EARTHQUAKE HAZARD MITIGATION IN URBAN AREAS BY THE INTEGRATION OF SOCIO AND ENGINEERING APPROACH

Masamitsu MIYAMURA*, Reiko AMANO** Ariyoshi YAMADA*, Kaoru MIZUKOSHI**
Kajima Corporation*
Engineering Risk Service Inc.**

***ABSTRACT*:** The vulnerability to earthquake hazards of urban areas such as Tokyo has increased with the wide spread of complex social systems. In order to solve such difficulties for hazard mitigation in urban area, a new approach of social engineering with the integration of engineering technology and socio-economic knowledge is presented in this paper. This approach stresses the necessity of the integration of knowledge from various research disciplines of which concept is composed of different components. Firstly, this paper describes the general concept of the proposed social engineering approach and study of damage propagation process based on the review of past large earthquakes. Secondly, in respond to the business continuity management (BCM) of private sectors, availability of effective technical tools is presented along the time axis of earthquake occurrence. As well as reinforcing and upgrading the weak facilities before earthquakes, herein, a real time mitigation system (named Kajima Incident Command System) applied for during an earthquake is presented by using several useful tools. By the integration of engineering tools and socio-economic knowledge, more realistic hazard mitigation systems can be constructed which is possible to apply for the damage mitigation especially in mega cities.

KEYWORDS: Social Engineering Approach, Incident Command System, BCM

1. RAPID INCREASE OF VULNEARBILITY IN URBAN AREAS

1.1 Resilience in urban areas

In recent years, it has become apparent that the vulnerability to hazards of urban areas such as Tokyo has increased with the wide spread of complex information networks, infrastructures and the rapid growth of high-density population and they are becoming more complex with the development of social systems. As major factors which influence on the fragility of urban areas are considered as follows.

・Mixture of old and new buildings and facilities with different level of seismic performance brings decrease of regional seismic potential.

・High-density population increase the danger of human life losses.

・Complex information networks and infrastructures brings long-term business disruption.

・Concentration of important functions of public institutions and private sectors brings long-term disruption of daily life.

These factors brings increase of vulnerability of urban cities as determined by the relation between the resilience of society and external force as shown in Fig1. Contrary to the decrease of society resilience, required level of society has increased due to the complex social systems. From such background, if a big earthquake hits the mega city like Tokyo, it is forecasted that unpredictable tragic damage may bring boundless losses in social systems.

1.2 Large impact on business continuity

Advances in technology in the last few decades has definitely improved the earthquake-resistance of building and the structural damage decreases in accordance with the time passing. On the other hand, the damage of lifeline systems and secondary systems including equipments have increased which affects the long-term operational disruption especially for the business continuity of private companies as shown in Fig.2.

Looking back the past earthquakes after the Hyogoken-Nanbu earthquake in 1995, many damaged earthquakes occurred around Japan, and inflicted severe damage mostly in the local cities as shown in Fig3. It is noted that blank areas can be seen especially in large cities around Tokyo with significant high population density, which implies the threat of future occurrence of earthquakes.

In order to mitigate the hazard in such urban area, it is not sufficient to consider only the hard ware countermeasures like structural seismic reinforcing but also incorporate the supporting soft wares tools associated with human action plans to reduce the long-term influence on socio-economic loss.

2. COMPLEX DAMAGE PROPROPAGATION PROCESS IN PAST EARTHQUAKE

2.1 Various causes hidden in direct damage

When a big earthquake occurs, we have a tendency to concentrate on calamities such as fallen buildings, damaged roads and bridges, and causalities caused by ground shaking, tunamis and fires. We often miss to understand the real background and causes of such terrible events. It is of vital importance that we detect potential disasters in advance and prepare sufficient countermeasures. The collapse of

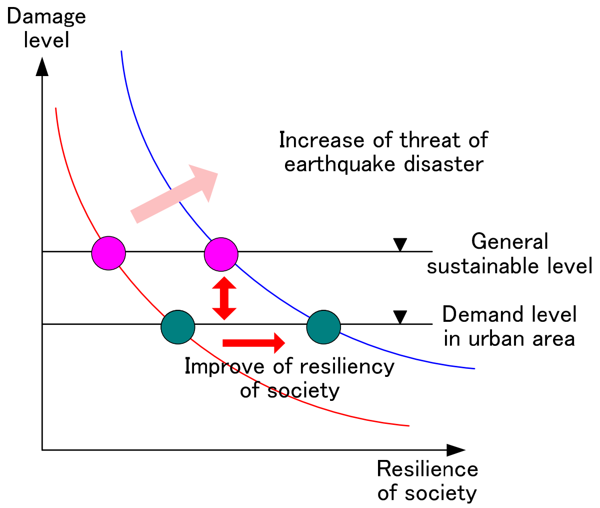


Fig1 Relation between resilience and acceptable damage of society

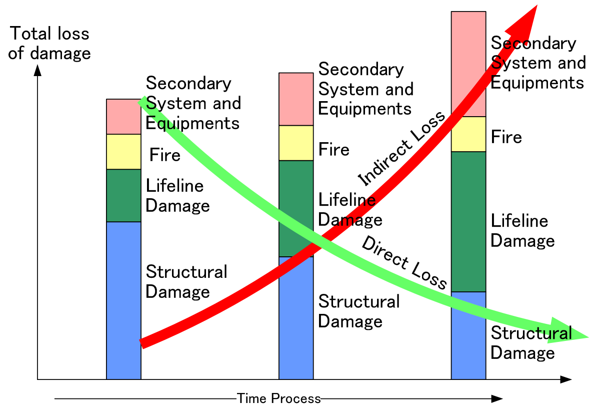


Fig2 Change of damage pattern along time process

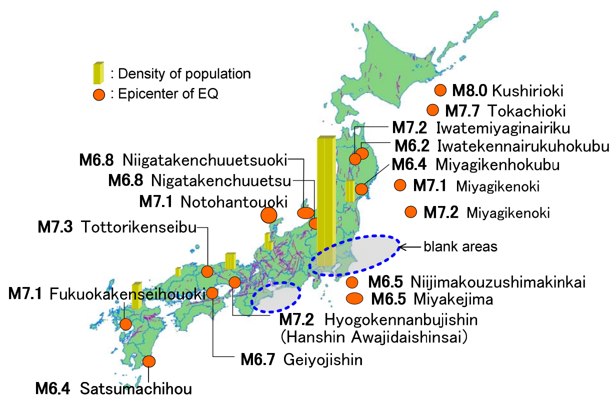


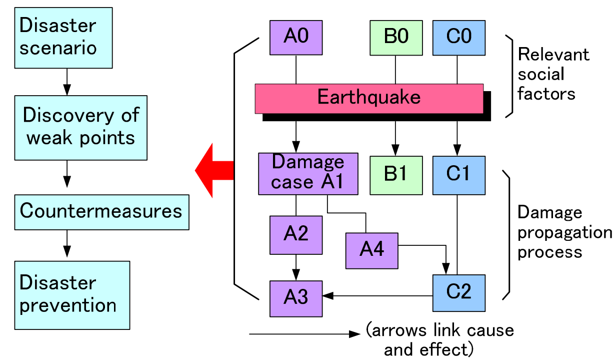
Fig3 Earthquake occurrence and distribution of population density after the Hyogoken-Nanbu EQ

buildings and express ways can not only be attributed to design issues but the social circumstances from which a design emerged. These circumstances include economic factors, such as cost and the availability of materials, engineering factors such as personnel skills and construction methods, administrative factors, such as whether there is time for proper construction and inspection systems. Reviewing the history of earthquake disasters, it is clear that the nature of earthquake damage has changed as society changed. This implies that it is not appropriate to use the general hazard mitigation methodology regardless of the regional social characteristics. In order to reduce the regional damage, it is important to identify the weak factors to induce fatal damage and study the complex objects and processes in detail by socio-engineering approach associated with purely engineering approach.

2.2 Damage Propagation Flow

In order to evaluate the risk in urban city, understanding of the damage pattern of past earthquakes is the first step.

Fig4 shows the general flow of the preventing earthquake disasters and the concept of damage propagation flow chart. A disaster scenario is devised which reflects past disaster experiences. In the diagram, the lower half shows damage caused by the earthquake and its propagation process indicating the relationship between the cause of the damage and its



(a) Disaster prevention flow (b) Damage propagation flow

Fig4 Disaster prevention flow and concept of damage propagation flow

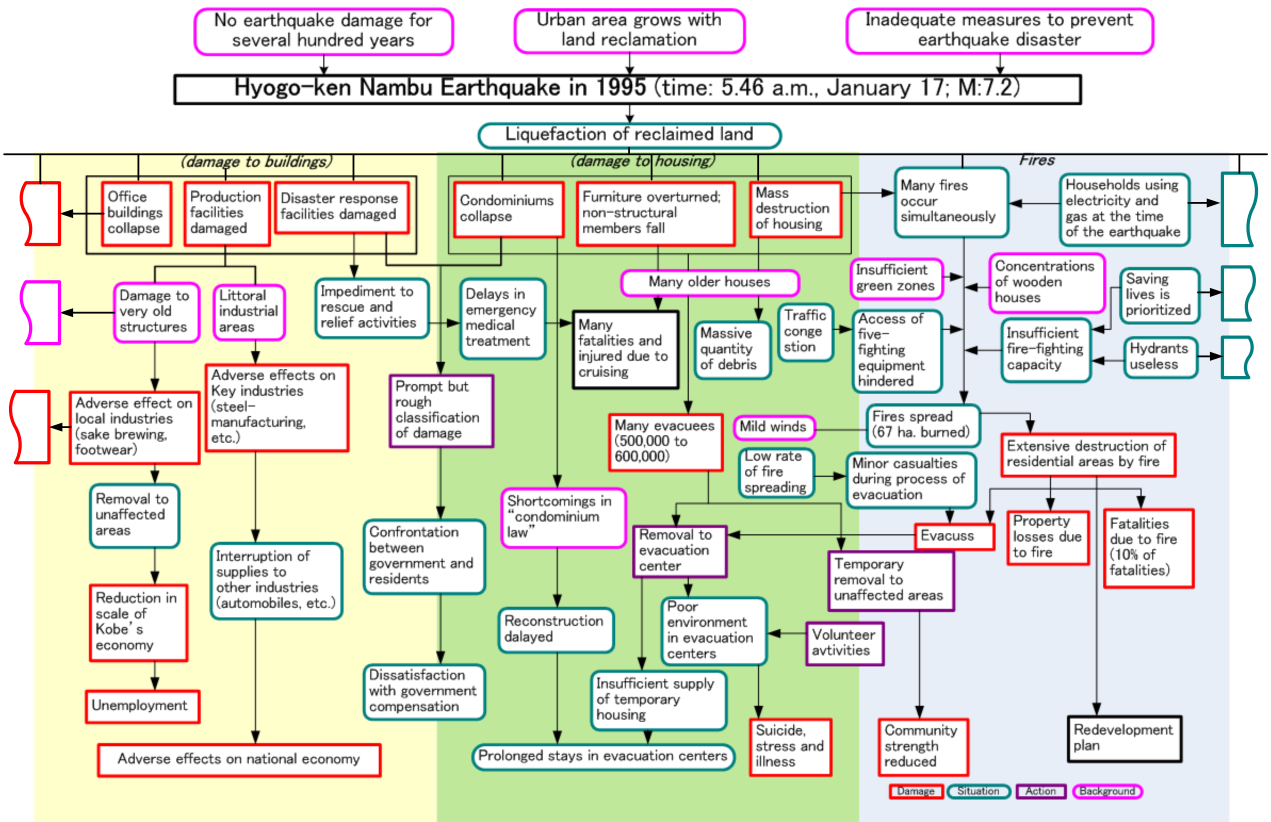


Fig5 Damage propagation flow chart in the Hyogoken-Nanbu EQ (1995)

result. Social background and weather phenomena or geographical conditions which are thought to have some relations with the damage are also shown in the upper part of the chart. To create the charts, newspaper articles and various research reports were reviewed and the social circumstances of the time and place were investigated. Relationships between cause and effect were determined mainly through discussions among residents, officials and professional people.

In an earthquake, many phenomena interact each other in a complex manner and seem to propagate damage in the dimensions of space and time. The damage propagation flow chart is studied by investigating damage inflicted by earthquakes that had occurred in Japan. The chart showed that the damage features varied to a great extent depending on individual earthquake.

As an example, the propagation flow of the Hyogoken-Nanbu Earthquake (1995, M7.2) is shown in Fig5 as one of the most tragic earthquake to hit modern city. Considering key factors of the social background described in the upper portion, we can find the important factors to facilitate the damage propagation. The flow chart shows a broad perspective on how the disaster initiated and developed. A variety of damage factors, interacting with each other in a complex manner propagated gradually from the brief moments of shaking to the days, and months following the earthquakes. The earthquake inflicted serious damage not only to individual private production facilities, moreover, extensive damage to infra-structures such as the bullet train, expressway facilities which caused great economic impacts far beyond the immediately stricken areas.

We can find some common links between damages and key words in several past earthquakes, and compare these chart the same way each other and understand that each earthquake shows a significant difference between the factors causing damage, which are affected interactively with complex manner by size, location, era, season, and time of day of occurrence.

3. DEVELOPMENT OF TECHNICAL TOOLS FOR THE SUPPORT OF BCM

3.1 BCM process and available technical tools

Due to the frequent occurrence of large earthquakes in Japan, both public institutions and private companies have been getting much interests in the introduction of Guideline for business continuity management (BCM), and its concept is shown in Fig6. In this process, as a basic issue, it is necessary to reinforce and upgrade the weak buildings and critical facilities before earthquake. However, it is difficult to reinforce required all fragile buildings due to budget limitation. Accordingly, it is necessary to take countermeasures to reduce the functional losses and shortening repair time considering tolerable level of a company after suffering damages. Though construction companies conduct such works by using technical tools as shown in Table1, most of the tools are developed for the use of before earthquakes. In order to shorten the recovery time, it is necessary to develop tools associated with human actions available for during or just after the earthquakes.

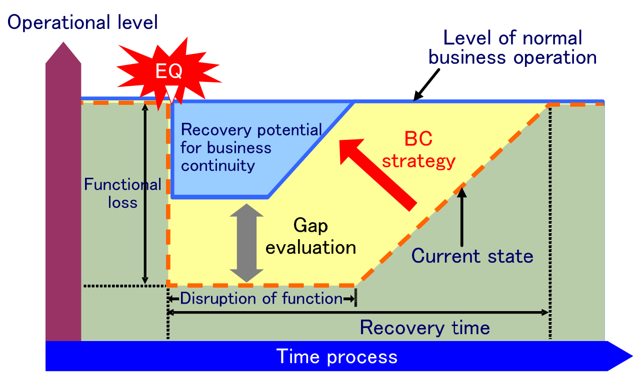


Fig6 Schematic process of business recovery

Table1 Available technical tools in a construction company

Time / Damage	Before EQ	During EQ	After EQ
Tsunami	Construction method of Breakwater	Tsunami warning	Early recovery strategy
Fire	Fire protection, Fireproof technology, Green belt	Evacuation guidance system, Fire alarm system, water screen system	Prevention for fire spread
Soil	Construction method for liquefaction, Anchor, land slide, Soil improvement	Alarm system for landslide	Technology for soil improvement, Evaluation system for underground struct.
Structure	Evaluation system for existing old build. Active, passive control of build.	Structural control system	Evaluation system of damage states, Construction of, Disposal method for rubble
Transportation	Road network analysis	Emergency control system	Early recovery construction method
Gas, Electricity, Water and sewerage	Network analysis, Redundancy	Emergency control system	GIS, Cross support system

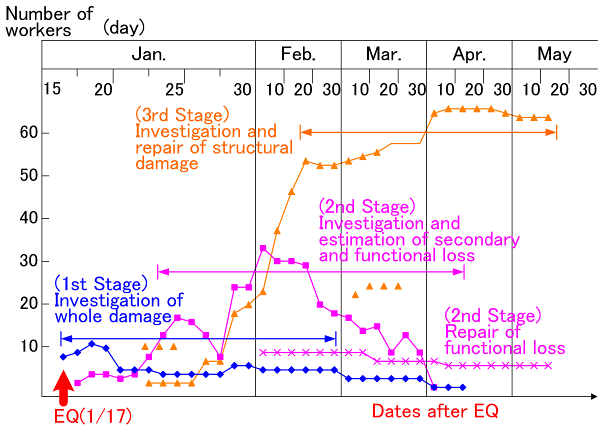


Fig7 Recovery process by supporting workers in the Hyogoken-Nanbu EQ

3.2 Major problems in recovery process

One of the important items in business continuity is how to evaluate the recovery process. Fig7 shows an example of the change of numbers of supporting workers involved in repair works for damaged buildings in the Hyogoken-Nanbu earthquake.

At the first stage, research and development people were called out to collect the damage information and figure out the regional damage aspect. Next stage is to review and repair the secondary and functional losses of buildings by facility managers and design people. And at last stage, repair of structural damage or reconstruction works were started about one month after the earthquake occurrence. In this process, it should be noted that the repair periods are widely scattered between the ranges of 2 to 7 months with little relation with damage states as shown in actual data observed at the Hyogoken-Nanbu earthquake as shown in Fig8. This is because many factors are included in the process of actual repair works, which is influenced not only by the worker’s skills or construction procedures but also complex recovery process as shown in Fig7. Furthermore, the seismic reinforcing is conducted at the same time of reforming or upgrading the interior and exterior decorations. Such data implies that it is important to evaluate the repair

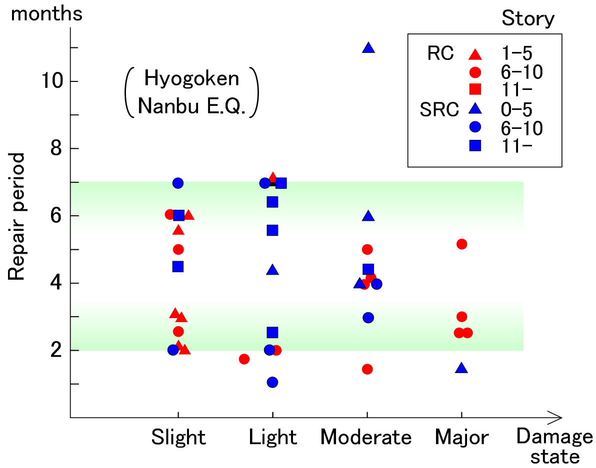


Fig8 Variance of repair period of office buildings in the Hyogoken-Nanbu EQ

period and understand the upper and lower boundaries of the variance considering the importance of the functions of critical facilities for the realistic application of BCM.

3.3 Emergency response support system

Considering the difficulties of reinforcing the weak facilities in advance, it is necessary to take appropriate actions associated with supporting system which can mitigate the secondary damage and losses just after the earthquake occurrence. As one of the supporting system during earthquake, Fig9 shows the schematic flow of the proposed emergency response support system. The system is composed of following several key elements.

① Simulation tool for the evaluation of recovery potential mainly before an earthquake

・Evaluation of seismic performance of employee's residence

・Road network analysis to evaluate the ability of accesses to critical facilities

This provides basic information for the estimation of numbers of available workers.

② Supporting tools during earthquake

・Early warning system to transfer real time earthquake information

The combined system of early warning and on-site warning system is useful to provide information just before the arrival of strong shaking. Since the available time is very short, the main purpose is for human evacuation and safe shutdown or control of important equipments in critical facilities.

③ Real Time Damage monitoring of critical facilities

Next is the stage just after the earthquake, and the quick damage monitoring is useful to detect the damage states of critical buildings by various sensors installed in the buildings,

④ Distribution map of strong shaking and damaged facilities

This provide the distribution map of strong ground shaking associated with location of employees residence, completed buildings, etc with assistance of the geographical information system (GIS).

⑤ Emergency information binder

This provides the integration of actual damage information from construction sites and making quick reports to understand the damage profile. This is very important to know actual damage states.

⑥ Construction of necessary database

・Human resources such as available number of employees, construction workers and location of

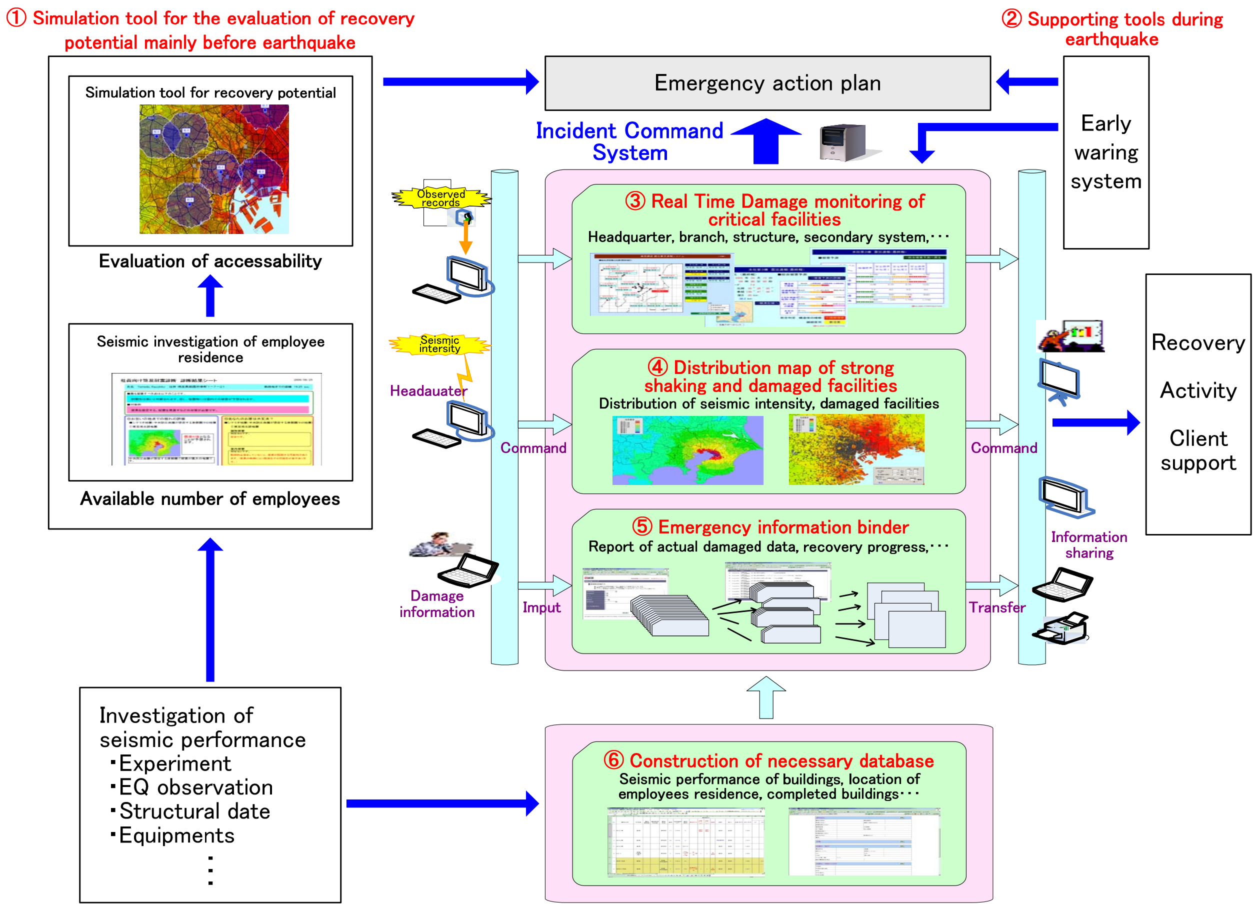


Fig9 Emergency response support system

construction sites, completed buildings, etc.

・Seismic performance of critical facilities (Structure, non-structural components, equipments, etc.)

When an earthquake occurs, earthquake information is transferred to the operation center and early warning system starts to trigger and distribution map of ground shaking and damage monitoring system evaluates damage states of critical buildings along the time passing. These are used for the estimation of damage states during blank time until the time when actual data are sent to the station along the time passing.

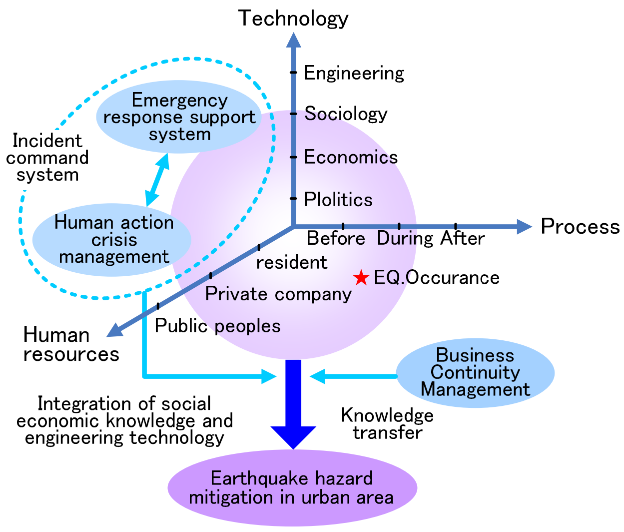


Fig10 Concept of social engineering approach

4. INTEGRATION OF SOCIAL AND ENGINEERING KNOWLEDGE

4.1 Social Engineering approach

For the future hazard mitigation in such vulnerable urban areas, a concept of social engineering approach is proposed in this paper. The approach stresses the necessity of the integration of knowledge from various research disciplines of which concept is composed of different components. First is the human resources how to improve the cooperation of residents, enterprises and governments. Second is the comprehensive use of technologies and knowledge ranging from hardware to software. Third are well-balanced countermeasures and operations before, during and after an earthquake. Such general concept is shown in Fig10. For one of the actual application of such concept, an incident command system by making use of specific factors in three dimensional axes in Fig.10, and concrete procedure or operation of knowledge transfer is very important.

4.2 Application to business continuity process

The proposed system is possible to apply for business continuity management (BCM) to enhance the strategy of disaster mitigation program and support the emergency action plans as shown in Fig11. BCM is one of the managing policy of a private sector and composed of several key elements along the defined process in Fig. 11. At the stage of business impact analysis, risk assessment becomes important to evaluate probable size and magnitude of the threat to the company. In this process, several hazard analyses are studied to evaluate the strong ground motions and its quantitative damage on buildings and facilities before earthquake. The result is utilized for the evaluation of business impact. An early warning system and seismic intensity distribution map are utilized when a big earthquake occurs. The results are quickly reflected to estimate the damage level and necessary recovery time. At the process of gap evaluation, it is important to evaluate the resilience or potential of a private sector having in the process before and during earthquake. In this paper, focusing on the stage of during earthquake, quick information sharing system by using damage monitoring and emergency information binder is proposed based on the result of seismic evaluation of employee’s residence and road network system. These results are used for the planning of strategic planning of early recovery in respond to the time dependent variable damage propagation. In this

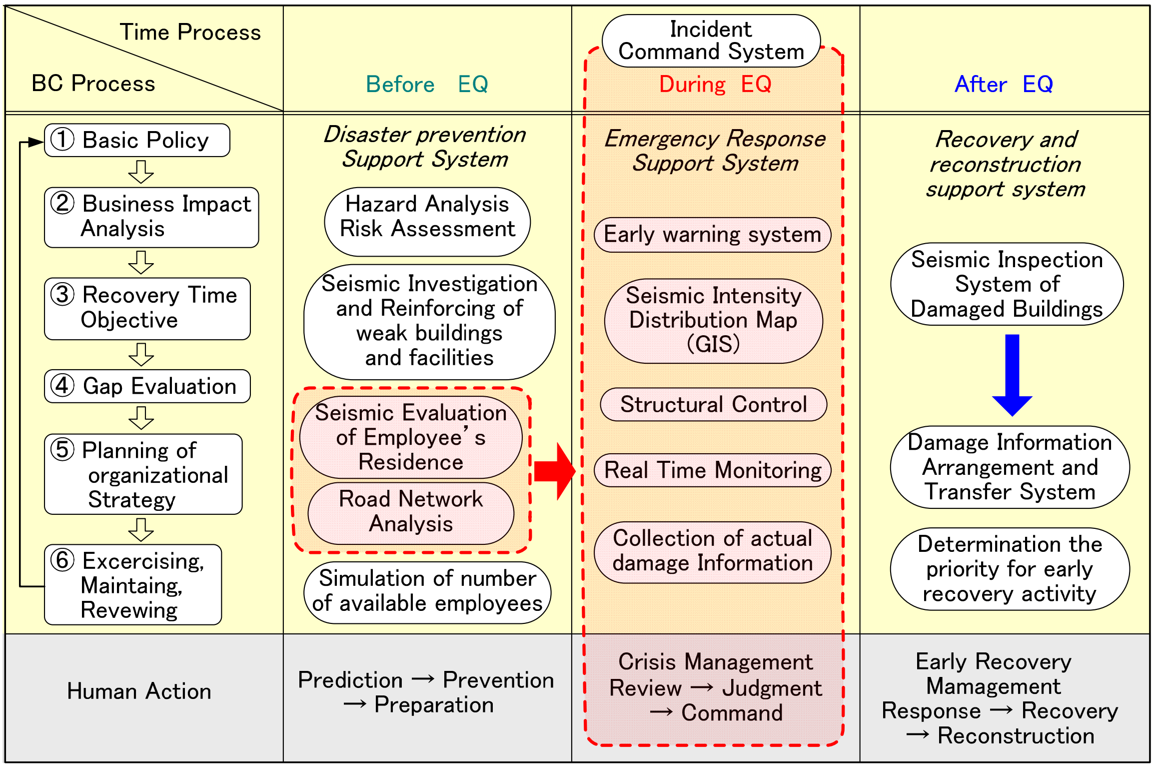


Fig11 Application to business continuity process

process, it is necessary to select appropriate human action plans and supporting tools to compass the necessary information along time passing. The decision making supporting system during earthquake aims to process necessary information by computer and select the optimum measures automatically based on modeling of the corporate activities conducted in the building concerned. These data comprise the internal resources for corporate activities, such as the company's facilities and assets, sources of income and human resources, and external information such as regional lifelines, the supply potential for goods and materials. Effectiveness of such system will be raised depending on how external information will be incorporated into mathematical model. In this paper, a concept of incident command system named

Kajima Incident Command System (KICS) is proposed based on the social engineering approach by utilizing the developed technical tools and to explore the possibility of application for BCM process especially for a private company. In order to realize such system for the actual application in a company, it is not only to use individual technical tools, but to integrate it with human actions managed by socio-economic knowledge through time process.

REFERENCES

T. Kobori et.al., SEEHM (1991~1999), LONG ROAD, No.1 ~No.9., Kajima Corporation

M. Miyamura, K. Mizukoshi, Robert Olson, and K. Yamada, 2008. Social Engineering Approach toward earthquake hazard mitigation in urban areas, 14WCEE, Beijing, China

M. Miyamura, T. Kobori, and K. Mizukoshi, et.al., 1991. Seismic Hazard Mitigation based on Social Engineering Approach, AJI, (in Japanese)

Cabinet Office, Government of Japan, 2005, Business Continuity Guideline, Central Disaster Management Council,

Robert A. Olson, Robert L. Nigbor, M. Miyamura et.al, Including Earthquake Risk Perception in Risk Reduction Modeling, Kajima-CUREE Joint Research Project, 2003