URBANIZATION AND URBAN DISASTER PREVENTION

by

Tomomitsu FUJII[1)]

ABSTRACT

In Japan, urbanization has been accompanied by the appearance of increasingly advanced and complex social systems. And disasters caused by earthquakes, intensive rainfall and other natural forces that caused property damage and human casualties have evolved into quite complex urban disasters that bring secondary disasters in addition to the primary damage.

This report reexamines past urban earthquake and flood disasters to study changes and features in urban disasters accompanied by urbanization. The report also presents an outline of urban disaster prevention measures that must be promoted to prevent urban disasters and minimize their effects to increase the safety of urban areas.

KEY WORDS: Urbanization
Urban Disaster
Earthquake, Flood
Disaster Prevention Measure

1. INTRODUCTION

The rapid industrialization and urbanization since the beginning of high-speed economic growth in 1955 has concentrated the population in the three huge metropolitan regions around Tokyo, Nagoya, and Osaka. Urbanization has been accompanied by the appearance of advanced social systems and facilities, and by their increasing close interrelationships.

Once social systems and facilities are destroyed or disrupted by natural disasters, not only does the system itself fail, ripple effects cause chain reactions triggering new forms of disasters that did not seen in the past. In this way, disasters that occur in urban area have been transformed and evolved as a by-product of urbanization.

Focusing on natural disasters accompanied by urbanization, this report reexamines past earthquake and flood disasters to study the changes, features and lessons of urban disasters. The report also includes an outline of urban disaster prevention measures against earthquakes and intense rainfalls that must be promoted to prevent urban disasters and minimize their effects considering recent social trends including internationalization, information technology revolution, and aging of society.

2. URBAN DISASTER

2.1 Urbanization

Figure 1 shows changing numbers of human casualties due to past natural disasters. Although continuous implementations of disaster prevention

---

1) Director-general, Public Works Research Institute, Ministry of Construction
1 Asahi, Tsukuba, Ibaraki 3050804 Japan

measures has been rewarded with a steady fall in the number of casualties, continued concentration of properties and population in urban regions increased their susceptibility against natural disasters. And the 1995 Hyogo-ken Nanbu Earthquake caused the most serious disaster in the recent history of Japan.

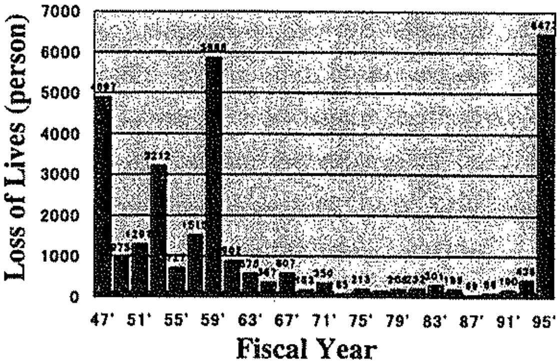

Fig. 1 Human Casualties due to Natural Disasters

In urban regions, new social systems and facilities have appeared and spread to support the socio-economic activities (**Figure 2**). Many of these social systems and facilities have never been exposed to a large-scale disaster and have the potential to cause unpredictable forms of damage and complex chain-reactions of secondary disasters.

Background	Facilities and Functions	Years 30' 50' 70' 90'
Rising Price of Land, Concentration of Population/ Functions	Multistory Buildings	
	Underground Arcade	
	Reclaimed Land	
	Chemical Plant	
Rapid/ Mass Transportation System	Highway System	
	Subway System	
Information Oriented	Online Computer System	
Improvement of Living Condition	Water Supply/ Sewage	
	Convenience Store	
Major Earthquakes		Kanto EQ Niigata EQ Hyogo-ken Nanbu EQ

Fig. 2 Appearance of New Social Systems and Facilities

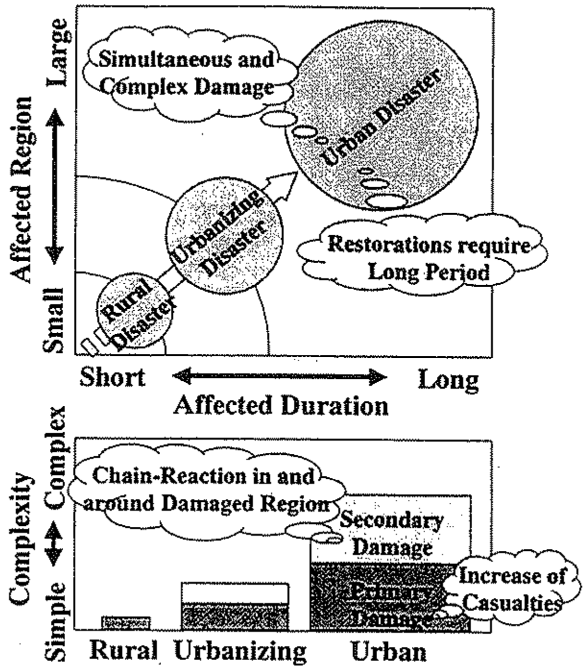

Fig. 3 Evolution and Classification of Natural Disasters (schematic)

2.2 Recent urban disasters

(1) Classification of natural disasters

Figure 3 schematically presents that natural disasters have evolved by focussing on their "effected duration", "effected region" and "complexity of influence". This report categorizes natural disasters as a "rural disaster", an "urbanizing disaster" and an "urban disaster".

1) Rural disaster:

This type means a classical disaster developed in a region where urbanization has not initiated and neither infrastructures nor disaster prevention facilities have been provided. Most of the effects caused are primary damage such as property damages and human casualties. Effected duration and region are limited.

2) Urbanizing disaster:

This type of disaster occurs in rapidly urbanizing regions where population has been increasing but infrastructures and disaster prevention facilities have not been sufficiently provided. Rapid urbanization in developing countries has increased the frequency of this type of disasters around the world. Although effects caused by the disaster are mainly primary damages, effected duration and region are larger than rural disasters.

3) Urban disaster:

This type of disaster occurs in highly urbanized metropolises and regional core cities. Where the infrastructures are not sufficiently safe, extremely severe primary damage occur, and cause disruption of urban functions as the secondary damage. Because urban functions are highly interdependent and complexes, it is difficult to predict the relationship between the external natural force and the form of damages. Influence of the disaster spread over wide area, and disaster restoration requires long period comparing with previous types of disasters.

(2) Recent urban disasters in Japan

1) Niigata Earthquake (1964/6/16, M 7.5)

Photo. 1 Failure of Highway Bridge due to Ground Liquefaction

Earthquake disaster developed in the urbanizing Niigata Prefecture caused approximately 470 of casualties, 1,960 of totally destroyed buildings, and failures of highway bridges. Ground liquefaction that occurred over wide areas of soft soil deposit was an unpredictable phenomenon that have never experienced before. And it was pointed out that a ground cave-in and a lateral ground flow induced by the ground liquefaction are likely to enlarge human and property damages. Because most of core cities are placed on soft ground soil deposit in Japan, this disaster experience enforced countermeasures to prevent the ground liquefaction.

2) Miyagi-ken-oki Earthquake (1978/6/12, M 7.4)

Earthquake disaster developed in an urbanized regional core city of Sendai in Miyagi Prefecture caused appropriately 1,350 casualties and severe damages on lifeline facilities for electric power/ gas/ water supply and sewerage. Damage of buildings in newly prepared residential districts and human casualties due to the collapse of block walls were never experienced in previous disasters. Because damages of lifelines influenced daily lives and socio-economic activities for several weeks after the earthquake, upgrading the seismic safety of lifelines was pointed out to be important.

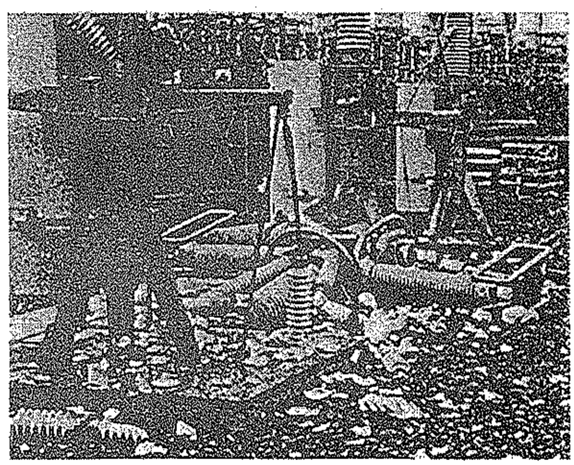

Photo. 2 Damage of Power Plant

3) Nihonkai-Chubu Earthquake (1983/5/26, M 7.7)

Earthquake disaster developed in the urbanized regional core city of Noshiro in Akita Prefecture caused approximately 270 casualties, severe damage on transportation systems including highways and railroads, and lifeline facilities. The fact that about 75% of the casualties were the direct result of Tsunami triggered by the earthquake served as a sharp reminder of the importance of prompt evacuation activities and provision of information to residents following an earthquake. Transportation systems and lifelines were seriously disrupted by damages to embankments and buried pipelines. Because it takes a long time to find out and repair damage of underground facilities, it was pointed out that seismic strengthening of underground facilities is important.

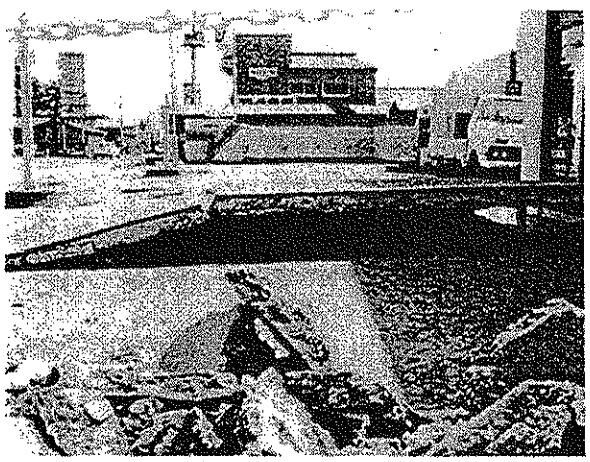

Photo. 3 Up-lift of Underground Gas Storage Tank

4) Intensive Rainfall in Nagasaki Pref. (1982/7/23, 187 mm/ hour)

Flood disaster developed in the urbanized regional core city of Nagasaki caused slope failures and sediment flows around residential districts, and disruptions of highway network. Approximately 1,100 casualties and 600 totally collapsed buildings were developed. Because the City of Nagasaki is located in a peninsula surrounded by the sea, disruptions of highway network temporarily isolated the city and obstructed rescue activities. Even after the flood waters had receded, mountains of debris and abandoned automobiles blocked the streets so that it took a week just to re-open the trunk roads. The disaster was a sharp reminder of the importance to secure the highway network redundancy, and to re-open trunk road promptly after flood disasters.

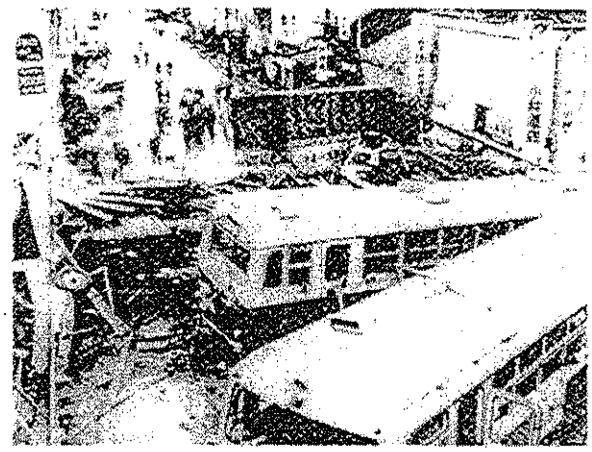

Photo. 4 Closure of Trunk Road due to Flood Debris

5) Hyogo-ken Nanbu Earthquake (1995/1/17, M 7.2)

Hyogo-ken Nanbu Earthquake was one of the largest earthquake disaster developed in highly urbanized region in Japan. Extensive ground motion that was not formerly anticipated caused approximately 5,500 fatalities, 93,000 totally collapsed buildings, catastrophic damage of transportation systems and lifelines, and damage of other industrial facilities. Because disruptions of arterial highways caused serious and long lasting influence on nationwide transportation activities, importance to provide alternate arterial transportation routes was pointed out. The importance of wide-area improvements to urban districts was also illustrated by the spread of uncontrollable fires that swept through districts with high concentrations of wooden dwellings. Damage to disaster prevention bases and information systems that seriously hampered the urgent response after the earthquake also reminded the importance to prepare appropriate crisis management programs in addition to disaster prevention programs.

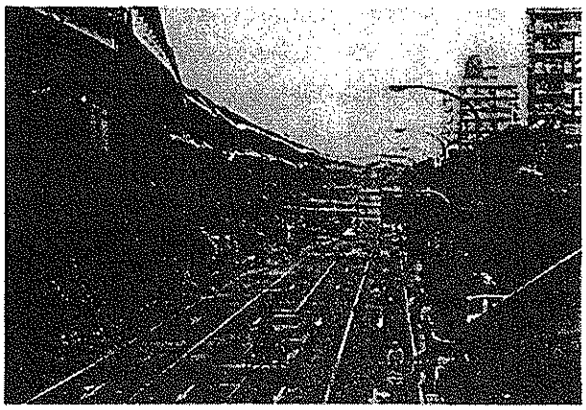

Photo. 5 Disruption of Arterial Viaduct

6) Intensive Rainfall in Fukuoka Pref. (1999/1/29, 122 mm/ hour)

Flood developed in Fukuoka city caused 2 fatalities, and slope failure developed in Hiroshima Pref. caused 31 fatalities and 153 collapsed buildings. Around the Hakata Station where the use of underground space was advanced, an underground arcade and underground station were flooded. In the basement of a nearby office building, people who failed to evacuate promptly were drowned. The flooding cut off transportation routes and caused the failure of power system equipment blacking out the Hakata Station area. This flood clearly indicated that the city was susceptible to the influence of intensive rainfall that exceeded the anticipated amount of rainfall. The flooding of underground space was never experienced before, and reminds the need of flood disaster prevention measures for underground space.

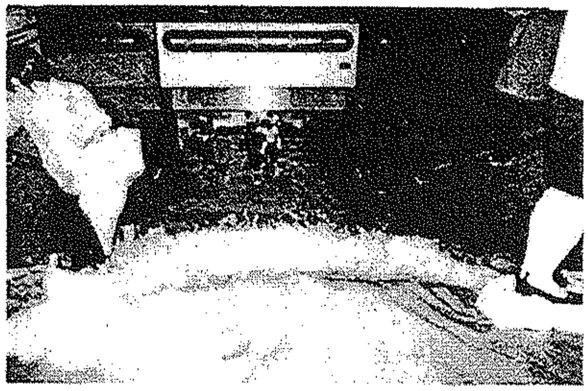

Photo. 6 Flooding of Underground Station

2.3 Features and lessons learned

(1) Features of urban disaster

1) Simultaneity and complexity

In addition to the damage of human lives and properties, complex disasters including city fire, slope failure, tsunami, flooding, lifeline damage, transportation damage, rumors, deteriorate of environment, and other disasters are developed simultaneously. And the form of disasters varies according to topographical conditions, ground conditions, and other unique features of regions.

2) Increase of human casualties

Highly concentrated populations tend to cause an extremely increase of human casualties. Extensive rescue and medical treatment activities are required. Also numbers of emergency facilities for medical treatment and evacuation are needed.

3) Influence to socio-economic activities

Socio-economic activities in urban regions are highly dependent on infrastructures including lifeline facilities, transportation facilities, information related facilities, etc. Once infrastructures lost their functions, serious repercussion may be induced. In the 1995 Hyogo-ken Nanbu Earthquake, for example, disruption of expressway not only cause delayed evacuations, delayed restorations works and traffic congestions in the damaged region but indirectly affected nationwide socio-economic activities. And the damage of port facilities at Kobe not only cause loss of functions but also affected socio-economic status in neighbor countries through import/ export activities.

4) Chain-reaction and expansion of disaster

As a consequence of the highly interdependence of urban functions, primary damage may induce chain-reaction and cause the expansion of secondary damage. For example, urban functions are extremely dependent on electricity, failure of power station affects almost all the urban functions and socio-economic activities as the secondary damage.

5) Difficulty of disaster prediction

Due to the complex relationships between urban functions, damage that does not seem to be related with external natural force may be developed. And due to recently appeared new facilities and functions, unexpected new forms of damage may be developed. In the 1971 San Fernando Earthquake, for example, explosion of gas pipeline and falling-off of curtain walls in high-rise buildings were developed. In the 1978 Miyagi-ken-oki Earthquake, more than half of the fatalities were induced by the collapse of block walls. In the 1995 Hyogo-ken Nanbu Earthquake, malfunctions of fire hydrants prevented firefighters from halting the spread of city fires, and the damage of gas stations help leaving many vehicles abandoned on city streets.

(2) Lessons learned from urban disasters

1) Importance of disaster mitigation planning

Although frequency of large-scale urban disasters is quite low, disaster potentials is extremely high. For promoting countermeasures and securing safety of urban regions against such kind of "low frequency and high influence" disasters, it is quite important to develop appropriate disaster mitigation plans that include risk management measures for damage prevention and crisis management measures for minimizing disaster influences by urgent response works. Also construction of infrastructures must balance the pursuit of advanced functions with consideration of their safety and roles during disasters.

2) Assessment of growing susceptibility

It is essential to carefully study the credible external natural force, and evaluate susceptibility of urban regions. Susceptibility must be appropriately evaluated from the following viewpoints;

a) Distribution and attribute of population:

As the population concentrate to the urban regions, disaster potential increases. As the population increases, residents with various attributes also increase, i.e. elderly, handicapped, foreigners, and infants. As the population increases, relationship in community is likely decline and residents with little experience of disasters are increase. Housing problem enforce long distance commute, and induce huge population gap between daytime and nighttime. Depending on the time disaster occurs, human casualties due to panic and traffic accidents may extensively increase.

b) New facilities/ functions and chain-reactions:
As new facilities/ functions increase, new form of damage and propagation of disaster due to chain-reaction are likely developed. It is therefore essential to evaluate disaster susceptibilities by understanding vulnerability of facilities/ functions and their relationships.

c) Spread of residential districts:
Accompanied with the spread of residential districts, residents living in risky districts from disasters are increasing. Districts with extremely high concentration of wooden dwellings have risk from city fire. Districts along steep slopes have risk from slope failure. Districts with low elevation have risk from flooding and tsunami. And districts formed in reclaimed land have risk from ground liquefaction.

d) Advanced use of urban space:
Accompanied with the lack of land, elevated structures have been constructed for utilizing urban space. Although these structures are necessary in urban regions, vulnerability and risk from disasters must be carefully studied. For example, High-rise buildings have risk from fire, underground facilities including arcade and stations have difficulty in emergency evacuation, and elevated railways and viaducts have risk from earthquakes.

e) Hazardous plants and materials:
As the urban functions concentrated, hazardous plants and materials to sustain urban activities are required. These plants and materials include energy production plants, pharmaceutical and chemical plants, gas storage tanks, petroleum supply bases, gas stations, etc. These plants and materials have risk from explosions and serious environmental problems.

3. DISASTER PREVENTION MEASURES

3.1 Basic concept

The "Disaster Countermeasures Basic Act" was enacted in Nov. 1961 in response to a large-scale disaster caused by the 1959 Ise-wan Typhoon. The Act established the framework for disaster prevention measures in order to protect human lives and properties from external natural forces including earthquakes, tsunamis, windstorms, intensive rainfalls, landslides, floods, high tides, volcanic eruptions, heavy snows, etc. **Figure 4** shows the relationship between disaster prevention plans prepared for national level, Prefectural level, municipal level and citizens' level.

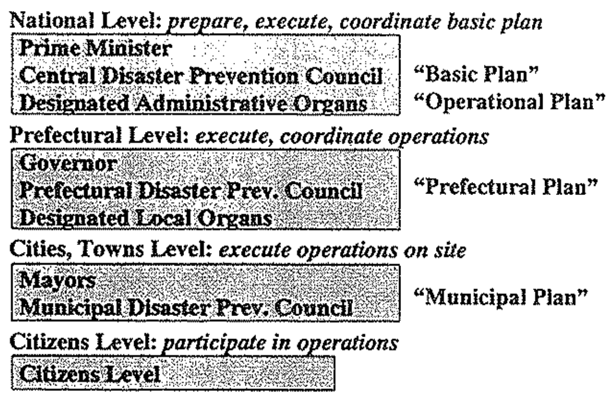

Fig. 4 "Basic Plans for Disaster Prevention" in Japan

Here, the disaster prevention plan was revised following the 1995 Hyogo-ken Nanbu Earthquake. Although disaster countermeasures have been implemented to protect human lives and properties from anticipated natural external forces, the concept of crisis management to minimize the disaster influence was additionally introduced. This is because we must recognize technical difficulties to predict a maximum limit of external natural forces, and technical/ financial difficulties to completely protect facilities/ functions from damages against catastrophic levels of external natural forces.

3.2 Earthquake disasters

(1) Basic concept for disaster prevention

Although a mechanism of earthquake occurrence have been investigated, it is technically difficult to predict the maximum scale, accurate location and time of earthquakes. And it is financially/ technically unrealistic to attempt protecting facilities/ functions from damage considering catastrophic levels of external earthquake force. In the "Basic Plan for Disaster Prevention" described above, basic concept for preventing damage of structures/ facilities is described as follows (**Table 1**):

Table 1 Basic Concept for Preventing Damage

		Earthquake Motions	
		Ordinary Motion once or twice during lifecycle	Extremely Strong Motion very low probability during lifecycle
Importance	Ordinary Structures	Significant Loss of Functions must be Prevented	Threat to Human Lives Must be Prevented
	Important Structures		Significant Influence To Urgent Activities and Social Activities Must be Prevented

1) External earthquake forces

Two levels of earthquake motions must be considered in the seismic design of structure/ facility. The first level is ordinary motion that has certain probability to strike structure/ facility once or twice during its lifecycle. The second level is extremely strong motion that has very low probability to strike structure/ facility during its lifecycle. The second level of motion includes that generated by interplate earthquakes in the ocean, and that generated by earthquakes due to inland faults.

2) Requirement of safety

Significant loss of functions must be prevented against the first level of ordinary earthquake motion. And serious threat to human lives must be prevented against the second level of extremely strong earthquake motion. In addition, sufficient seismic safety must be provided to structure/ facility that failure of function affect significant influence to urgent response activities and socio-economic activities. The amount of safety must be determined by considering importance of each structure/ facility.

For securing safety of structure/ facility, other than the individual seismic design, it is also important to secure function of systems by increasing system redundancy and providing alternatives.

(2) Disaster mitigation measures

After the 1995 Hyogo-ken Nanbu Earthquake, the Ministry of Construction compiled the "Concept of Urban Planning emphasizing on Seismic Safety". Based on the concept, disaster mitigation measures have been promoted. In addition to the seismic design/ retrofitting of infrastructures/ buildings, following principal policies have been strongly focused.

1) Reduction of vulnerability

The policy includes the reconstruction of vulnerable districts with high concentration of wooden dwellings, establishment of disaster proofing zones, and distribution of open spaces to prevent the spread of city fire.

2) Improvement of core public facilities

For securing urban functions for evacuation, fire fighting and emergency transportations, the policy enforcing implementations of the evacuation route network, emergency transportation route network,

3) Upgrading safety of lifeline facilities

The policy includes construction of common utility ducts accommodating water, gas, electricity, telephone and other pipelines, providing backup water sources needed for fire fighting and daily lives, and improving information systems to collect, analyze, disseminate disaster information.

(3) Technological development

The Public Works Research Institute has been promoting R&Ds for the urban earthquake disaster mitigation. Followings are the principal research themes.

1) Technologies for disaster prevention

- Preparation of seismic hazard map taking effects of inland faults into account
- Evaluation of emergency transportation route seismic performance

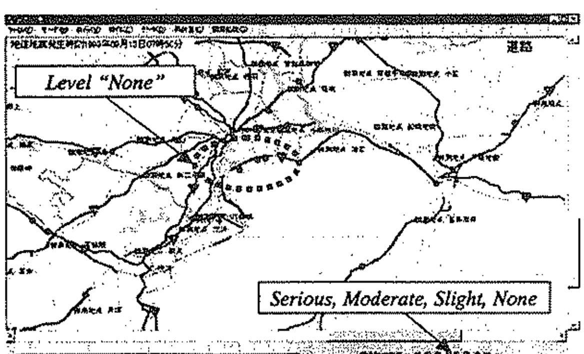

Fig.5 Urgent Damage Estimation Technology (Highway Bridge Damage)

2) Technologies for crisis management

- Urgent damage estimation using ground motion observation network (**Figure 5**)
- Urgent damage detection using advanced information technologies including satellite image and sensors

3.3 Flood disasters

(1) Basic concept for disaster prevention

Conventional measures have been promoted in order to prevent flood-induced damage against anticipated level of rainfalls. Although the frequency of flood disasters has been reduced, the scale of disasters has tented to increase due to the urbanization. The basic concept of flood disaster prevention becomes, therefore, an appropriate control of the relationship between intensive rainfall and induced damage. Based on this basic concept, comprehensive flood disaster mitigation measures are needed in order to create watershed systems where intensive rainfall does not significantly affect the socio-economic activities.

1) External natural force

Relationship between anticipated intensive rainfalls and induced damage in the existing watershed must be carefully studied. Anticipated form, scale and influence of flood disaster must be studied considering past disaster experiences, changes of watershed and safety of related facilities.

2) Requirement of safety

Requirement of the flood frequency reduction and flood-induced damage reduction must be studied considering above described relationships in each watershed. Combination of disaster mitigation facilities must be carefully selected considering the reliability/ deterioration and cost/ effect/ limitation of facilities.

(2) Disaster mitigation measures

Followings are basic approaches for flood disaster mitigation implemented by the Ministry of Construction.

1) Facilities to deal with anticipated floodwater

These include river course improvement, levees, diversion channels, dams, retarding basins, drainage pumping stations, high tide levees, etc.

2) Facilities to reduce damage due to extreme floodwater

These include super levees, forest zones, double levees, emergency drainage gates, and land side channel networks.

3) Measures to reduce floodwater

These include the conservation of water retention/ retarding functions by constructing storage/ infiltration facilities in the watershed, and the control of woody debris and harmful sediment by constructing sediment dams.

4) Reduction of disaster potential in watershed

This approach includes the management of land use, and the promoting of flood-proofing city planning.

5) Improvement of urgent response

This approach includes improvement of urgent warning, dissemination of hazard map, improvement of evacuation by education/ drills.

(3) Technological development

Followings are principal research themes conducted by the Public Works Research Institute for flood disaster mitigation.

1) Technologies for disaster prevention

- Preparation of flood hazard map for displaying distribution of risks in each watershed **(Figure 6)**

2) Technologies for crisis management

- Pre-disaster dissemination of flood information for the awareness/ education of residents

- Post-disaster dissemination of flood information for the effective evacuation activity

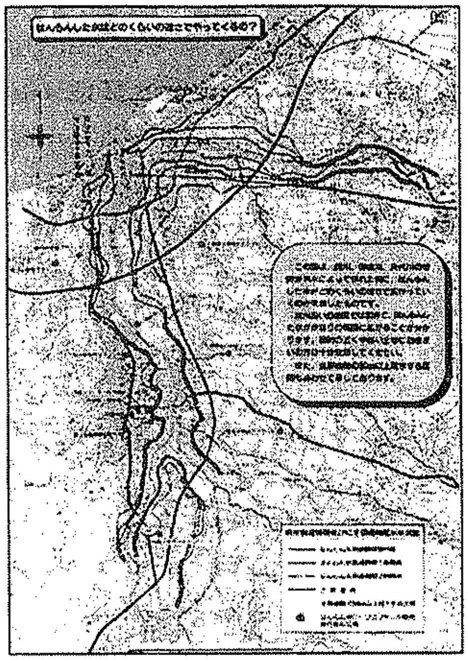

Fig. 6 Flood Hazard Map

4. CONCLUDING REMARKS

This report reexamines past earthquake and flood disasters to study the changes, features and lessons of urban disasters. This report also introduced the basic concept, policy measures and technological development for the urban disaster mitigation in Japan.

Features of urban disaster can be summarized as follows;

1) Highly concentrated population and properties tend to cause an extremely increase of human casualties and structural damages.
2) Once urban infrastructures lost their functions, serious repercussions to socio-economic activities are developed. As the consequence of highly interdependence of urban functions, primary damage induces chain-reaction and

causes the expansion of secondary damage in and around the damaged region.

3) Accompanied with newly appeared urban facilities/ functions and the chain-reaction effects, unexpected forms of damage tend to be developed.

Lessons learned from past urban disasters can be summarized as follows;

1) For securing safety against "low frequency and high influence" urban disasters, it is essential to develop appropriate disaster mitigation plans that include risk management measures for damage prevention and crisis management measures for minimizing damage influence. It is also essential to disseminate appropriate disaster information to public for the better awareness and education.
2) It is essential to assess the susceptibility of existing urban regions. Viewpoints include distribution and attribute of population, newly appeared facilities/ functions, chain-reactions, spread of residential districts, advanced use of urban space, and distribution of hazardous plants and materials.

REFERENCES

1) PWRI: Report on disaster caused by the 1964 Niigata Earthquake, report of PWRI, vol. 125, 1965.6
2) PWRI: Report on disaster caused by the 1978 Miyagi-ken-oki Earthquake, report of PWRI, vol. 159, 1983.3
3) PWRI: Report on disaster caused by the 1983 Nihonkai-chubu Earthquake, report of PWRI, vol. 165, 1985.3
4) Earthquake Engineering Division of PWRI: Report on disaster caused by 1982 Intensive Rainfall in Nagasaki Pref,, technical memorandum of PWRI, vol. 2417, 1986.11
5) PWRI: Report on disaster caused by 1995 Hyogo-ken Nanbu Earthquake, report of PWRI, vol. 196, 1996.3
6) Central Disaster Prevention Council: Basic Plans for Disaster Prevention, 1997.6
7) Ministry of Construction: Concept of Urban Planning emphasizing on Seismic Safety, 1995.4