assuming the future significant earthquakes, *i.e.*, 'scenario earthquakes,' earthquake planning scenario maps have been drawn in U.S.A. and in Japan (California Department of Conservation, Division of Mines and Geology, 1982a, 1982b, 1987; Urban Planning Bureau, Tokyo Metropolitan Government, 1984, 1987, 1991; Watabe *et al.*, 1991; Kobayashi, 1991). In this approach, attention must be paid to the fact that an earthquake different from the scenario earthquakes will result in a different pattern of damage.

Figure 2. Faults and significant historical earthquakes of California (Bertero, 1991)

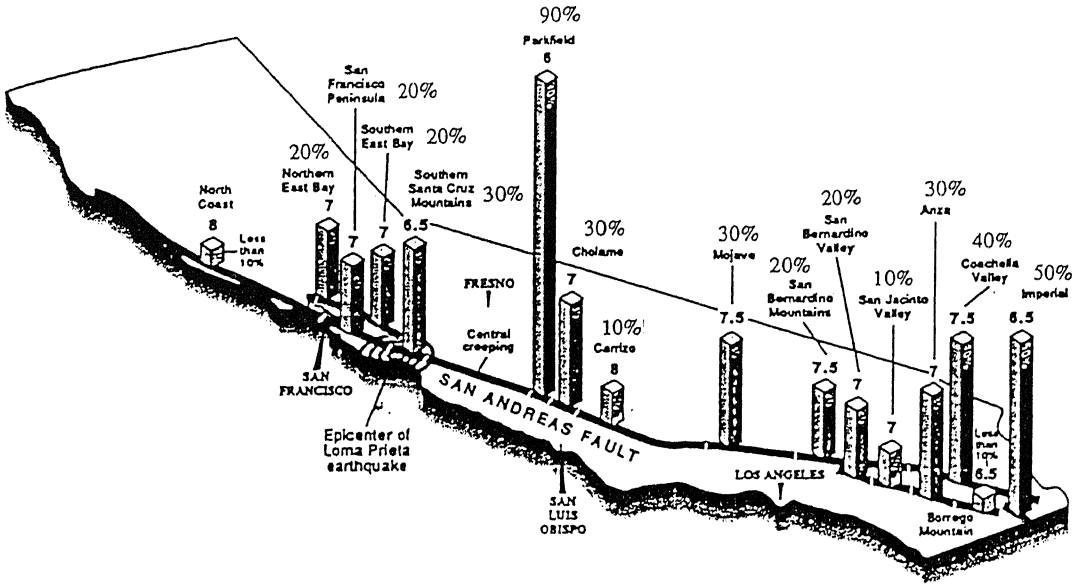

Figure 3. Probability of major earthquakes occurring between 1988 and 2018 along the San Andreas fault and its major branches (U.S. Geological Survey, 1989)

2.2 Estimation of ground shaking

It is well known that strong ground motions are influenced by the seismic source, the propagation path, and the local site conditions. In order to establish seismic zonation, strong ground motions must be estimated at a large number of sites with a wide range of soil conditions and at different distances from the seismic source.

2.2.1 Estimation of earthquake ground shaking in the planning area

At present, the following five approaches can be used to estimate site-dependent earthquake ground motions (Watabe *et al.*, 1992):

① Use of the data of damage patterns, ground shaking intensities, or strong-motion records at the sites for past significant earthquakes.
② Theoretical approach based on a fault model.
③ Semi-empirical approach based on a fault model.
④ Use of empirical attenuation formulas of ground shaking intensities, peak accelerations, peak velocities, or response spectra.
⑤ Use of alternative strong-motion records.

When there exist data of damage patterns, ground shaking intensities, or strong-motion records at the sites for past significant earthquakes, the first approach ① will be useful, because all the information is included in those data. Figure 4 shows the percentage of the collapsed wooden houses in Tokyo during the 1923 Kanto, Japan, earthquake (Imamura, 1925). The fact that the ground shaking intensity was especially high in alluvial areas gives us very important information on the effects of surface geology.

In case of lack of past data, when the detailed information on both the fault parameters and the velocity structure of the paths between the earthquake source and the sites can be specified, the second approach ② will be used. *However, in general, it is difficult to get the information* on both the source and the paths in the present state of knowledge.

When there are appropriate small-event records at the sites and information on fault parameters of the expected earthquake, the third approach ③ will be employed. This approach is useful for estimating the short-period motions, because the small-event motions include not only the local site effect and the inhomogeneous structures of the path but also the complex rupture mechanism of the source. However, it is generally difficult to get small-event records at a large number of sites in the planning area.

When the magnitude of the expected earthquake and the distances from the source to the sites are known, the fourth approach ④ will be employed. In this approach, the ground shaking is expressed by ground shaking intensities, peak accelerations, peak velocities, or response spectra. These values are usually estimated by empirical formulas based on regression analyses of many strong-motion records. Therefore, great attention must be paid to the range of applicability, which depends on the quality and quantity of the records. In spite of the limited applicability, this approach is widely used in microzonation because it is readily available for a large number of sites.

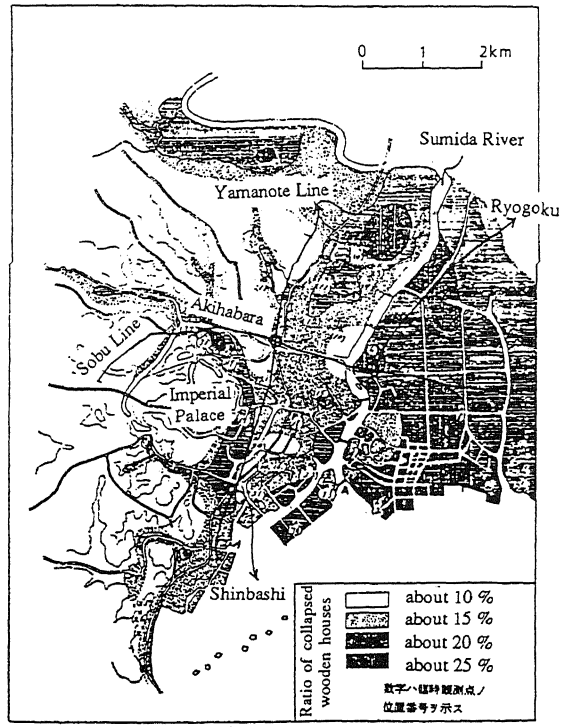

Figure 4. Map of the percentage of the collapsed wooden houses in Tokyo during the 1923 Kanto, Japan, earthquake (Imamura, 1925)

When there is no specific information on both the site and the seismic source, the fifth approach ⑤ will have to be employed. Nevertheless, this does not reflect well the characteristics of the source, the path, or the local site conditions.

When approaches ②, ④, or ⑤ are employed, the procedure to estimate the ground shaking at the sites usually consists of two steps. The first step is to estimate input earthquake motions at bedrock level under various sites in the planning area. The second step is to evaluate the site-dependent ground shaking at the surface by considering the amplification of the surface layers.

2.2.2 Estimation of effects of local geology

There are mainly three methods by which the effect of local site conditions on ground motions might be evaluated.

(1) Accumulation of data of ground shaking intensities or ground motion records for many past earthquakes

The effects of local site conditions can be extracted empirically by processing sufficient data regarding ground shaking intensities or ground motion records at a large number of sites with a wide range of soil conditions due to many past earthquakes. The ground shaking intensities can be also inferred from the damage pattern or the results from questionnaire survey on the situation during past earthquakes to inhabitants in the area (*e.g.*, Ohta, 1975). Furthermore, by comparison of the empirical results with the geological data at some sites, empirical relations between them can be derived. Nevertheless, the areas in which these data are available are limited.

(2) Use of analytical procedures

a. One-dimensional geological model

In many cases of microzonation for urbanized areas, the effects of the local soil conditions on the waves propagating from the bedrock to the surface are usually evaluated by a one-dimensional wave propagation theory (*e.g.*, Kanai, 1983) or a one-dimensional lumped mass model on the assumption that the geological structure below the site is modeled as horizontally infinite flat layers. This flat layer structure is assumed to vary site by site. This procedure has been widely used because only the multiple reflection phenomenon of S-waves with a resonant period of $T=4H/Vs$ (H and Vs indicate the thickness of the surface layer and the S-wave velocity, respectively) is the primary concern.

In this procedure, the S-wave velocity, the density, the thickness, the damping factor, and the nonlinear stress-strain relationship of each layer below the site are the principal parameters to characterize the local site conditions. The S-wave velocity, the density, and the nonlinear stress-strain relationship can be obtained by geophysical or geotechnical explorations. However, it is difficult to estimate the damping factor by these explorations. Recently, frequency-dependent characteristics of the damping factor for sediments have been studied from a borehole array observation.

b. Two- or three-dimensional geological model

Actual soft sediment layers are not infinitely flat but are laterally confined often in the form of sediment-filled basins. There have been many theoretical or numerical studies on responses of sediment-filled basins (*e.g.*, Bard & Bouchon, 1980; Kawase & Aki, 1989). According to these studies, the surface waves are generated at the edges of the basin and propagate horizontally in the basin.

Figure 5 shows the site response across downtown Santa Cruz City on the alluvial basin during an aftershock (magnitude of 2.9) of the 1989 Loma Prieta earthquake (U.S. Geological Survey, 1990). The effect of the laterally heterogeneous geological structure on the ground motion records is clearly observed. Several researchers have pointed out that this effect may be one of the reasons of the severe damage in Mexico City during the 1985 Michoacan, Mexico, earthquake (*e.g.*, Kawase & Aki, 1989). Therefore, two- or three-dimensional effects should be included in the future microzonation.

(3) Use of microtremors

Microtremors have been utilized as an effective tool to evaluate the dynamic behavior of geological structures and classify soil deposits because the observation of the microtremors is much easier than other exploration methods and it causes no environmental problems. The microtremors can be classified into two groups from the view point of source types. The first group uses microtremors generated by seismic sources and the second group uses those by other sources.

As for the seismic sources, the coda wave method has been developed. The coda waves are the sufficiently scattered waves with a small amplitude following the S-waves. This method is an effective way of finding a frequency-dependent site-specific amplification for the S-wave (Phillips & Aki, 1986).

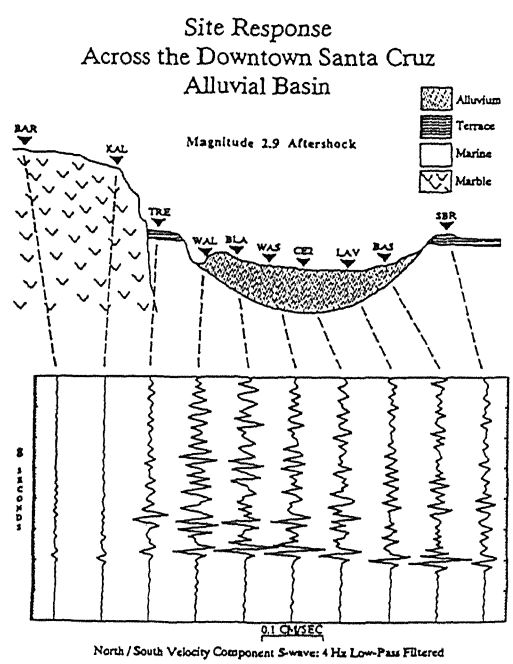

Figure 5. Site response across downtown Santa Cruz on the alluvial basin during an aftershock of M 2.9 of the 1989 Loma Prieta earthquake (U.S. Geological Survey, 1990)

As for other sources, the methods can be classified into two types: point-by-point measurement and array measurement. The first one consists in using the predominant period and/or the amplitude of the Fourier spectrum of the microtremor. Since Kanai & Tanaka (1961) first introduced this approach, there have been many studies using this method for microzonation (*e.g.*, Kagami *et al.*, 1986). For soil deposits with a large impedance contrast between the soft surface layer and the bedrock, the gross correlation of the predominant period and/or the amplitude of the microtremors with the *S*-wave velocity and thickness of soil deposits can be recognized (*e.g.*, Kobayashi *et al.*, 1986; Lermo *et al.*, 1988).

The second method consists in using the dispersion of the apparent phase velocities of the microtremors obtained by the array measurement. The velocity structure below the array site can be estimated by using the inverse method based on the assumption that the microtremors are mainly composed of surface waves (*e.g.*, Aki, 1957; Horike, 1985; Matsushima & Okada, 1990; Sato *et al.*, 1991). This approach is considered as one of the geophysical explorations. The estimated velocity structure is used in the analytical procedures.

The results obtained from the microtremor measurements, in which the strain level of the soil deposits is small, must be used carefully in estimating the behavior of the soil deposits at a large-strain level during major earthquakes, because the behavior of the soil deposits shows nonlinear property.

2.3 Example of microzonation in the Tokyo metropolitan area

2.3.1 Microzonation project in Tokyo

The latest microzonation project to assess damage due to a great earthquake which would affect the Tokyo metropolitan area was initiated in 1987 and completed in 1991 (Project MZ3). A similar microzonation study of the Tokyo metropolitan area had been carried out in the early 1980's (Project MZ2). The methodology used in these projects is explained here (Urban Planning Bureau, Tokyo Metropolitan Government, 1984, 1987, 1991; Watabe *et al.*, 1991).

2.3.2 Scenario earthquakes

In the Tokyo metropolitan area, two types of scenario earthquakes can be considered (Kobayashi, 1991).

Earthquakes of the first type are large-scale events with a source in the subduction zone between the Philippine Sea plate and the Eurasia Continental plate. From historical data and seismo-tectonics, the recurrence time of this type of earthquakes is inferred to be 100 to 200 years.

Earthquakes of the second type are events with a source in the inland zone. It is very difficult to predict the next earthquake of this type, but if it occurred just beneath the Tokyo metropolitan area, it might cause severe damage.

Examples of earthquakes which should be considered as the scenario earthquakes for the area are the 1923 Kanto earthquake with a magnitude of 7.9 and the 1855 Ansei Edo earthquake with a magnitude of 6.9 (see Figure 6).

Hereafter, the microzonation corresponding to the 1923 Kanto earthquake will be presented.

2.3.3 Classification of soil deposits and mapping

Geological features in the Tokyo metropolitan area are well investigated, especially in terms of seismic effect. There exist thick alluvial soil deposits with a maximum thickness of about 60 meters. Most of the surface layers are covered with so-called Kanto loam (volcanic ash) and the topography of Tokyo is essentially flat.

Quite fortunately, it is rather easy to obtain the soil boring data in the area, since many soil boring investigations have been conducted. Based on these several thousand boring data, geotechnical soil profiles of the entire Tokyo metropolitan area are classified into 22 typical patterns.

The Tokyo metropolitan area is then divided into square meshes of 500 m by 500 m, *i.e.*, 72 (north-south direction) by 67 (east-west direction) meshes as shown in Figure 7. The meshes are categorized into the 22 typical soil profiles indicated by alphabetic letters of A to V.

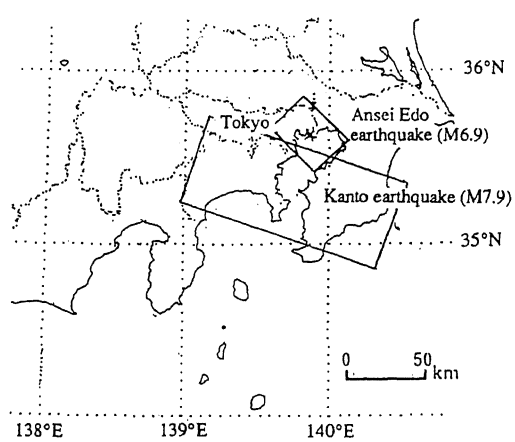

Figure 6. Example of the fault models of the subduction-zone earthquakes and the inland-zone earthquakes around Tokyo

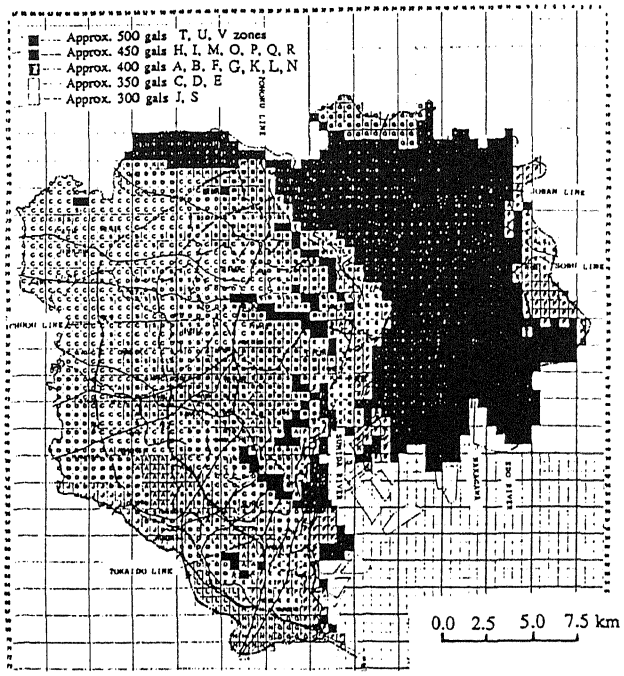

Figure 7. Microzonation of seismic intensity of the city of Tokyo (Watabe *et al.*, 1991)

2.3.4 Microzonation on seismic intensity in Tokyo

To determine the characteristics of earthquake motions at the ground surface in each mesh, the input motions at the bedrock were estimated by a hybrid method of approaches ①, ④, and ⑤ described in 2.2.1. Then, the ground motions at the surface were calculated for each mesh by the one-dimensional wave propagation theory with the shear moduli and the damping factors dependent on the shear strain. The results of the analysis are also illustrated in Figure 7, where the peak accelerations are classified into five ranges: 500, 450, 400, 350, and 300 Gals. It is interesting to compare this result with the distribution of the percentage of the collapsed wooden houses during the 1923 Kanto earthquake in Figure 4.

3 PRIMARY DISASTER

3.1 Structural damage

3.1.1 Buildings

From past experiences of destructive earthquakes, buildings, especially engineered buildings, have become more earthquake resistant. Still, several noticeable damage has been observed during recent earthquakes.

The 1985 Michoacan, Mexico, earthquake caused serious damage to buildings in a part of Mexico City. A number of studies pointed out that the local soil conditions and the basin structure of Mexico City had a great influence on the damage. Figure 8 depicts one of the interpretations in which the area of a large amplification of seismic waves agrees with that of severe structural damage (Singh *et al.*, 1988). The experience in Mexico City confirmed the old lesson about the correlation between the local soil condition and the damage to structures and showed that the local soil effect could be much greater than expected.

Another thing to be noted is that indigenous and traditional buildings often sustain damage. Adobe and unreinforced masonry buildings are often vulnerable even to moderate earthquakes. Retrofit strengthening of such buildings is one of the major issues to be considered. In Japan, wood-frame houses are traditional and still most common and they are more ductile than masonry buildings. Recently, a shaking table test was conducted to destroy a full-scale wood-frame house and the test confirmed its strength.

Reconnaissance reports often state that some of the damage to the buildings results from poor design or construction. Such a type of damage should be firstly avoided.

3.1.2 Bridge structures

The damage to the Cypress Viaduct and the San Francisco-Oakland Bay bridge in the 1989 Loma Prieta earthquake still carries a great impression among engineers. The damage to the Cypress Viaduct has a clear correlation with the ground condition as shown in Figure 9

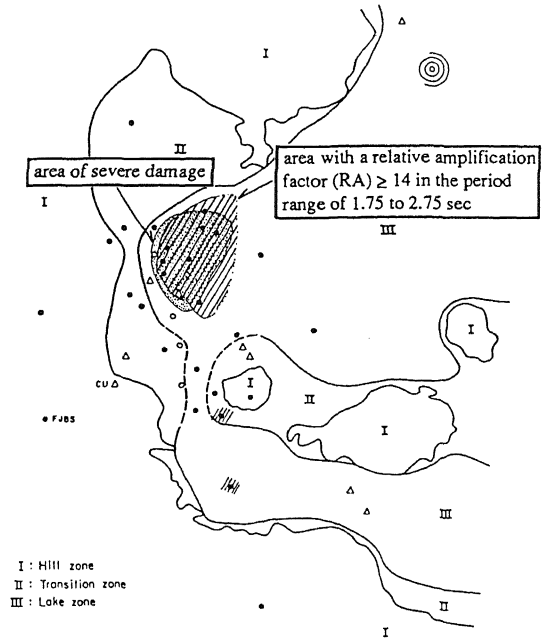

Figure 8. Area of severe damage during the 1985 Michoacan, Mexico, earthquake and area with a relative amplification factor (RA) over 14 (after Singh *et al.*, 1988)

(EERI, 1990). At the time of the earthquake, the California Department of Transportation was conducting and executing the seismic retrofit program to reinforce the bridges designed and constructed before the mid 1970's

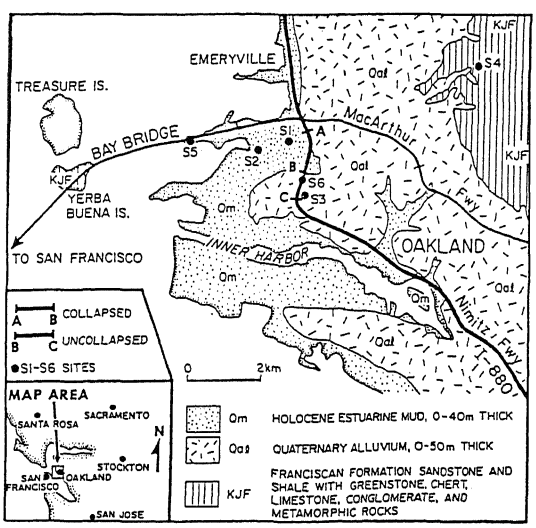

Figure 9. Relation between the collapsed section of the Cypress Viaduct (A to B), due to the 1989 Loma Prieta earthquake, and the subsurface condition in Oakland, California (EERI, 1990)

(Roberts, 1991) and, thus, it was unfortunate that the earthquake had occurred before the program was completed.

After an earthquake, highway networks play an important role of transporting rescue teams and retrofit materials. In light of this, the damage to the bridge structures should be minimized.

3.1.3 Other structures

San Fernando Dams suffered severe damage from the 1971 San Fernando earthquake primarily due to liquefaction. Fortunately, the water from the dams was not released and the worst result was somehow avoided. The collapse of a large dam may result in a loss of thousands of human lives. In addition, it impedes the water and electric power supply for years.

Damage to other structures such as airports, harbors, and industrial facilities also have direct and indirect impacts on modern society.

3.2 Ground failure

3.2.1 Landslides and rock falls

An earthquake which struck Peru in 1970 caused a massive rock avalanche and killed over 18,000 people. Although such a catastrophe is a rare event, landslides and rock falls often cut roads and railroads in mountainous regions and isolate damaged towns from rescue and retrofit as was observed in the 1989 Loma Prieta and the 1992 Erzincan, Turkey, earthquakes. In the case of the Erzincan earthquake, roads were reopened for service soon after the earthquake since they were reportedly well prepared for seasonal avalanches and rock falls. This suggests that it is important to estimate the landslide and rock-fall susceptibility and to use the results for preparedness. A state-of-the-art report on the earthquake-triggered landslides was documented by Hansen & Franks (1991). Figure 10 shows an example of landslide susceptibility map (Wieczorek *et al.*, 1985; Hansen & Franks, 1991).

3.2.2 Liquefaction

Liquefaction and liquefaction-induced damage are reported at various degrees in recent earthquakes. Since many cities lie on a lowland near the sea, lakes, or rivers, liquefaction is inevitable when an earthquake hits such areas.

A typical example of liquefaction-induced damage is the failure of buried pipes. In many cases, pipe failures occur in the liquefied area. Buildings, houses, roads, embankments, and port facilities also often sustain damage induced by liquefaction. Some examples were seen in the

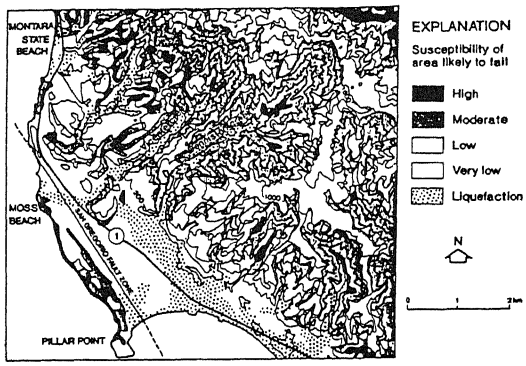

Figure 10. Slope stability map (Wieczorek *et al.*, 1985; Hansen & Franks, 1991)

1964 Niigata, the 1989 Loma Prieta, and the 1990 Luzon earthquakes.

This kind of damage is primarily due to the lateral spread and the differential settlement induced by liquefaction. Although significant efforts have been made in modeling and prediction of ground deformations resulting from liquefaction, further studies are necessary to predict accurately the amount of ground deformations.

Liquefaction-susceptibility maps which take into account historic, geologic and/or geotechnical criteria have been compiled and used in various areas (Youd, 1991). Figure 11 is a liquefaction potential map in the Tokyo lowland, where all of the above criteria are considered (Kusano *et al*, 1990). To mitigate the liquefaction-induced damage to structures, improvement of soil or application of methods to protect structures against liquefaction is necessary in the area with a high liquefaction potential.

4 SECONDARY DISASTER

4.1 Fire following an earthquake

There was a major fire in the Marina district following the 1989 Loma Prieta earthquake. Gas leaking from appliances in the collapsed structures reportedly contributed to the fire. Neither the Auxiliary Water Supply System (AWSS) nor the regular water system were available because of the loss of pressure due to pipe failures. Fortunately, the location of the fire was not too far from the bay which enabled the use of a fire boat. The fire in the Marina district confirmed the importance of the redundancy of lifeline systems.

The fire following the 1923 Kanto earthquake burned down 50 % of old Tokyo City and 80 % of Yokohama City. The traditional wooden structures in Japan made it difficult to control the fire. As a result, more than 100,000 lives were estimated to be lost by the fire. Therefore, the fire that may follow an earthquake is of major concern in Tokyo. The Tokyo Metropolitan Government simulated

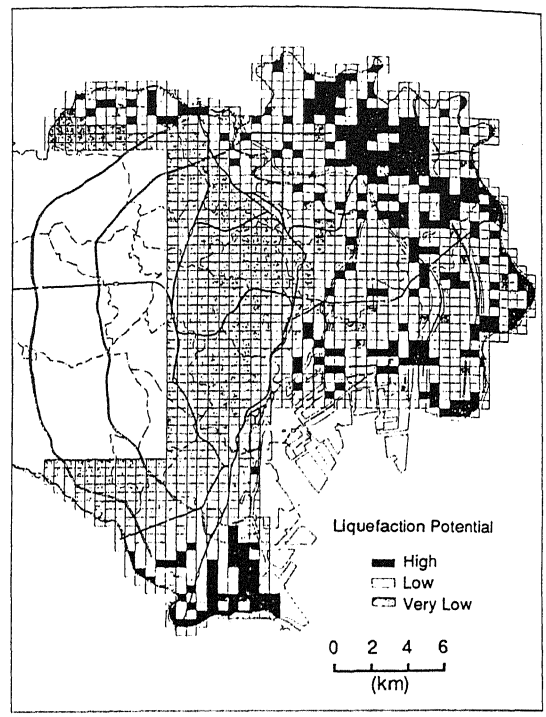

Figure 11. Liquefaction potential map in Tokyo lowland (after Kusano *et al.*, 1990)

the spreading of fires which would be caused by the Kanto earthquake if it occurred today as well as the resulting loss (Urban Planning Bureau, Tokyo Metropolitan Government, 1991). The results are used for the fireproof planning of the area. Besides, a remote controlled shut-off system of gas lines is adopted for blocks or sub-blocks of service areas in case of a substantial earthquake. In addition, gas meters with a microprocessor have been installed to each customer for an automatic stop of gas supply (Yoshikawa, 1991).

4.2 Damage to lifelines

Since the 1971 San Fernando earthquake, damage to lifeline systems such as electric power supply, water supply, gas supply, sewage, transportation, and telecommunication systems has attracted earthquake engineers' attention. This is related to the fact that the daily activity relies more and more on these lifeline systems. The damage to lifeline systems does not necessarily threaten public safety directly but lowers the emergency response and causes significant inconvenience in the daily activity.

Figure 12 shows that the most damage to the regular water system pipelines due to the 1989 Loma Prieta earthquake occurred in the area with a poor ground condition (EERI, 1990). Even though the pipe failure in such an area is predictable, it is difficult to upgrade existing

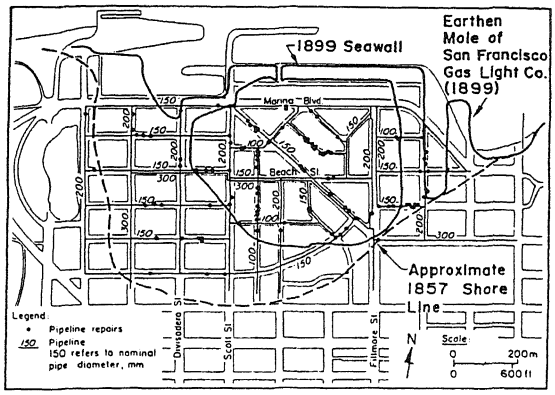

Figure 12. Pipeline repairs in water supply system in the Marina district after the 1989 Loma Prieta earthquake (EERI, 1990)

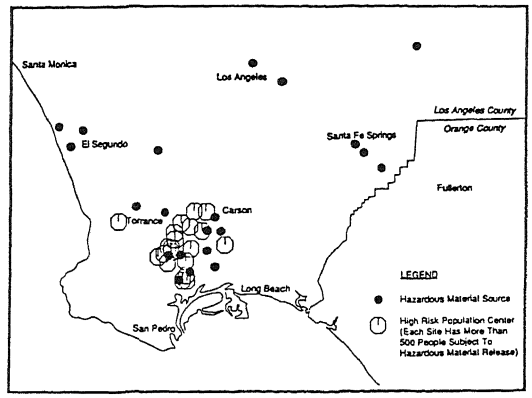

Figure 14. Population centers with high risk potential from hazardous materials release during a hypothetical earthquake (Seligson *et al.*, 1991)

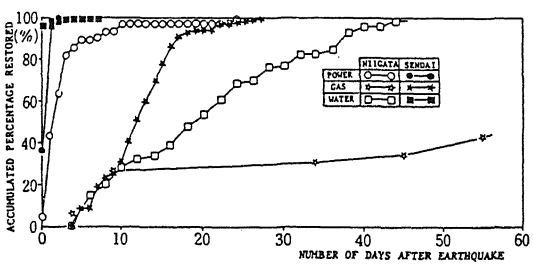

Figure 13. Comparisons of restoration process of lifelines after the 1964 Niigata and 1978 Miyagi-Ken-Oki earthquakes (Katayama, 1991)

pipelines in a short time. Because lifeline systems contain various subsurface structures and also because they are distributed over a wide area with different ground conditions, damage to the existing lifeline systems cannot be prevented. Therefore, redundancies and backup systems should be added to the systems if necessary.

Another important feature of lifeline systems is their functional interaction, which was clearly observed in earthquake damaged areas (Nojima *et al.*, 1991). In general, malfunction of electric power significantly reduces the serviceability of other systems. Furthermore, the recovery of water and gas systems requires more time than that of electric power system does (Figure 13, Katayama, 1991), partially because it needs electric power. Such an interaction should be considered in the disaster estimation and mitigation planning.

4.3 Environmental contamination

One of the major issues related to the earthquake disaster is the environmental contamination caused by the release of hazardous materials. For example, several crude oil pipelines pass within and close to the New Madrid seismic zone in the central Mississippi Valley. Damage to these pipelines would result in the contamination of the Mississippi River and underground water (Ariman *et al.*, 1990).

In an industrialized and densely populated area, the release of hazardous chemicals such as chlorine and ammonia would be a direct threat to residents in the immediate and surrounding communities (Figure 14, Seligson *et al.*, 1991).

4.4 Social impacts

An earthquake causes not only physical damage but also significant short- and long-term social and economic damage.

Some of the items which are considered in the microzonation project conducted by Tokyo Metropolitan Government are as follows: ① lack of food, water, and other necessities of life, ② loss of homes, ③ increase in unemployment, ④ lowering of medical service quality, and ⑤ deterioration of education due to damage to schools or use of schools as refuges (Urban Planning Bureau, Tokyo Metropolitan Government, 1991).

5 DISASTER MITIGATION STRATEGY

Since the specific characteristics of the area are reflected in the disaster pattern, they must be well taken into account in planning and executing the strategy to mitigate disasters.

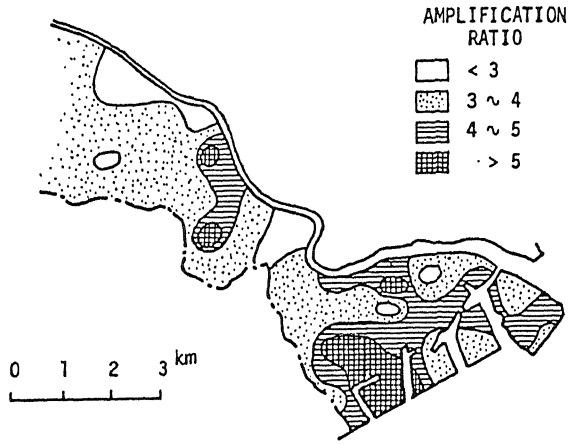

Figure 15. Microzonation in Kawasaki City based on ground-bedrock amplification ratios (Kobayashi & Kagami, 1972)

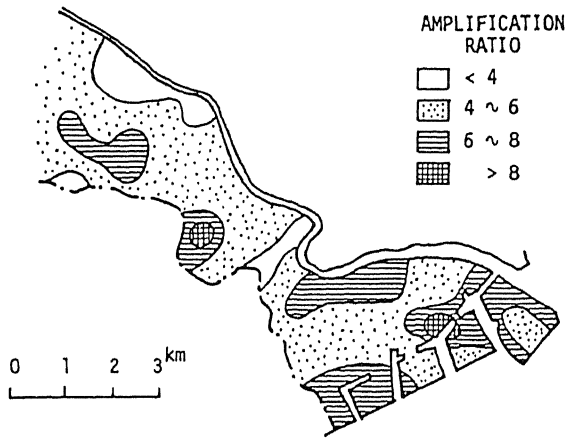

Figure 16. Microzonation in Kawasaki City based on structure-bedrock amplification ratios (Kobayashi & Kagami, 1972)

5.1 Earthquake resistance and fireproofness of the area

For the earthquake resistance of the area, each structure must resist strong earthquake motions and the ground must be stable during the motions to support the structures.

Figures 15 and 16 show examples of the microzonation in Kawasaki City (Kobayashi & Kagami, 1972), which is the neighboring city southwest of Tokyo. Figure 15 shows the distribution of ratios of the peak acceleration at the ground surface to the peak acceleration of the incident wave at the bedrock. The bedrock in this city is encountered at the depth of 30 to 150 meters from the ground surface. The frequency characteristics of the incident waves at the bedrock are estimated from the actual records of minor earthquakes observed at the ground surface. Furthermore, the distribution of ratios of the peak acceleration acting on structures with various fundamental periods to the peak acceleration at the bedrock is computed. Figure 16 shows an example for structures with a fundamental period of 0.3 second.

For fireproofing of the area, the prevention of fire spreading is needed as well as the fireproofing of each structure. The following strategy is recommended:

① Consolidation of firebreaks such as roads, parks, and rivers. The firebreaks have the function of evacuation routes, too.
② Fireproofing of structures along the firebreaks.
③ Fireproofing of structures inside risky sub-areas surrounded by the firebreaks.

Figure 17 shows a conceptual disaster-proof living zone in Tokyo illustrated based on the recommendation mentioned above.

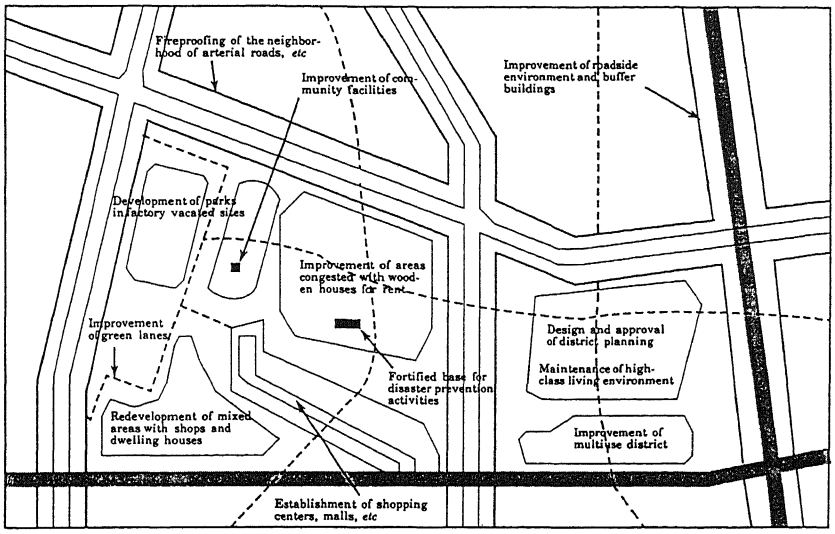

Figure 17. Conceptual disaster-proof living zone

5.2 System for disaster response

Several local governments have established a system for a disaster response (*e.g.*, Moore, 1989; State of California, Governor's Office of Emergency Service, 1989; Tokyo Metropolitan Government, 1991).

The system in Santa Cruz City, California, which actually functioned after the 1989 Loma Prieta earthquake, is introduced here (Kameda *et al.*, 1991). Santa Cruz City adopts the Incident Command System (ICS) as local government's action against disasters. The administration action was executed following the ICS just after the Loma Prieta earthquake.

This section describes the total system against disasters in U.S.A. and the frame of the ICS.

5.2.1 Disaster response system of federal, state, and local governments

(1) Federal government

The laws of U.S.A. prescribe that the federal government gives a financial support to the state government when the President proclaims a 'major disaster' for a large-scale disaster which spreads beyond one state. However, the state government is primarily responsible for the disaster response.

Table 1 shows the proclamation of the existence of a disaster in California. The Federal Emergency Management Agency (FEMA) is a disaster-response system of the federal government. The Disaster Relief Act of 1974 states that the FEMA is responsible for the operation of advice, guidance, and support to the state or local governments.

(2) State government

In California, the California Office of Emergency Service (OES) is mainly in charge of the disaster response. The OES is under immediate control of the state governor. The OES, located in the suburbs of Sacramento City, keeps in touch with the FEMA and the local governments. The Natural Disaster Assistance Act (NDAA) of the State of California clarifies the responsibility of the state governor accompanying the proclamation of the 'local emergency' and prescribes the operation of the temporary expedients by the administration order. Based on the proclamation of the local emergency, the governors of counties, cities, and special wards can request the supports to the state or federal governments prescribed in the NDAA.

(3) Local governments

In Santa Cruz City, the Incident Command System (ICS) is adopted for the local emergency. The ICS is planned by the California Office of Emergency Service and was operated efficiently after the Loma Prieta earthquake. It is adopted in San Francisco City, too, and was well operated in the disaster fields of Marina and Oceanview districts, after command posts were set up in the field. In Oakland City, where the Cypress Viaduct collapsed, as nobody was familiar with the operation of the ICS, the California Department of Forestry was asked and a command post in the field was reportedly established in a different form on the third day after the earthquake. In Los Angeles, after the 1987 Whitter Narrows earthquake, the Emergency Operation Organization was set up 20 minutes after the earthquake and was in charge of the disaster response. The system for the disaster response varies in each county

Table 1. Proclamation of existence of a disaster in California, U.S.A.

Government	Proclamation	Law	Organization
Federal	Major Disaster	Disaster Relief Act	Federal Emergency Management Agency
State	State Emergency	Natural Disaster Assistance Act	California Office of Emergency Service
Local	Local Emergency	Ordinance	Not Specified

or city in the State of California and seems to be entrusted to the local governments.

5.2.2 Incident Command System

The Incident Command System (ICS) is planned for an efficient and rapid response to emergencies such as natural disasters, riots, accidents, and military crises. It was motivated by a large-scale mountain fire in South California in 1970 and is adopted in many counties, cities, and federal agencies in California now. The ICS is an organization extending across many different agencies, such as the police, the fire fighting agencies, the first aid organizations, the Red Cross, and the public projects, aiming at their cooperation to mitigate the disaster. After an emergency takes place, the ICS is organized crossing different daily functions and personnel of the relevant agencies and a command post is set up to deal with the emergency.

The tasks of the ICS are as follows: ① to define the tasks of the members of the ICS in order to clarify their responsibility, ② to make manuals of each task and check lists of necessary materials for an efficient operation of the system and efficient use of the resources, and ③ to unify the command systems for precise and rapid transmission of the information.

The formation of the ICS varies according to the kind and the size of the emergency. It changes flexibly according to the situation of the emergency, too. Table 2 summarizes the tasks each relevant agency must perform.

The organization chart of the ICS is shown in Figure 18. The ICS consists of five main sections as follows.

(1) Incident Commander and Officers

The Incident Commander is authorized to manage all the actions for the emergency response, such as assigning the staff and the materials, and responsible for all the actions.

The Public Information Officer is in charge of collecting all information and providing it to the media.

The Liaison Officer is in charge of organizing the cooperation between the representatives of the assisting agencies. One representative is selected from each agency and authorized to decide how the agency will cooperate.

(2) Operations Section

The Operation Section is in charge of executing the Incident Action Plan. It demands and assigns the staff and the materials and it also directs and supervises the action in the disaster field. Furthermore, it can change the Action Plan according to the situation and must report to the Incident Commander.

(3) Planning/Intelligence Section

The Planning/Intelligence Section collects all information

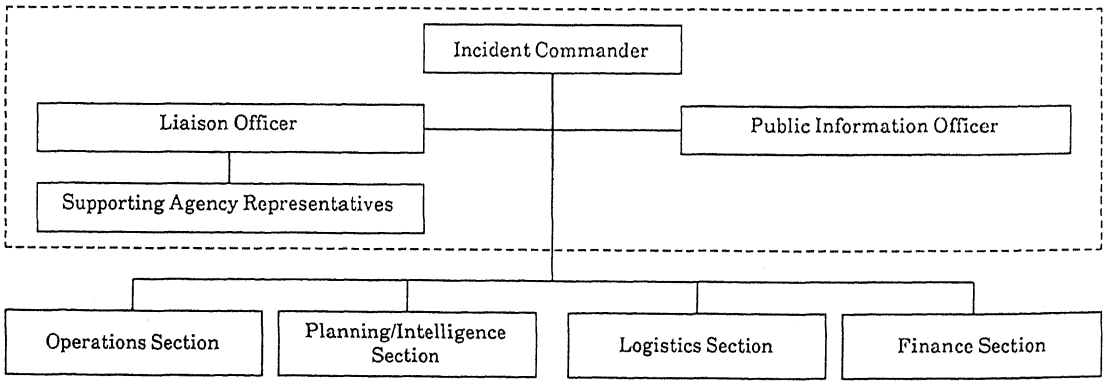

Figure 18. Incident Command System (ICS) in California, U.S.A.

Table 2. Responsibility matrix in California, U.S.A.

	Notification	Identification, Analysis, & Technical Assistance	Coordination	Law Enforcement & Traffic Control	Rescue, Suppression, & Containment	Cleanup & Disposal	Evacuation & Area Control	Emergency Medical	Public Health & Sanitation	Education & Public Information	Recovery	Training & Exercises	Natural Resources Protection & Damage Assessment	Conducts Criminal & Civil Investigations
FEDERAL AGENCIES														
Federal Emergency Management Agency			X				X					X		
U.S. Coast Guard	X	X	X	X	X	X				X	X	X		
EPA	X	X	X			X						X		
Others		X							X			X		
STATE AGENCIES														
Office of Emergency Services	X		X							X	X	X		
California Highway Patrol	X	X	X	X			X			X		X		X
State Water Resources Control Board		X	X			X			X	X	X	X	X	X
Department of Fish & Game		X	X	X			X					X	X	X
Department of Conservation (Oil & Gas)		X	X		X	X						X		
State Lands Commission		X	X		X	X						X	X	
Department of Transportation		X				X	X				X	X		
Department of Health Services		X				X	X	X	X	X		X		
Department of Food & Agriculture		X				X			X		X	X		
Department of Industrial Relations		X						X	X		X	X		X
Department of Water Resources		X			X				X			X	X	
Air Resources Board		X							X			X		
Department of Forestry					X	X						X	X	
Department of Parks & Recreation						X	X					X	X	
Military Department				X	X		X	X				X		
Public Utilities Commission		X										X		
Attorney General		X									X		X	
Department of General Services				X			X							
Emergency Medical Services Authority								X						
Department of Social Services			X								X			
LOCAL AGENCIES														
Emergency Services Coordinator	X		X							X	X	X		
Fire Service		X	X		X		X					X		
Law Enforcement		X	X	X			X					X		
County Health Officer		X				X		X	X	X	X	X		
Agriculture Commissioner		X				X			X	X	X	X		
Air Pollution Control Officer		X							X			X		
Public Works		X			X	X			X			X		
Supervisors/Councilmen										X	X	X		
Schools							X	X				X		
Hospitals		X						X				X		
NON-GOVERNMENT														
Private Facility Owners	X	X	X			X	X	X		X	X	X		
Industry Co-Ops		X				X	X					X		
Private Hazardous Waste Services		X				X	X					X		
American National Red Cross								X	X		X	X		
Salvation Army								X	X		X	X		
Civil Air Patrol								X				X		
Hospitals, Ambulances		X							X			X		

on the damage, the retrofit, the weather conditions, and the range of action, predicts the future conditions, and then reports to the Incident Commander. It is in charge of making the Action Plan.

(4) Logistics Section

The Logistics Section is in charge of supplying all resources of persons and materials necessary for the disaster response. It calls up persons in need and orders and provides machines, vehicles, fuel, medical materials, bedclothes, and food.

(5) Finance Section

The Finance Section is in charge of preparing the documents on the cost of compensation for human beings and damaged materials and of the disaster response in order to ask for the financial supports to the government such as disaster compensation to the federal government.

6 CONCLUDING REMARKS

Microzonation is still in progress now. There remains a lot of work to be performed especially in executing the disaster mitigation strategy depending on the specific characteristics of each area. Besides, the strategy should evolve because society itself changes day by day.

Although the individual technology for the earthquake resistant structures has been almost established at present, it is important for society as a whole, especially the administration, to continue the effort to achieve the goal of microzonation.

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