ROAD BLOCKAGE IN AN AREA AFFECTED BY THE GREAT HANSHIN-AWAJI EARTHQUAKE AND INFULUENCE OF BLOKAGE ON TRAFFIC FLOW
–The study area: Eastern part of Higashinada-ku, Kobe City, Hyogo Prefecture, Japan

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Abstract: In the case of the Great Hanshin-Awaji Earthquake in Japan in 1995, street blockages occurred in narrow roads in many residential areas because of collapsed buildings, toppled poles or damaged pavement. This study aims to analyze the influence of street blockages on traffic flow on the eastern part of Higashinada-ku of Kobe City where damage was especially extensive. First, through the examination of aerial photos, we studied how relatively narrow roads in the area became blocked immediately after the earthquake. We then studied the distribution of vehicle traffic and parked vehicles on the road networks in an effort to understand the overall traffic situation at that time in the area. Further, with a view to securing passages for rescue and emergency vehicles in the event of disasters, we demonstrated the effects of road blockage on traffic flows through the quantitative analysis of vehicle mobility on the road network in the area.

1. INTRODUCTION

An earthquake of tremendous strength hit the southern part of Hyogo Prefecture on the early morning of January 17, 1995. Named the Great Hanshin-Awaji Earthquake, the violent tremor destroyed scores of houses, buildings, and other structures, owing largely to the fact that its focus was directly below the urban area. Casualties were heavy. All the lifelines of electricity, gas, and water were cut off, and roads and railway lines were torn almost everywhere, throwing the urban functions into complete chaos. Not only main roads between and within the cities were seriously affected, but other minor routes that ran through residential areas suffered great damage as they became blocked by toppled houses and fires. Those road blockages posed serious problems. (See Tukaguchi (1996), Tokunaga (1996) and Ieda (1997)) Immediately after the earthquake, they hindered people from evacuating to safer places. Those obstacles also made it difficult for emergency vehicles and heavy machines to enter the affected places to come to the rescue of the injured and others trapped inside the collapsed houses. In some areas, it took several months to remove damaged structures. Many roads remained blocked not only immediately after the quake, but for quite a while (for several months in some areas). As a result, the efforts to supply relief items and daily necessities to the shelters there were seriously hindered, and the work to restore gas and water lines was delayed. They also made it difficult to secure school routes for children.

This study focused on the eastern part of Higashinada-ku of Kobe City where damage was especially extensive. First, through the examination of aerial photos, we studied how relatively narrow roads in the area became blocked immediately after the earthquake. We then studied the distribution of vehicle traffic and parked vehicles on the road networks in an effort to understand the overall traffic situation at that time in the area. Further, with a view to securing passages for rescue and emergency vehicles in the event of disasters, we demonstrated the effects of road blockage on traffic flows through the quantitative analysis of vehicle mobility on the road network in the area.

2. STUDY AREA AND SURVEY METHOD

2.1 Study area

Fig. 1 shows the areas affected by the Great Hanshin-Awaji Earthquake, with black strips marking the places particularly hard hit by the quake (registering the intensity of 7 on the JMA (Japanese Meteorological Agency) scale). In this study, we surveyed the eastern part of Higashinada-ku of Kobe City (including part of Ashiya City, about 325 ha), which is right on the intensity-7 black belt as shown in Fig. 1.

Fig. 2 shows a network of roads in the study area with their widths indicated by the thickness of the road lines. The area borders on the Yamate kansen (the main road on the mountain side, which does not run all the way through the area) to the north and National Route 43 to the south, with Route 2 running through the middle East and West. Fig. 3 shows the ratios of road widths in the area, calculated in terms of the aggregate lengths of the roads. Of the entire road lengths in the area, those measuring 6 meters or less in width account for 47.1 percent and those measuring 4 meters or less for 12.4 percent (for Route 2, Route 43 and others with median strips, we added up the road lengths in each direction).

Shown in Fig. 4 is the extent of damage to structures (collapse percentage) in each of the 43 town blocks in the study area. Structural damage to varying degrees was evident in every single town block, with the overall collapse percentage reaching as high as 54 percentage. Damage was especially serious in places near the municipal borders with Ashiya City and Kobe City and between the JR line and Route 2, with the collapse percentage exceeding 70 percent in some sections.

2.2 Survey method

To study the extent of road blockage, about where roads became blocked and how and why, we

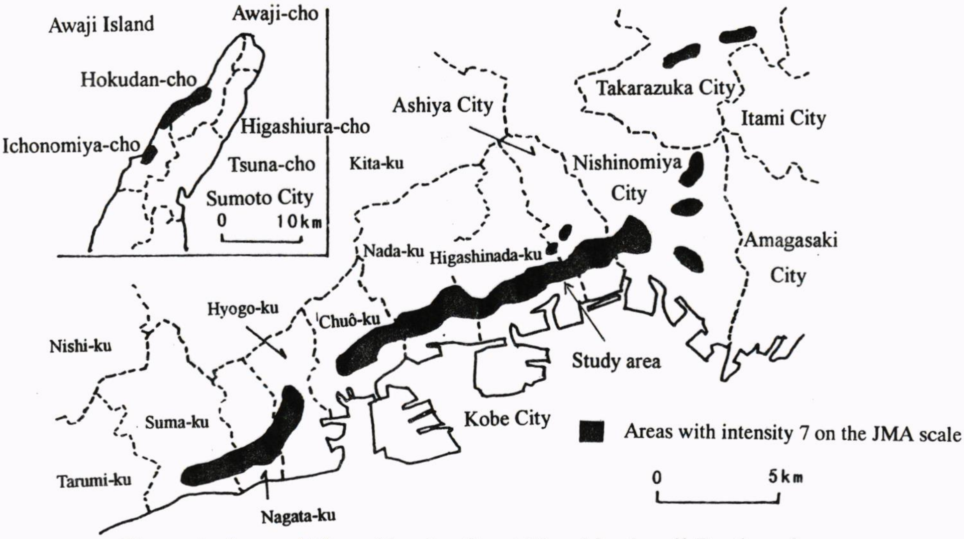


Figure 1. Areas Affected by the Great Hanshin-Awaji Earthquake

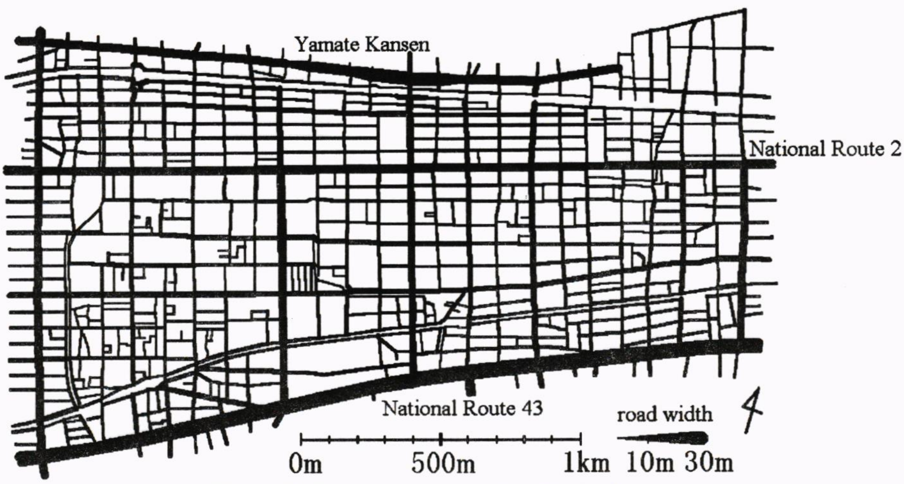


Figure 2. Road Network in the Study Area
(East of Higashinada-ku,Kobe City,including part of Ashiya City)

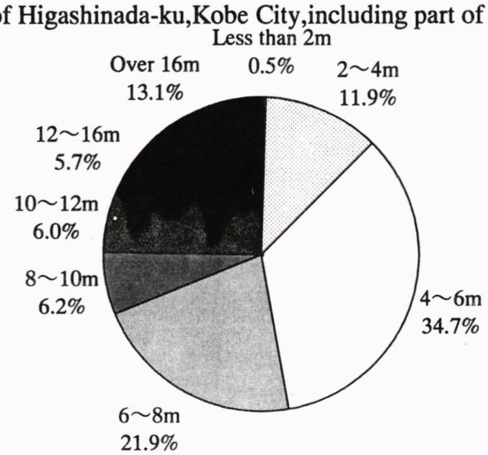


Figure 3. Road Width Ratios

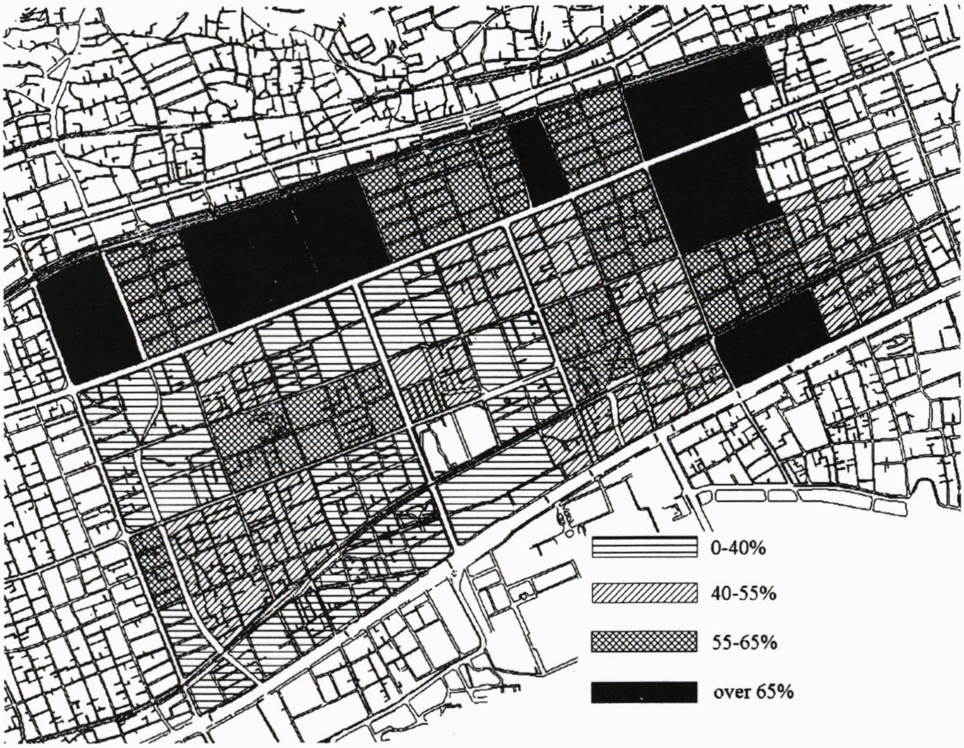


Figure 4. Structure Collapse Ratios in Town Blocks

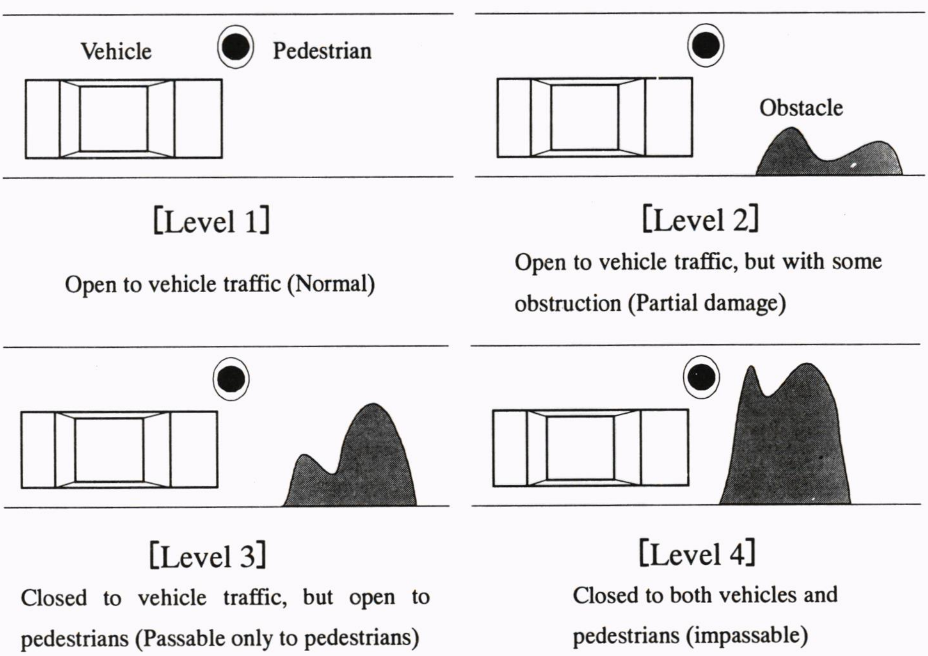


Figure 5. Extent of Road Blockage in Four Levels

examined the aerial photos of the entire study area (1:4000 scale, January 17, 1995; and 1:5000 scale, January 18, taken by Kokusai Kogyo Co., Ltd.). Where these photos were insufficient, we walked the area and conducted a resident hearing survey to obtain more detailed data. Road divisions we surveyed numbered 1,711 in all. The extent of blockage to the road was divided into four levels depending on the passableness of the road to pedestrians/bicycles and automobiles, as shown in Fig. 5. Photo 1 (road width 12 m), Photo 2 (6 m) , and Photo 3 (4 m) each show the extent of blockage to the roads.

To understand how the traffic flow was affected, we counted the number of moving vehicles on the 17th and 18th of January in the study area, by link, direction, and vehicle type (passenger cars or commercial vehicles). We also counted the number of cars parked in the area on each day (those parked on the road and those parked in parking lots and evacuation zones).

3. ROAD BLOCKAGE

3.1 Blockage in the road network

Fig. 6 shows these four levels of road blockage, indicated by line types, in the survey area. Of the total 1,711 road blocks, 521 or 30.5 percent suffered damage to varying degrees--Level 2 of road blockage is seen in 191 blocks, Level 3 in 185 blocks, and Level 4 in 145 blocks. Within the survey area, main roads including Route 2 and the Yamate (mountainside) route escaped with less damage, with the exception of Route 43 along the southern edge of the area where some sections of the road became completely blocked from the toppled Hanshin Expressway. On the other hand, road blockages were frequent and severe in narrower town streets, especially in places north of Route 2 where structural damage was serious and in the east near the borders of Kobe City and Ashiya City.

3.2 Extent of road blockage by road width

Fig. 7 shows the extent of road blockage by road widths divided into seven levels. The lengths of the roads of the same width were added up for comparison. As seen in the graph, the narrower the road, the more serious and frequent the road blockages, with the exception of Route 43 where a stretch of the road on one side (16 meters or more in width) became totally impassable to automobile traffic because of the collapsed expressway. A closer observation reveals that roads, even if partially damaged, still allowed automobile traffic to some degree if their widths were 12 meters or more, but that the roads became blocked to automobile traffic (about 25 percent of total road lengths) and even to pedestrians (about 10 percent) if they were 6-8 meters in width. These figures sharply increased to 40 percent (blocked to automobiles) and 25 percent (blocked to pedestrians) when the roads were less than 4 meters in width. As these data clearly show, roads even with partial blockages can be expected to remain passable in ordinary residential areas if they are at least 12 meters in width. We can say from these data that roads wider than 8 meters are likely to sustain far less damage than those that are narrower.

Photo 1. Local Distributor Road Blocked by Toppled Houses (road width :12m)

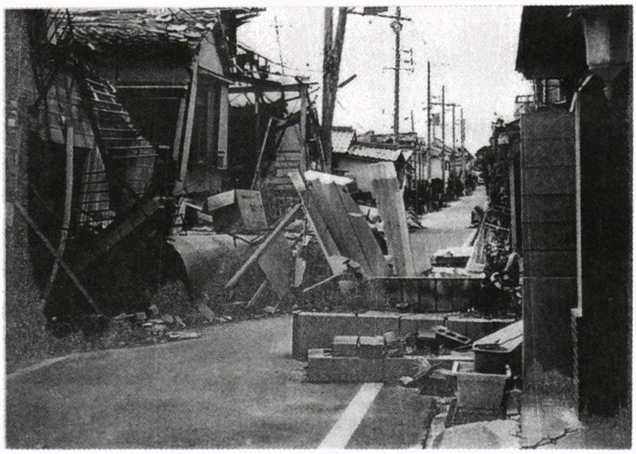


Photo 2. Residential Road Blocked by Toppled Gate Poles and Chimneys (road width :6m)

Photo 3. Residential Road Blocked by Toppled Fences
and Houses that Lined the Street (road width :4m)

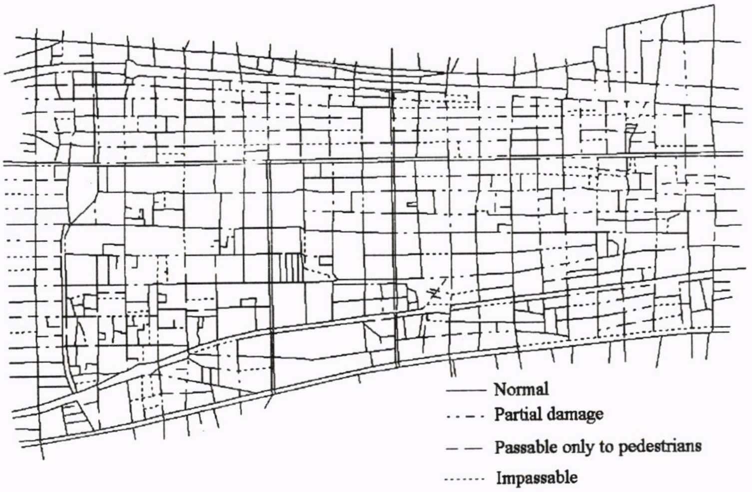


Figure 6. Extent of Blockage on the Road Network

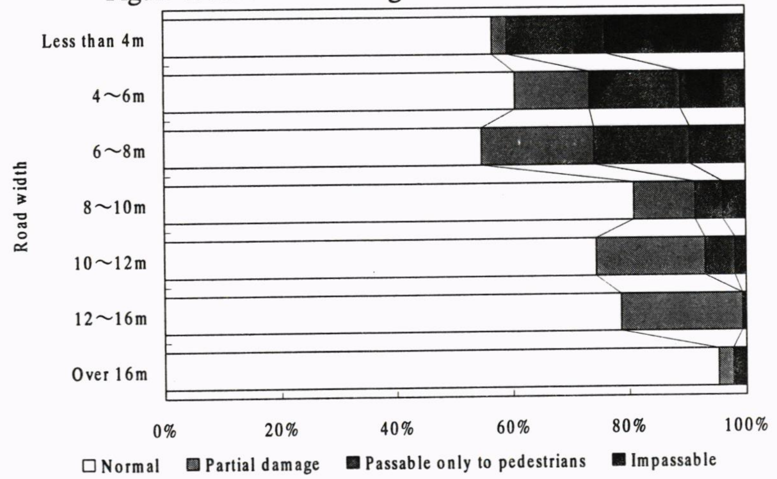


Figure 7. Ratios of Blockage Levels by Road Width (in total road lengths)

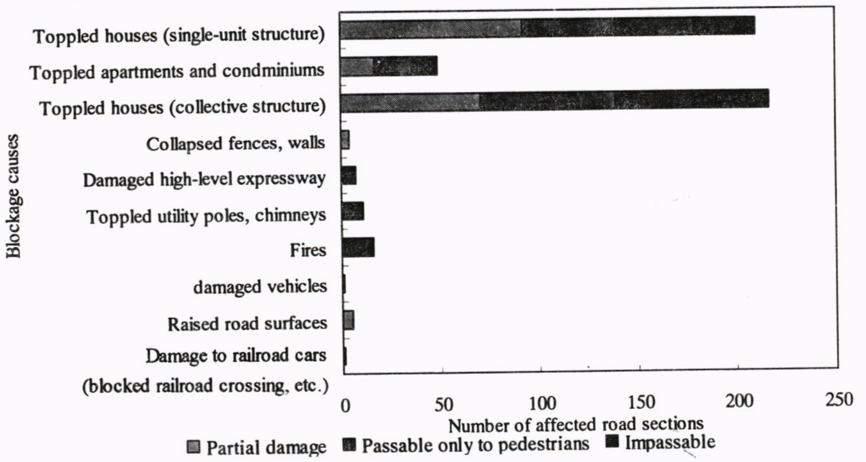


Figure 8. Frequency of Main Road Blockage Causes by Road Section

3.3 Analysis oı road blockage

Several factors apparently contributed to the road blockages in the study area. In this paper, we ranked the extent of blockage by road link, analyzing the most serious causes of blockages in each link. Fig. 8 shows main road-blocking causes and the extent of their contributions to road blockages. We can see in the graph that collapsed houses, both single unit structures and collective units, were a major factor causing extensive road blockages, followed by collapsed condominiums and apartment buildings. Other causes include fires, toppled utility poles, and damaged fences and walls.

4. AUTOMOBILE TRAFFIC

4.1 Moving vehicles

Fig. 9 shows the flow of road traffic at 3 p.m. on January 18 on the road network immediately after the earthquake (based on the aerial photo). The dotted lines show sections impassable to automobiles, with the thickness of the lines indicating the number of moving vehicles per link length. The drawing shows that there were traffic jams on the main roads and sub-main roads, especially where the Yamate main road merges with Route 2. On the other hand, there was virtually little motor traffic along other minor roads in the area because of extensive blockages. However, there is a sign of traffic congestion in the northeastern part of the area even though the roads are very narrow there, indicating that drivers used them to avoid heavy traffic jams on the main roads.

Table 1 shows the number of vehicles counted on January 17 and 18, by direction and by road types (main and minor roads). As these numbers show, the east-west traffic was heavier than the north-south traffic, and there were more east-bound cars and trucks than west-bound ones. This means that more drivers headed for less damaged areas (mainly Osaka). By date, the overall traffic volume declined from the 17th to the 18th, but the volume of cargo traffic increased on the main roads, especially the west-bound ones, apparently as a result of the stepped up efforts to transport rescue and relieve items into the affected areas. The volume of cargo traffic was very small on other roads, as shown in the table.

4.2 Parked vehicles

Fig. 10 shows the distribution of parked vehicles in the study area, traced from the same aerial photo taken at 3 p.m., January 18. As in Fig. 10, the dotted lines show the road blocks impassable to motor traffic, the number of vehicles parked per link length is indicated by the thickness of the lines, and that of vehicles parked in school yards and other open spaces by the size of circles. As this map shows, vehicles parked on the roads were frequently seen along the portions of the main roads with relatively less traffic, near large condominiums, and close to parks and schools where people were evacuated.

Table 2 shows the number of vehicles parked on January 17 and 18, grouped by where they were

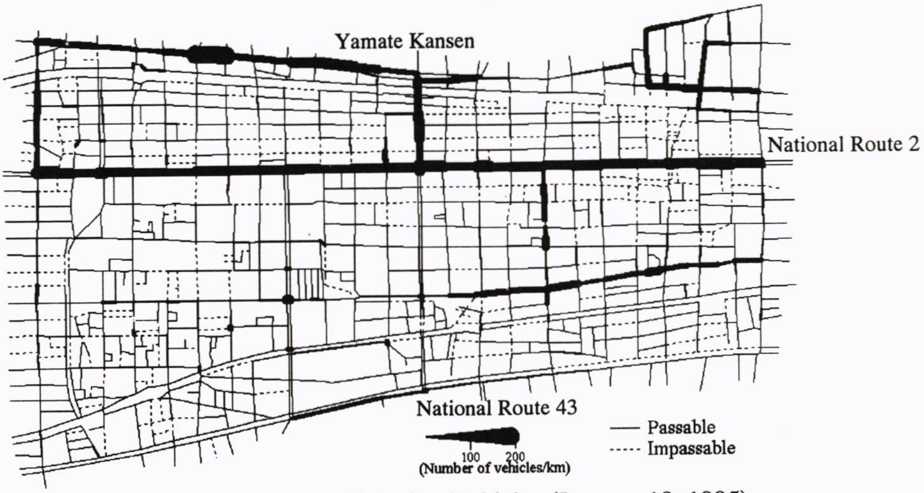


Figure 9. Distribution of Moving Vehicles (January 18, 1995)

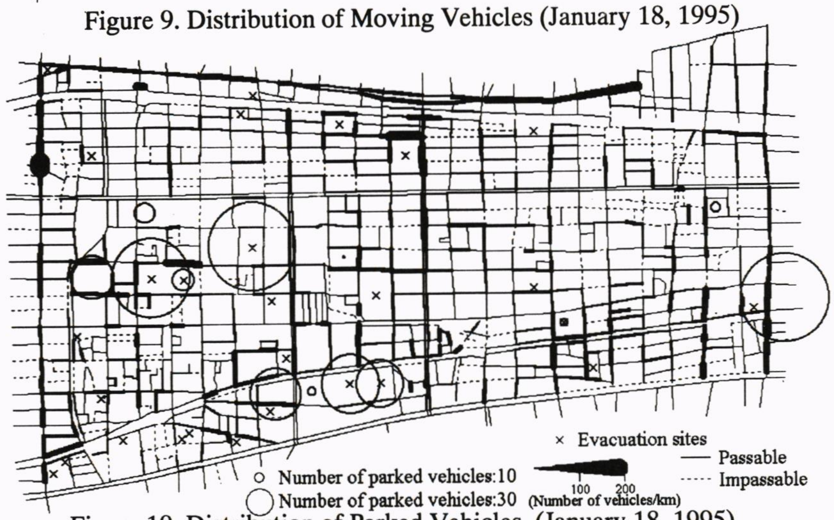


Figure 10. Distribution of Parked Vehicles (January 18, 1995)

Table 1. Number of Moving Vehicles by Direction

		17th		18th	
		Main roads	Others	Main roads	Others
East-west	To east	1021	77	1078	77
		(135)	(0)	(178)	(2)
	To west	491	69	218	99
		(8)	(1)	(82)	(1)
	Total	1512	146	1296	176
		(143)	(1)	(260)	(3)
North-south	To south	109	63	122	106
		(0)	(5)	(10)	(8)
	To north	248	56	72	64
		(62)	(2)	(9)	(4)
	Total	357	119	194	170
		(62)	(7)	(19)	(12)

( ): Number of trucks

Table 2. Number of Parked Vehicles by Site (number of vehicles/day)

	17th	18th
On street	2431	2336
Parking space	6100	5169
Evacuation site etc.	72	608

parked. The number of those parked on the roads remained about the same between these two days. Vehicles parked off the roads dropped by about 900 in number, while those parked in school yards, parks and other evacuation spaces sharply increased by about 550. We can surmise from these numbers that scores of people affected by the earthquake took their vehicles out and used them for shelters.

5. ASSESSMENT OF VEHICLE MOBILITY

5.1 Impassable link lengths and the number of isolated nodes

As defined, Level 3 and Level 4 roads are blocked to automobile traffic. These portions of the roads blocked to traffic created sections or nodes (hereinafter referred to as isolated nodes) completely cut off from the surrounding area. Of the entire link lengths that allow automobile traffic under normal circumstances, about 13.9 km or 20.4 percent of the total has become impassable following the quake and isolated nodes appeared at 64 points (5.7 percent of the total number of nodes). Of these, 21 nodes were inaccessible even by bicycles and pedestrians, posing a serious problem over the rescue and relief operations.

5.2 New approach toward automobile mobility during disaster

In this study, we attempted a quantitative analysis of how the mobility of rescue and relief vehicles was affected by blocked roads immediately after the earthquake. (See Li (1996 and 1997) As stated in 3. above, very few roads measuring 12 meters or more in width became completely impassable to automobiles, with the exception of portions of the main road along the collapsed Hanshin Expressway. Assuming that any main roads and others 12 meters or more in width allow automobile traffic even in the event of a major earthquake, we regarded an area surrounded by these roads as a single section. With several of these sections set up in this way, we then measured accessibility by car between these sections and their surrounding roads in both directions (from surrounding roads into sections and vice versa). The following three indicators were calculated:

(1) Ratio of impassable link lengths: Ratio of total road link lengths rendered impassable to vehicles to those (excluding surrounding road lengths) passable to vehicles under normal circumstances in the study area.

(2) Ratio of isolated nodes: Ratio of nodes that became isolated by road blockages to the total nodes within the area (excluding nodes on surrounding roads).

(3) Increase rate of minimum route lengths: Percentage at which the minimum route lengths increased after the roads became blocked following the quake. Here, the minimum route lengths are the distances between nodes inside each section and nodes on the surrounding roads at four corners of the section; we took the average of four route lengths before and after the quake when the roads became blocked. Isolated nodes were excluded from this calculation as the rate became infinite there.

5.3 Comparison of mobility in the sections

In this study, we divided the area into eight sections by the main roads and minor ones and calculated the above three indicators for each section, as shown in Fig. 11. Fig. 12 shows links impassable to automobiles, positions of isolated nodes and increase rates of the minimum route lengths in each section.

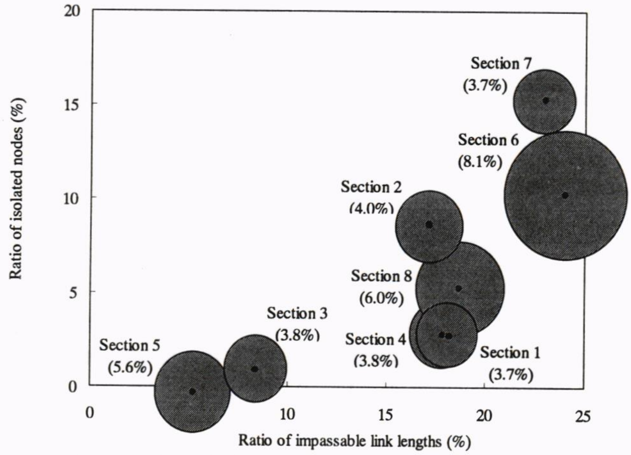
As it is clear from Fig. 11, the greater the ratios of impassable link lengths, the larger the ratios of isolated nodes. The ratios of isolated nodes are not the same from one section to another even at the same impassable link length ratios, attributable to network shapes and at what points the roads became blocked on the network. There appears no clear correlation between the increase rates of the minimum route lengths and the link lengths ratios or isolated nodes ratios.

By area, vehicle mobility was the lowest in Section 6 and Section 7 (rates of minimum route lengths increase are not considered here). Isolated nodes are found concentrated at some points within these sections, as shown in Fig. 12. All of them are narrow roads 4 meters or less in width, with a heavy concentration of old wooden houses along the streets. Vehicle mobility was also low, but to a lesser degree, in Sections 1, 4, 8, and 2. Section 3 and Section 5 escaped with less damage.

As for the rates of the minimum route lengths increases, the average is the largest for Section 6 as a whole. Scores of isolated nodes appeared in this section, and the drivers would often have to go around even after reaching these points. In the other sections, large increases in the rates of minimum route lengths are often locally seen. Several factors can be attributable to these large rates, including the presence of blocked road portions, a low road density within the section, and the occurrence of road blockages in some parts of the surrounding roads. In addition, it was sometimes difficult to set alternative routes in some places because of the presence of railroad crossings and other obstacles.

5.4 Importance of road links

We analyzed the importance of individual road links about their roles in securing traffic mobility in the study area. First, we compared two situations in each of these eight sections--when the road link is blocked and when there is no link blockage--and then calculated the rate of the minimum route lengths. The results are an indicator of the importance of each road link. Fig. 13 shows the results of this calculation in each section. The increase rates are indicated in three levels in the map. As can be seen, of the links are less important in sections where there are grid-like road networks because of the relative ease of obtaining alternative routes there. (In usual case, grid like road networks are easy to allow through traffic, and some traffic management measures should be implemented to exclude those traffic.) In comparison, links are more important when there are surrounding roads and railroad crossings and other roads connected to them where it is difficult to obtain alternative routes. In other words, it is important that these roads remain unclogged in the event of a disaster.



Note: The size of the circles and percentages in the parentheses indicate the rate of the minimum route length increases.

Figure 11. Comparison of Vehicle Mobility by Section in the Study Area

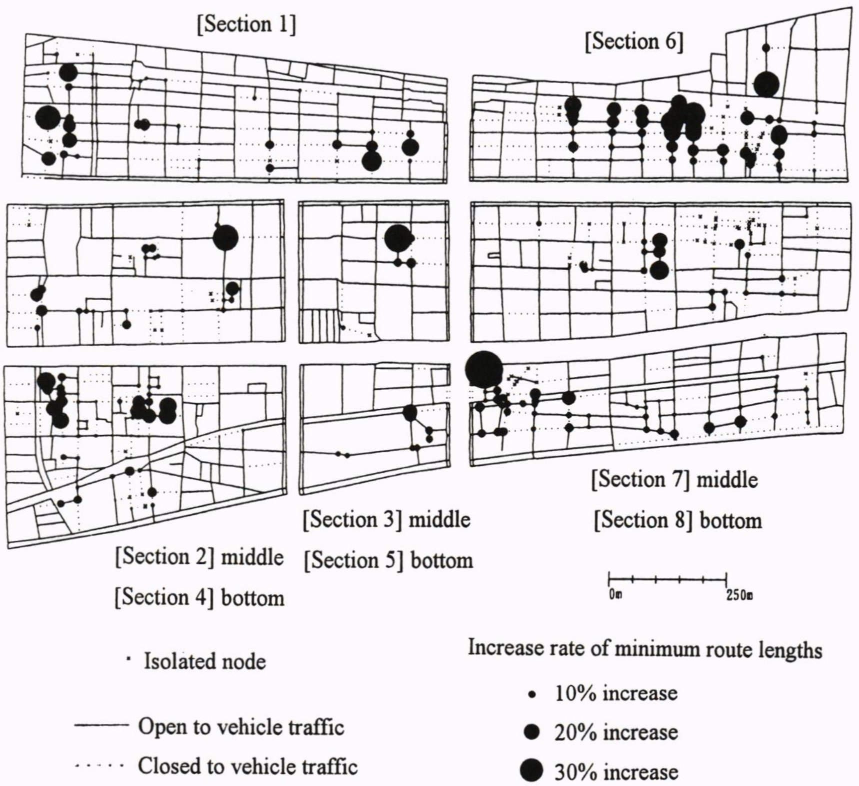


Figure 12. Vehicle Mobility by Section

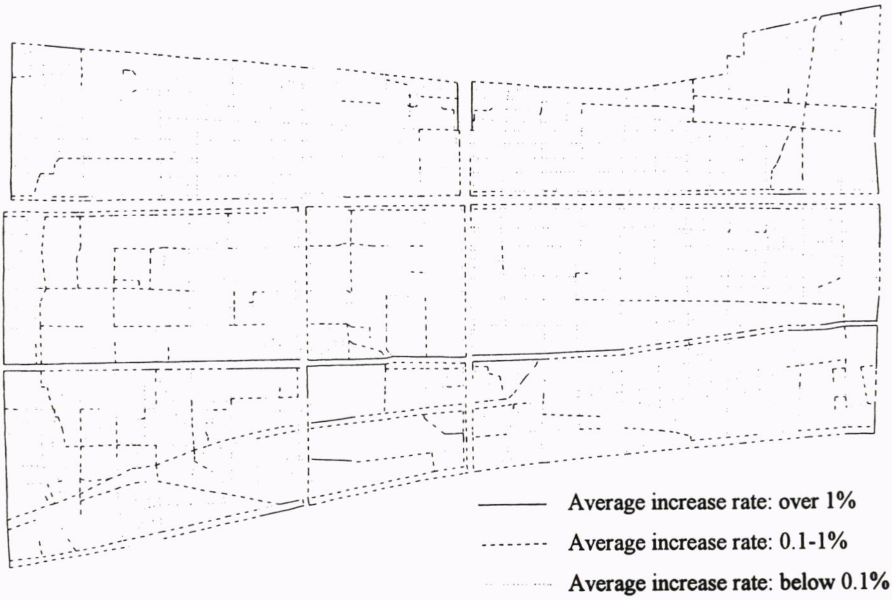


Figure 13. Importance of Road Links, Calculation Results

6. SUMMARY

In this study, we examined how the roads became blocked and how traffic flows were affected immediately after the Great Hanshin-Awaji Earthquake based on aerial photos of the survey area. At the same, we analyzed, quantitatively, how vehicle mobility was affected as a result of road blockages. The findings of the study are as follows:

1) The aerial photos taken immediately after the quake enabled us to divide the extent of road blockages into four levels.

2) It was found that roads measuring 12 meters or more in width retained their functions as viable traffic routes in the ordinary residential area, and that quake-caused damage to the roads increased when the road width was 8 meters or less.

3) Toppled utility poles and fences of private houses and fires were among the factors contributing to road blockages, most of which were caused by collapsed houses that lined the streets.

4) Traffic jams were mostly on the main roads, but virtually no traffic flows were seen in the study area because of extensive road blockages. Vehicles were frequently parked on the streets, especially in school yards, parks and other evacuation spaces in the area, indicating that many people evacuated in their vehicles.

5) Our study on detour routes and isolated nodes enabled us to locate points which became closed to varying degrees to emergency/rescue vehicles following the quake. Further, the analysis of road links based on detour routes calculations showed the importance of grid-shaped road networks and problem with railroad crossings and other roads for which alternative routes are difficult to find.

In some urban areas, relatively narrow roads are being used as main routes. In the event of a major disaster such as the one caused by the Great Hanshin-Awaji Earthquake, blocking of those roads is expected to deal a serious blow to the functions of these areas. As this study shows, road widths as well as types of structures along the roads largely contribute to road blockages. Moreover, such road conditions as the presence of street trees, utility poles, pedestrian paths, and guardrails also make the difference. These factors were not taken up in this study, but their influence over road blocking has been reported in other studies. All these factors discussed above in this paper must be taken into consideration in making viable disaster prevention plans. The challenge is to design road networks that they retain their functions to a satisfactory degree even in the event of a major disaster.

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