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OPTIMUM RESTORATION MODEL CONSIDERING INTERACTIONS AMONG LIFELINE SYSTEMS -INTERACTIONS AMONG RESTORATION ACTIVITIES OF LIFELINE UTILITIES-

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SUMMARY

With urbanization, interdependency of urban functions has been getting larger and larger. Once a disaster occurs in urban areas, its influence causes not only structural damage, but also functional damage to various lifeline systems and affects the lives of the people in damaged areas. It is, therefore, important for many related fields/organizations to collaborate with each other for developing an integrated earthquake disaster reduction system. The objective of this research is to propose an optimum recovery model considering interactions among related organizations. At the first step, we have collected the data on actual recovery activities of each lifeline utility after the 1995 Kobe earthquake and analyzed them from the viewpoint of both time and space domains. Based on the real data, we found that there were several problems raised during lifeline restoration activities. From the results of this study, we can say that there are severe problems/obstacles that can not be solved appropriately by individual lifeline utility with independent measures and integrated approach is very important for decreasing the total negative impact due to a disaster.

1. INTRODUCTION

A general survey on Kobe earthquake and its influence in urban areas lead us to believe that there were situation in which organizations and institutions related to disaster reduction did not take proper measures against the disaster with mutual collaboration. Although we agree that individual organization, like lifeline utility did its best for getting “individual best”, the summation of “individual best” can not be a “total best” of the damaged area, and it can hardly say that mutual collaboration system was prepared sufficiently before the earthquake.

A large number of reports have been published and many researchers have studied various themes after the Kobe earthquake. Although there are many materials and data compiled in time history, there are very limited research works that have been carried out from both time and space domains. Such kind of research is important because the damage and influence due to an earthquake spreads to large area. In this study, we survey the various

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response activities of lifeline utilities after Kobe earthquake and analyze the activities from the viewpoint of both time and space domains in order to propose a proper mutual collaboration system for minimizing the total negative impact due to a disaster.

2. INTEGRATED EARTHQUAKE DISASTER REDUCTION SYSTEM

It is impossible to prevent the occurrence of a hazard since it is a natural phenomenon. However, we believe that it is possible to reduce the damage caused by a hazard. In general, there are three kinds of countermeasures for disaster reduction. They are "Disaster Mitigation", "Disaster Preparedness" and "Optimum Recovery/Reconstruction Strategy". "Disaster Mitigation" is a countermeasure for mitigating disaster by means of building disaster-resistant structures, such as a high embankment or well designed earthquake resistant structures. "Disaster Preparedness" is to reduce the impact of hazard by taking proper response and emergency management systems before the occurrence of hazards. "Optimum Recovery/Reconstruction Strategy" is to accelerate the recovery and reconstruction activities to avoid long term ill function of the damaged areas caused by severe hazard. In the past, the main engineering countermeasure against disaster was "Mitigation". However, all of the three countermeasures mentioned above should be well coordinated for reducing the impact of disaster. It is clear that the impact of disaster changes greatly by the efficient operation of these countermeasures. Also a disaster causes not only physical and structural damage, but also adverse effects to various social functions and it spreads to whole society. Implementation of these countermeasures to reduce negative impact by disaster requires integrated approaches and activities of various related fields and organizations (Science, Engineering, Social Science, Governments, Private Enterprise, Mass Media, Inhabitants, etc.). Figure 1 shows the concept of an integrated earthquake reduction system. It shows disaster-free and disaster periods (that is the periods before and after an earthquake), and the effects of the three disaster countermeasures. When we compare the seismic force/impact to water wave and/or flood, "Mitigation" is construction of an embankment to prevent flood tide in order to prevent the hazard from becoming a disaster. The concept of "Preparedness" is to prevent the damage propagation that is difficult to be taken care of by only "Mitigation". It is like a moat prepared in advanced to store the water exceeding the embankment. The purpose of "Optimum Recovery/Reconstruction Strategy" is to minimize the negative impact by well-coordinated recovery/reconstruction activities based on proper action plan prepared before the event and modified based on the real situation. Implementation and reinforcement of these countermeasures should be done during the disaster-free period and as the basic information and essential issues for implementation of above-mentioned measures, we should properly understand the mechanism of hazards and disasters.

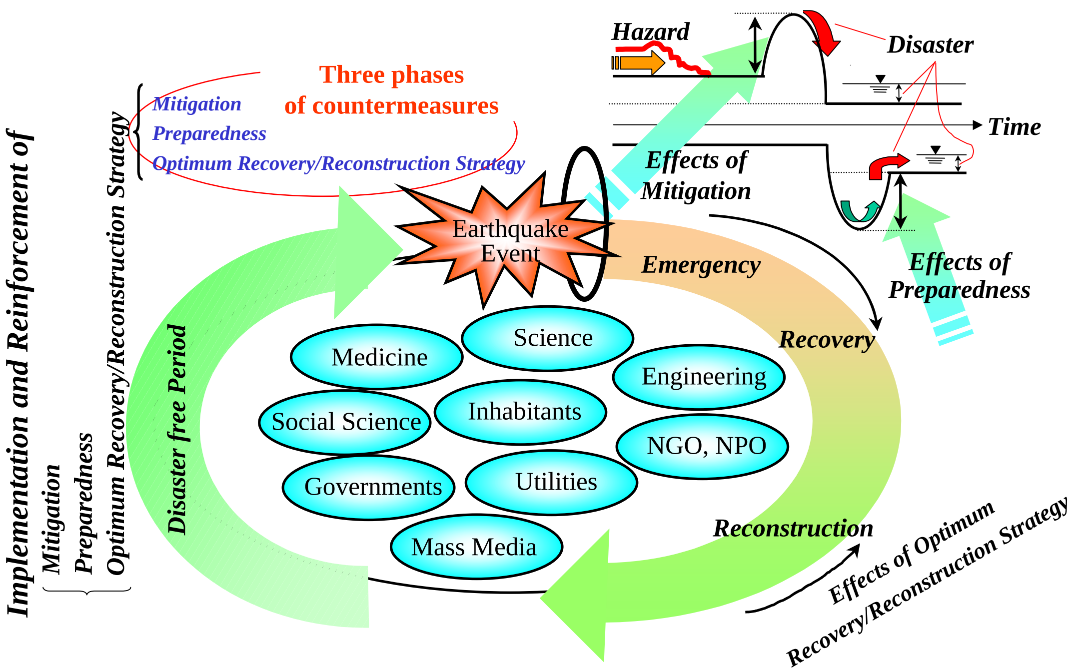


Figure 1 Integrated earthquake disaster reduction system

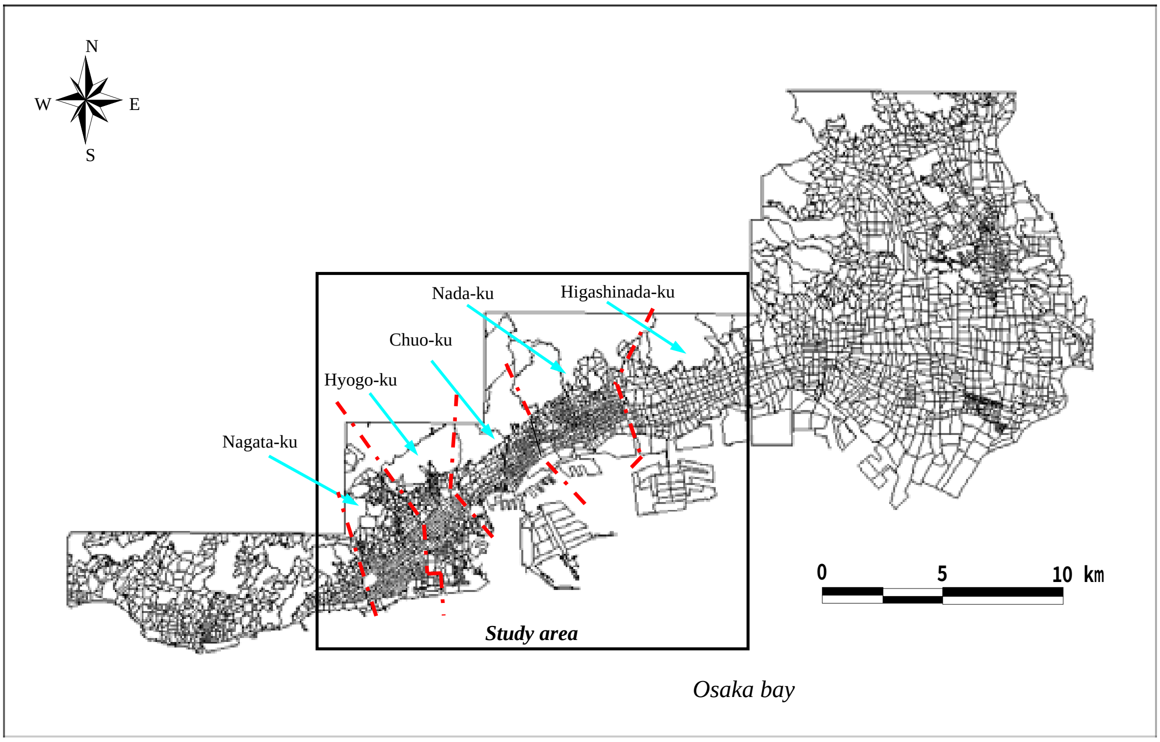


Figure 2 Study area (Kobe City: Nagata, Hyogo, Chuo, Nada and Higashinada wards)

3. OUTLINE OF THE STUDY

3.1 Study area

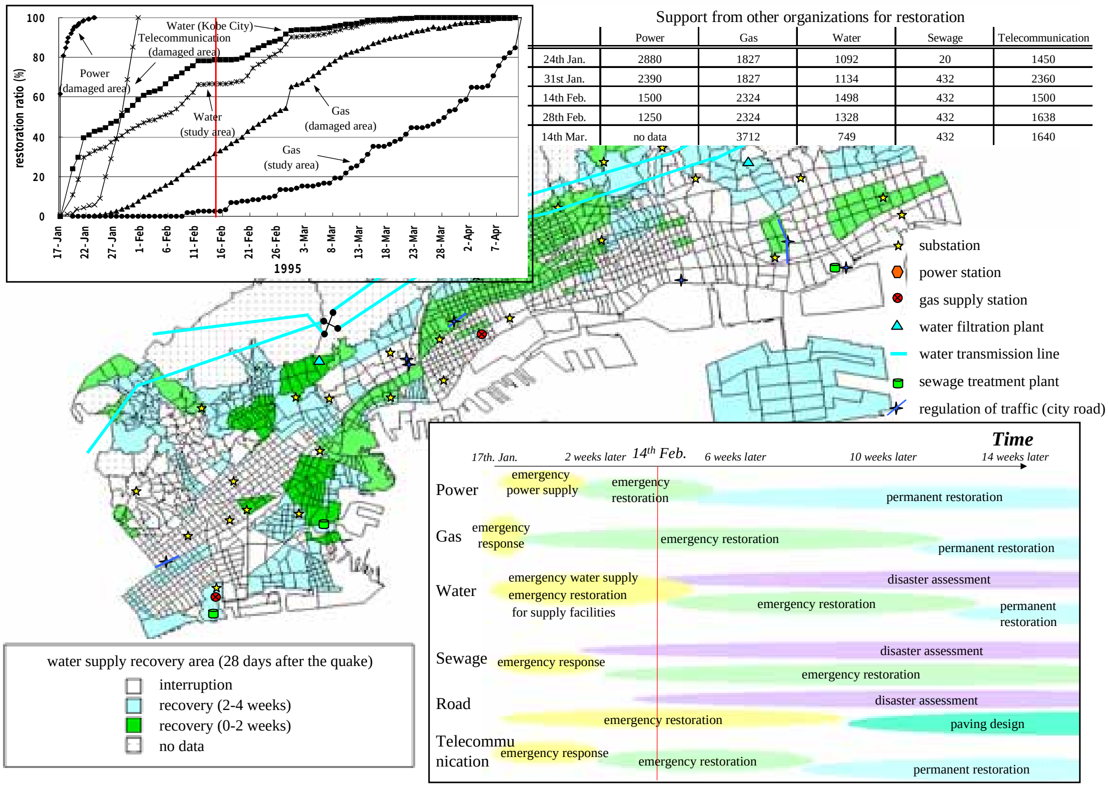
Five wards out of nine wards of Kobe City as shown in Figure 2 are taken into account in this study. These wards (Nagata, Hyogo, Chuo, Nada and Higashinada wards) were severely damaged area including seismic intensity of 7 as reported by Japan Meteorological Agency (JMA). In this area, there are 1,606 cho-cho-moku (CCM: minimum administrative unit) and 119 sectors (Gas restoration unit).

3.2 Reasons for dealing with lifelines

The main reasons to deal with lifelines in this study are as follows. “Social influence is quite large”, “Interaction exists among systems” and “It takes a long time span for recovery and reconstruction”. Figure 3 shows the phases of recovery stages of different lifeline systems after the Kobe earthquake. In case of power, we can see that the functional restoration was completed within 6 days after the earthquake when emergency activities of other lifeline utilities were still going on. However, complete recovery activities of power had not been completed and restoration activities for permanent restoration were still continued even after the functional recovery. Generally speaking, only immediate response and functional recovery are dealt with and discussed often as the fundamental issues of lifelines after an earthquake. However, the strategy of recovery and reconstruction term is an important issue and it should be studied and developed considering the situations of the other lifelines to minimize the negative impact due to a disaster.

3.3 Data collection

The data of water works was provided by the Kobe Municipal Water Works Bureau. The data consists of beginning and completion day of restoration of all distribution mains. The data of gas utility was obtained from the Osaka Gas Co. Ltd., and composed of beginning and completion day of restoration of mains and services on low-pressure pipeline.



	Power	Gas	Water	Sewage	Telecommunication
24th Jan.	2880	1827	1092	20	1450
31st Jan.	2390	1827	1134	432	2360
14th Feb.	1500	2324	1498	432	1500
28th Feb.	1250	2324	1328	432	1638
14th Mar.	no data	3712	749	432	1640

Figure 3 Water recovery area (28days after the earthquake)

4. ANALYSIS AND RESULTS

4.1 Restoration activity

In this study, the restoration activities of waterworks and gas utilities are analyzed by Geographic Information System (GIS) in order to grasp them from the viewpoint of both time and space domains. For example, Figure 3 shows the status of waterworks recovery and the other lifelines in the study area four weeks after the earthquake (24^{th} Feb., 1995). The recovery status of water and gas supply in the study area was 67% (79% in the whole Kobe City) and 3% (33% in the whole damaged area), respectively. Although this fact tells us that recovery activities in the study area were delayed comparing to other areas, the functional recovery of power and telecommunication had already been completed. Water restoration activity was completed in the Chuo-ku, where many administrative organizations and offices are located, and in the east of Higashinada-ku. After completion of these areas, recovery activities were started from the mountainside to coastal areas. At this stage, the restoration phases of power and telecommunication were changed from functional recovery to emergency or permanent restoration phase. Supporters from the other organizations for restoration rushed into the damaged areas. The most concerned issues of lifelines after the earthquake are mainly the delayed water and gas recovery, and it is commonly identified that the early functional recovery of power and telecommunication is most probably possible. However, emergency and permanent restoration activities were continued after completion of functional recovery and these activities had to share the spaces in the same roads because these facilities were installed using buried pipelines and/or suspension cables along the roads. We have identified that the interactions among lifeline systems in restoration activities are very important issues for discussing the optimum recovery/reconstruction activities of whole lifeline systems.

4.2 Problems raised during lifeline restoration activity

Initially, it was thought that the main obstacle to recovery was physical damages to supply facilities. However, it has been latter reported that there were some other problems in recovery activities after the Kobe earthquake in addition to physical damage. From the interview survey of officials in different lifeline utilities, it becomes clear that the main sources of problems of restoration activities are traffic congestion, street-blockade and damaged buildings. Sashimizu (water flowed into buried gas pipeline from broken water supply system and/or due to liquefaction) was also the major problem to gas restoration activity. The influences of traffic congestion, street-blockade, damaged buildings and Sashimizu are discussed in this research.

Table 1: Water restoration activity and street-blockade (between R-43 and Yamatekansen)

Number of blockades in one CCM* [1]	Number of CCMs in study area [2]	Number of CCMs where started restoration activity up to 23 days later [3]	Number of CCMs where their restoration activity was completed up to 23 days later [4]	Ratio of start of restoration activity [5] = [3] / [2]	Ratio of completion of restoration activity [6] = [4] / [3]
0	461	263	156	57%	59%
1	87	57	36	66%	63%
2	53	24	11	45%	46%
3	28	14	3	50%	21%
4	23	11	3	48%	27%
5,6	22	12	4	55%	33%
more than 7	20	14	4	70%	29%

* CCM: cho-cho-moku (minimum administrative unit)

4.2.1 Effects of street-blockade

The data of street-blockade was obtained from Dr. Usui of Nara University. The observations were taken on Feb. 10th, Feb. 28th, Mar. 11th and Mar. 28th, 1995 in Kobe and Ashiya Cities. Before using these data, the number of street-blockades per CCM and sector was counted. The relationship between the number of street-blockades (the units in case of water and gas are CCM and sector, respectively) and restoration activities is analyzed. Table 1 shows the street-blockades on Feb. 10th and water restoration activities. The study area of this table is Yamatekansen (City road) in the north to R-43 (National Route) in the south where there were a lot of street-blockades. We can see that the restoration ratio of the area with more than 2 street-blockades is less than that of the areas with single or no street-blockade. This shows that street-blockades played an important role in the restoration activity. Figure 4 shows the relationship between completion of gas restoration and blockade. The vertical line and the size of circle on each figure indicate the observation time of road status and the total number of working groups involved in each sector, respectively. We can see that there are a few areas with complete restoration at the early stage in the areas where the number of street-blockades is high. This indicates that the number of street-blockades impeded the gas restoration activities.

4.2.2 Effects of damaged buildings

Figure 5 shows the relationship between the number of heavily damaged low-rise buildings/houses and gas restoration activities. The size of circle is the total number of groups of workers involved in each sector. We can see the tendency that the starting time of restoration activity was late when the number of heavily damaged buildings was larger. In the figure, Group 1 or 2 includes exceptional sectors against this tendency. Group 1 is an area where the progress of restoration activity was not easy due to the heavy damage and the restoration was started at the early stage. Group 2 is an area where the efficiency of the restoration activity was not so good, although the magnitude of damage to buildings was low and the restoration activity started at the late stage. The characteristics of each sector belonging to Group 1 were investigated (Table 2). The number of street-blockades in sectors A and C was large. It was thought that the interactions between water and gas restoration was one of the major causes because the restoration activities were carried out at the same time. In the sector in the coastal side (Group 2), the number of collapsed buildings was less due to low building density, however because of liquefaction, duration of restoration activities became longer. The other sectors include busy street areas (around Sannomiya), it is thought that the restoration activity was done carefully in order not to hinder the business activity of the area.

4.2.3 Effects of "Sashimizu" (water flowed into gas pipeline)

Figure 6 shows the effects due to Sashimizu. The region surrounded by ellipse lined region includes the areas where the efficiency of the restoration was not so good, although the number of heavily damaged buildings was small. From the investigation of these sectors, we found that the influence of Sashimizu was very large in these areas.

4.3 Towards optimum recovery/reconstruction strategy

It is essential to discuss the efficient restoration order for obtaining "the total best" considering the other lifeline systems. To improve the situation, it is important to collect and share information of the location of physical damage and the changes of conditions in time domain. To make this task simple, preparation of a mutual collaborative system is important because there are many factors that affect the recovery/reconstruction activities. The important point is that these factors change with time and space. It was difficult for each organization to

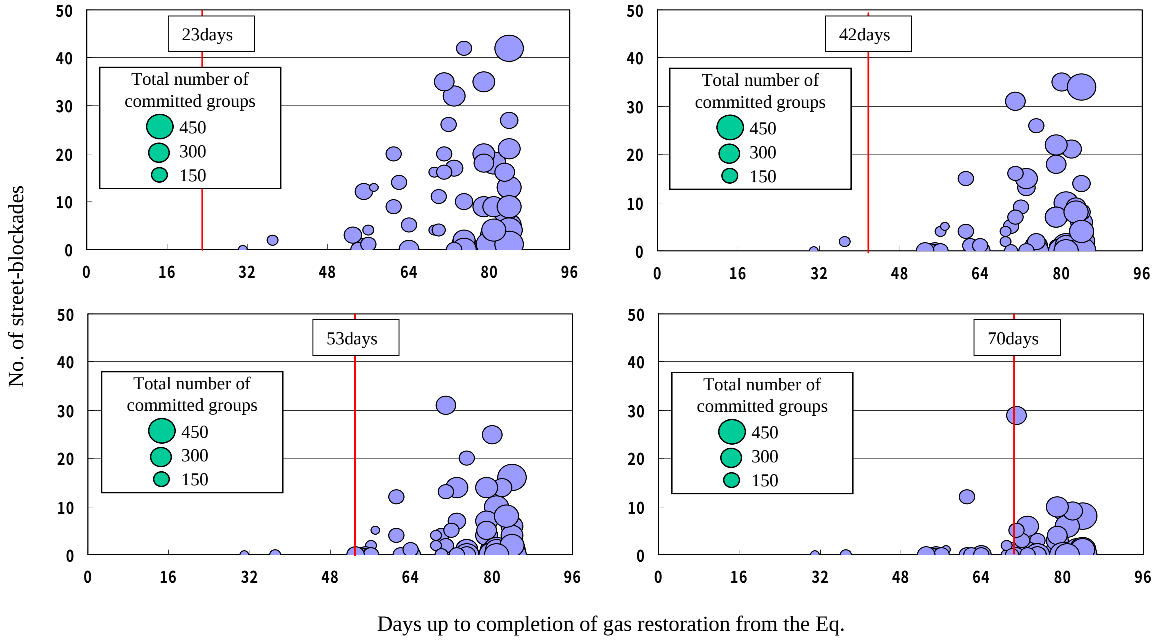


Figure 4 Relation between gas recovery and street-blockade in each sector

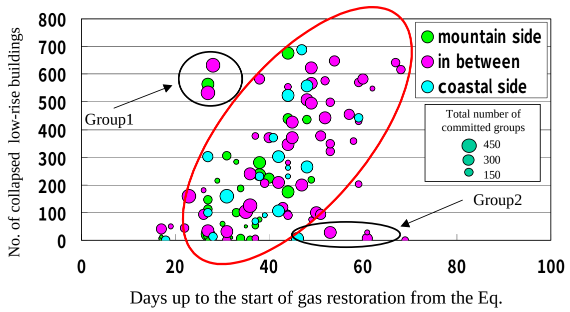


Figure 5 Effects of the damaged buildings on the recovery activities of gas system

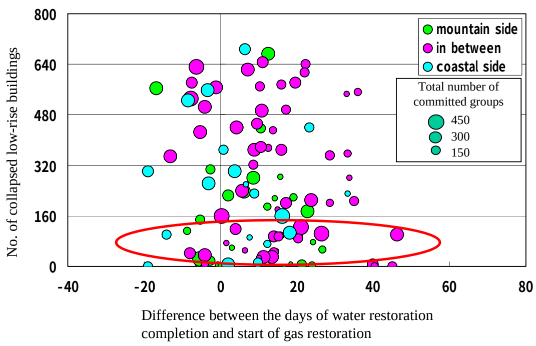


Figure 6 Effects of Sashimizu on gas restoration activities

Table 2: Character of Group 1 on Figure 4

Group 1	Number of the blockades (23days after the Eq.)	Difference between the days of completion and start of gas restoration activity	Total number of groups involved in each sector
A	42	-8	531
B	1	-6	467
C	22	-17	341

know by itself the restoration activities of other utilities such as situation of progress and order or plan of restoration works, real time information on traffic and road situation, and distribution of damaged buildings and demolishing work, etc. From the result of this analysis, we strongly recognized that we should study the system by which related information can be shared and updated in real-time basis because they severely influence the progress of restoration activities.

5. CONCLUSIONS

In this research, we point out the problems that affect the recovery/reconstruction activities (traffic congestion, street-blockade, damaged buildings and Sashimizu) and analyze their effects based on real data of restoration activities. These problems were very difficult for individual lifeline utility to solve appropriately by itself independently. This indicates that it is important to prepare the mutual collaboration system to share and update the information in order to carry out proper recovery and reconstruction activity with strategy after an earthquake. Based on the study, we understand that development of methodology for evaluating the effects of interactions among recovery/reconstruction activities by different lifeline utilities is important and proper objective function by which optimum recovery/reconstruction strategy can be discussed quantitatively should be studied.

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ABSTRACT

With urbanization, interdependency of urban functions has been getting larger and larger. Once a disaster occurs in urban areas, its influence causes not only structural damage, but also functional damage to various lifeline systems and affects the lives of the people in damaged areas. It is, therefore, important for many related fields/organizations to collaborate with each other for developing an integrated earthquake disaster reduction system. In general, there are three kinds of countermeasures for disaster reduction. They are "Disaster Mitigation", "Disaster Preparedness" and "Optimum Recovery/Reconstruction Strategy". The objective of this study is to propose an optimum restoration model considering interactions among related organizations. At the first step, we have collected the data on actual restoration activities of each lifeline utility after the 1995 Kobe earthquake and analyzed them from the viewpoint of both time and space domains. We found that there were several problems raised during lifeline restoration activities, such as "traffic congestion", "street-blockade", "damaged buildings" and "Sashimizu (water flowed into buried gas pipeline from broken water supply system and/or due to liquefaction)", and introduced their effects based on the real data. From the results of the study, we can say that there are severe problems/obstacles that cannot be solved appropriately by individual lifeline utility with independent measures and integrated approach is very important for decreasing the total negative impact due to a disaster.

TOPIC

LIFELINE SYSTEMS: Case Studies & field evaluation of lifelines

KEYWORDS

1995 Hyogo-ken Nanbu earthquake, Earthquake damage, Interaction effects, Lifeline damage, Lifeline system, Reconstruction, Recovery, Restoration activity, Restoration strategy, System interaction