ANALYSIS OF TRAFFIC SITUATION IN DISASTER AREA AFTER THE GREAT HANSHIN-AWAJI EARTHQUAKE IN 1995 BY USING AERIAL PHOTOS

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Abstract: In the Great Hanshin-Awaji Earthquake in Japan 1995, not only main roads, but also other minor roads suffered great damage. As a result, a great deal of car traffic converged on the limited road, causing a huge congestion immediately after the quake. Furthermore such congestion made it difficult for emergency and rescue vehicles to move. However, it was difficult to grasp the actual traffic situation at that time because the traffic control center was paralyzed. In this study, through the examination of aerial photos which were taken on the day of the quake and the next day, we showed the distribution of road damage and the traffic situation on the road network in the disaster area immediately after the quake. We then analyzed the influence of the damage to traffic flows on both main and minor roads. The study covered the seaside area of Kobe City where damage was extensive.

Key Words: Traffic Situation, Aerial Photo, Great Disaster

1. INTRODUCTION

An earthquake of tremendous strength, named the Great Hanshin-Awaji Earthquake, hit the southern part of Hyogo Prefecture on the early morning of January 17, 1995. Not only main roads between and within the cities were seriously affected, but also other minor roads that ran through residential areas suffered great damage as they became blocked by toppled houses and fires. Moreover, since the traffic control center did not work, it was difficult to grasp the degree of road damage and implement a quick traffic restriction. As a result, a great deal of car traffic converged on the limited roads, causing a huge congestion immediately after the quake. Such congestion not only made it difficult for emergency and rescue vehicles to move, but also affected people's life immediately after the quake. It is very important to grasp the road damage and how roads were used immediately after the disaster in order to implement traffic control, rescue and relief measures.

There was, however, only scant data left to know the actual traffic situation at that time because the traffic control center was paralyzed as mentioned above. Even so, some studies have been done to grasp the road damage and the traffic situation by aerial photos taken immediately after the quake. First, the degree of road damage caused by the quake was studied in several districts of the disaster area by Ieda *et al.* (1997), Tsukaguchi *et al.* (1996) and Odani *et al.* (1996,1997,1999). Tsukaguchi *et al.* (1997) also estimated the traffic volume on the trunk roads in the seaside area of Kobe City on the next day and on the third day of the quake. These studies, however, failed to clear some points. For instance, although road damage was examined in limited districts, the degree of damage across the entire disaster area was not clear. Although the influence of road damage on the moving vehicles was shown, how parked vehicles affected moving vehicles was not considered.

In this study, through the examination of aerial photos which were taken on the day of the quake and the next day, we aimed to show the distribution of road damage and the traffic situation on the road network in the seaside area of Kobe City immediately after the quake. We then analyzed the influence of the damage on traffic flows on both main and minor roads. First, we studied how and where roads became blocked, and then showed the distribution of moving and parked vehicles on the road network in order to understand the overall traffic situation at that time in the area. We also demonstrated the influence of road blockages on traffic flows through the estimation of traffic capacities on the road network.

2. STUDY AREA AND SURVEY METHOD

2.1 Study area

In this study, we surveyed the established city area located in the seaside area of Kobe City, over which the aerial photos were taken. Fig.1 shows a road network in the study area. The area borders on Ashiya City to the east and National Route 428 in Hyogo Ward to the west. The main traffic corridor, connecting the west and east parts of Japan, runs through in the disaster area, and 250,000 vehicles a day passed through the trunk roads before the quake. Moreover, there are only a few access routes connecting the affected area to the one behind Mt. Rokko. The study area has 2,200ha with the total road length of 643km. The road network consists of 13,905 links and 10,460 nodes. Fig.2 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, the aggregate lengths of roads measuring 8 meters or less in width account for about 70% and those measuring 4 meters or less account for 25%.

2.2 Survey method

We used the aerial photos taken by Kokusai Kogyo Co.,Ltd on the day of the quake and the next day (See Uranaka *et al.*, 2000). The following provides the general information of these photos.

- January 17, 1995 (13:09～14:11), 43 Photos,
  Interval of photography 7-20sec
- January 18, 1995 (14:29～15:14), 38 Photos,
  Interval of photography 12-22sec

We chose the photos which partially overlapped each other. After enlarging these photos to twice the size (about 1/5,000 scale), we counted the following items on each road link between two crossings.

- Road blockages on each road link (passable or impassable to vehicles.)

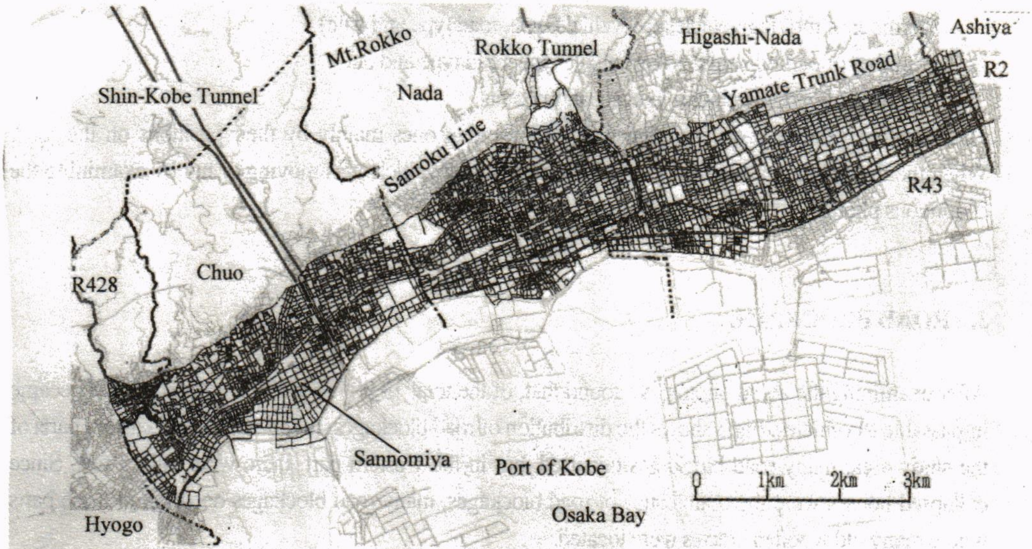


Fig.1 Road Network in the Study Area

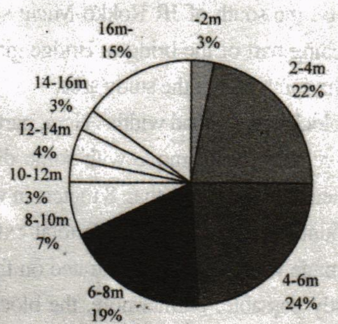


Fig.2 Road Width Ratio

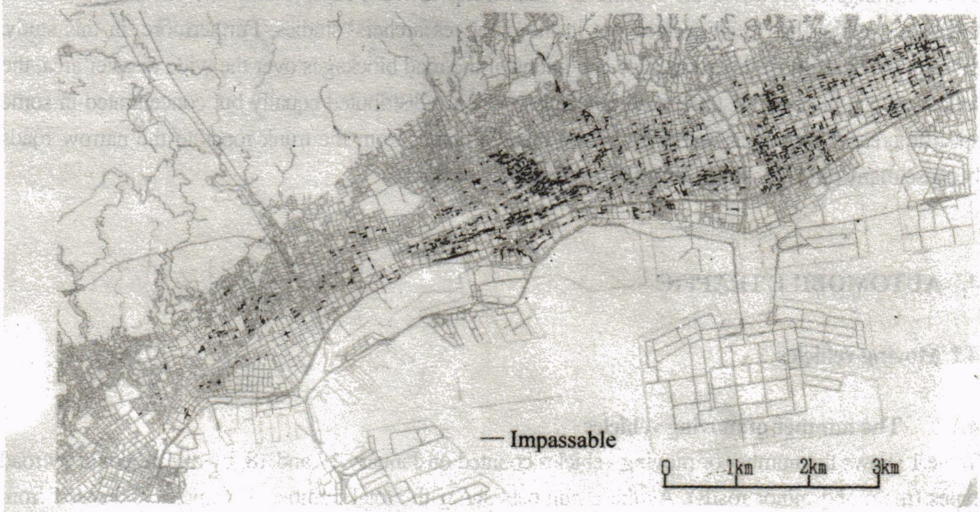


Fig.3 Distribution of Road Blockage

- Number of moving vehicles (by vehicle type, road type and date)
- Number of parked vehicles (by vehicle type, road type and date)
- Number of parked vehicles in evacuation points

These parked vehicles were distinguished from moving ones mainly by their positions on the road. When the distinction was unclear, we judged whether the vehicle was moving or not by examining the continuous photos.

3. ROAD BLOCKAGE

After examining the aerial photos, we found that, of the total 13,905 road links, 1,356 or 9.8% became impassable to vehicles. Fig.3 shows the distribution of road blockages. In the middle and eastern parts of the study area, many road blockages occurred, but in the western part, there were only a few. Since collapsed houses were the main cause of road blockages, many road blockages occurred in these parts where many old wooden houses were located.

The distribution of damage on the trunk roads is shown in Fig.4. Many road blockages caused by collapsed buildings were seen on the south of JR Rokko-Michi station, and also the level differences occurred mostly in the approaching part of the bridges. Bridge girders fell from elevated expressways and railways, concentrated on the south part of the study area.

Fig.5 shows the extent of road blockages by road widths. Here, partially damaged means partial damage to the multi-lane road though vehicles could move with some difficulty. As seen in the figure, road blockages began to increase when the road is less than 8 meters in width. Moreover, with roads less than 8 meters in width, which account for about 70% of the total extension, the ratio of impassable link lengths was over 10%, and damage was mostly concentrated on these roads. If they were 12 meters or more in width, they were mostly passable. Furthermore, the blockage of roads 16 meters or more in width was caused by the collapsed elevated roads and other structures, but these cases were rare.

These findings reconfirmed the significant relationship between road widths and occurrence of road blockages, which had been pointed out in the other researchers' studies. Furthermore, in this study, through the analysis of the occurrence conditions of the road blockages over the wide disaster area, the following can be said. First, the road blockages were not distributed equally but concentrated in some specific areas. Second, car traffic could not make a detour from the trunk roads to the narrow roads because many road blockages occurred on those narrow roads.

4. AUTOMOBILE TRAFFIC

4.1 Moving vehicles

4.1.1 The number of moving vehicles

Table.1 shows the number of moving vehicles counted on January 17 and 18, by direction and by road types (main and minor roads). As these numbers show, the total number of vehicles decreased from 11,319 to 8,666, down 23%. On the other hand, the number of trucks increased from 1,062 to 1,505, up

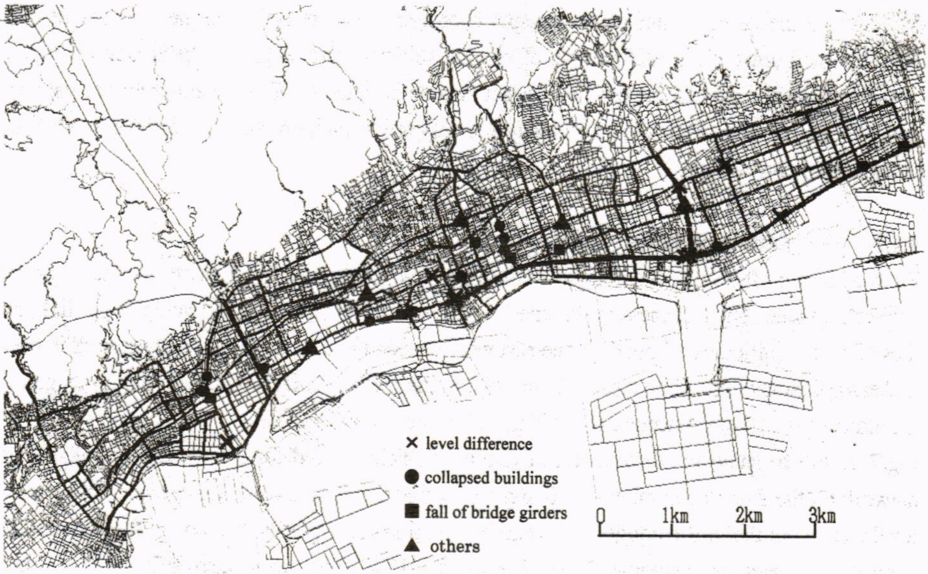


Fig.4 Distribution of the Trunk Roads Damaged by the Quake

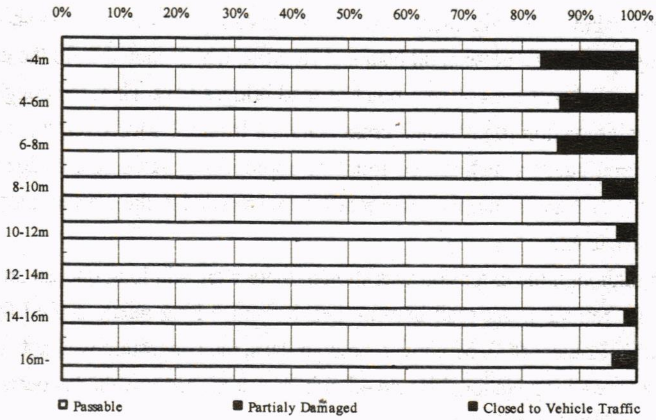


Fig.5 Ratios of Blockage Levels by Road Width

Table.1 Number of Moving Vehicles

		January 17			January 18		
		Trunk roads	Narrow roads	Total	Trunk Roads	Narrow Roads	Total
East-West Direction	East-bound	5764	440	**6204**	4230	396	**4626**
		(772)	(15)	**(787)**	(799)	(17)	**(816)**
	West-bound	2062	215	**2277**	1710	279	**1989**
		(119)	(9)	**(128)**	(508)	(21)	**(529)**
	Total	*7826*	*655*	***8481***	*5940*	*675*	***6615***
		(891)	*(24)*	***(915)***	*(1307)*	*(38)*	***(1345)***
North-South Direction	South-bound	1114	382	**1496**	661	368	**1029**
		(41)	(5)	**(46)**	(64)	(22)	**(86)**
	North-bound	1014	328	**1342**	702	320	**1022**
		(91)	(10)	**(101)**	(52)	(22)	**(74)**
	Total	*2128*	*710*	***2838***	*1363*	*688*	***2051***
		(132)	*(15)*	***(147)***	*(116)*	*(44)*	***(160)***
Total		**9954**	**1365**	**11319**	**7303**	**1363**	**8666**
		(1023)	**(39)**	**(1062)**	**(1423)**	**(82)**	**(1505)**

* ( ) : Truck Number

50%, which means that relief goods transportation became more active on the next day of the quake. About three fourths of the total number of moving vehicles were bound for the east and west, and 70% of the vehicles for the east outside the disaster area on both days. Of the total number of vehicles, 88% and 84% moved on trunk roads on each day and only few vehicles moved on narrower roads because of blockages on those roads.

4.1.2 Distribution of moving vehicles

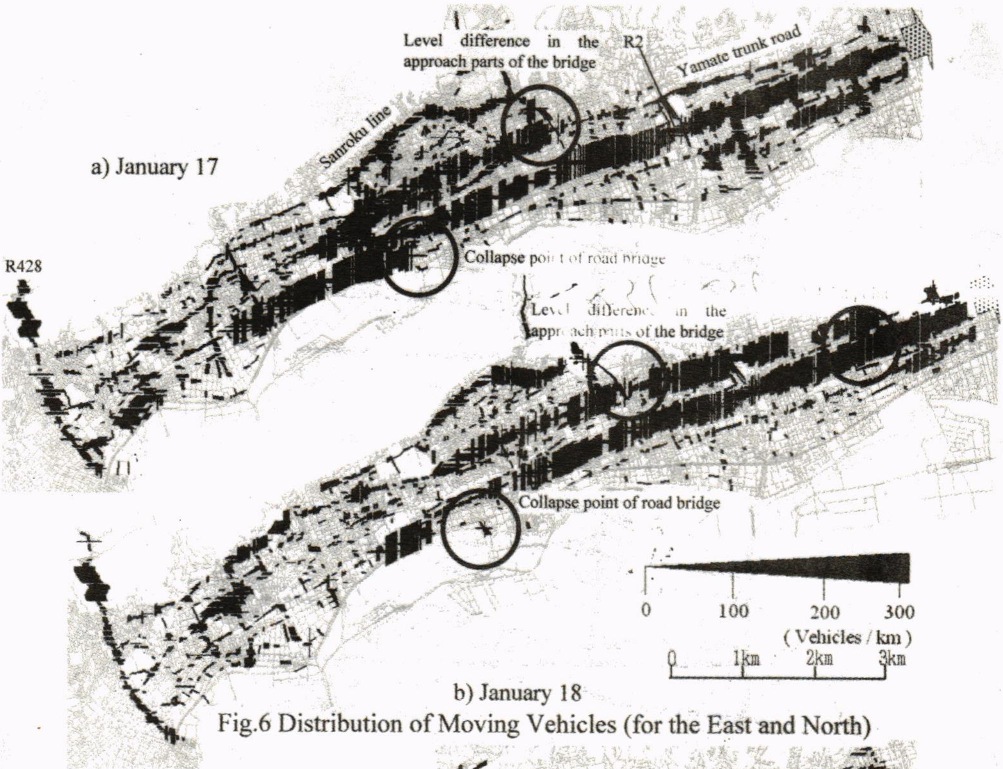
Fig.6 a) and b) show the distribution of moving vehicles bound for the east and north on the road network by date. The thickness of the lines indicates the number of moving vehicles per link length. In these figures, traffic flows bound for the east were concentrated on the trunk road network in the middle and eastern parts of the study area on both days. Furthermore, vehicles bound for the north, going out of the affected area, were concentrated on National Route 428 on both days.

Fig.7 a) and b) show the distribution of moving vehicles bound for the west and south on the road network by the day. The number of moving vehicles bound for the west was considerably less than that for the east, but the traffic congestion could be found in some places. Moreover, south bound vehicles were concentrated on National Route 428 on the 17th --they were also influenced by the heavy east-bound traffic, and the congested links were seen on both days.

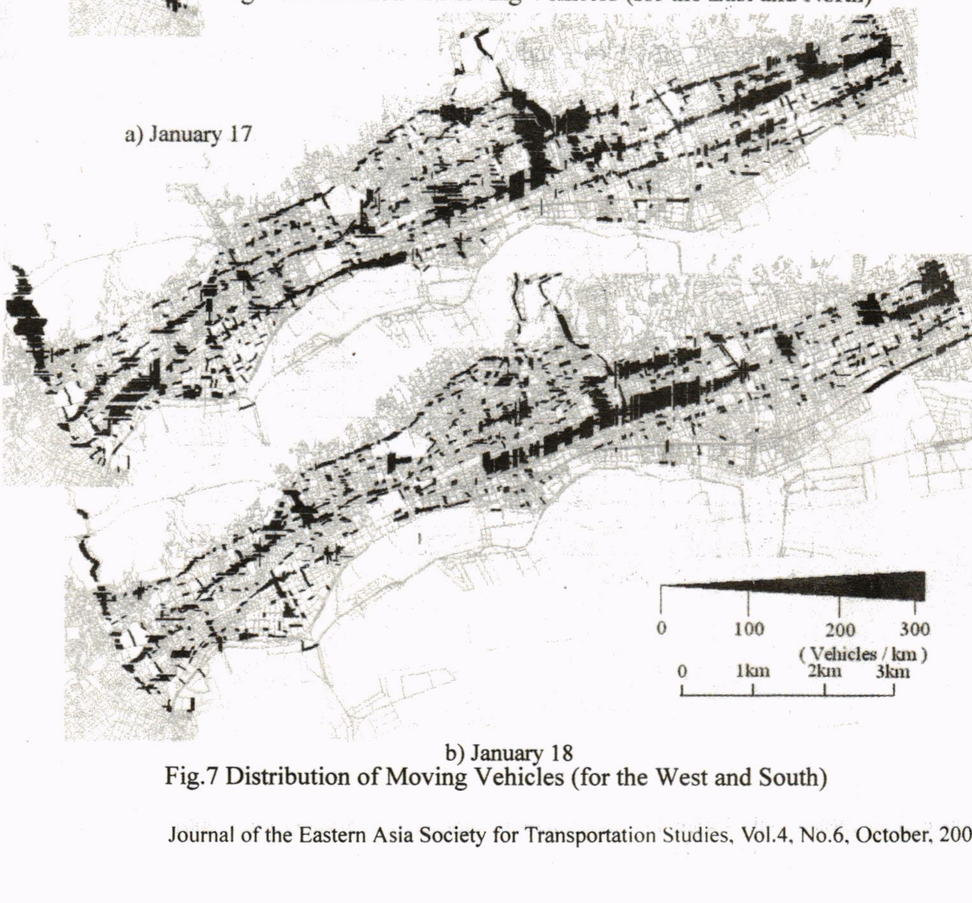
Fig. 8 a) and b) show the main traffic flow and congestion points by date. As shown in these figures, on the 17th, long queues can be seen on National Route 2, which started from the eastern end of the study area, and continued past the collapse point of road bridges (*1). Then the congestion also affected the north and south direction roads which cross National Route 2. Moreover, on Yamate trunk road, there was another long queue which started from the approaching part of the bridge where level difference had occurred (*2). However, only a few roads were crowded in the western area of Sannomiya, except on National Route 428.

On the 18th, although the extension was shorter, there were still long queues on National Route 2. The congestion on Yamate trunk road became heavier and a long queue started from the point where it joined National Route 2 (*3). Moreover, on both days, the congestion was not seen on the North-South direction roads reaching National Route 43, which was closed to vehicles because of collapsed bridge girders and toppled elevated bridges.

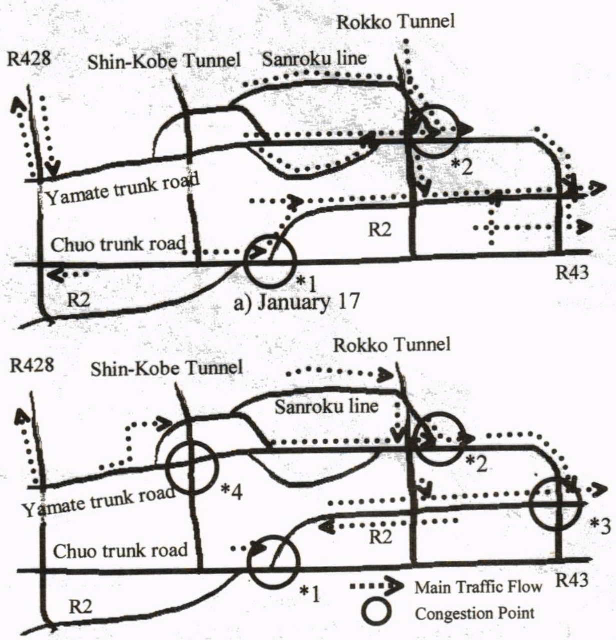
The study area is located in the belt area between Mt. Rokko to the north end and the Osaka Bay to the south. For this reason, the trunk road networks are concentrated east and west along this narrow belt area, with a few roads connecting this belt area and the area behind Mt. Rokko. This means that the trunk road network lacks capacity in both the East-West and North-South directions. (This means that few alternative roads were secured.) Under such a situation, many impassable sections for vehicles on the trunk road network were caused by the quake but car traffic could not make a detour from the trunk roads to the other narrow roads because many road blockages had occurred over a wide area. Consequently, a large number of cars were concentrated in the limited number of passable road sections and the serious traffic congestion occurred as a result.



b) January 18
Fig.6 Distribution of Moving Vehicles (for the East and North)



b) January 18
Fig.7 Distribution of Moving Vehicles (for the West and South)



b) January 18

Fig.8 Main Traffic Flows and Distribution of Traffic Congestion

Table.2 Number of Parked Vehicles

		January 17			January 18		
		Trunk Roads	Narrow Roads	Total	Trunk Roads	Narrow Roads	Total
On-street	East-bound	2052	2880	4932	1937	2941	4878
		(68)	(73)	(141)	(146)	(144)	(290)
	West-bound	1939	2436	4375	1891	2548	4439
		(117)	(50)	(167)	(181)	(100)	(281)
	South-bound	1224	2356	3580	1411	2473	3884
		(22)	(33)	(55)	(65)	(86)	(151)
	North-bound	1424	1924	3374	1581	2196	3777
		(46)	(26)	(72)	(102)	(90)	(192)
	Total	6489	9772	**16261**	6623	10355	**16978**
		(250)	(185)	**(435)**	(476)	(438)	**(914)**
Evacuation Points		812 [46Points]			3671 [77Points]		
		(10)			(69)		

* ( ) : Truck Numbers

4.2 Parked vehicles

4.2.1 The number of parked vehicles

Table.2 shows the number of parked vehicles on January 17 and 18, by direction, road types and site (on street and at evacuation points). The total number of on-street parked vehicles was about the same for each of these two days --16,261 for Jan.17 and 16,978 for Jan.18. On the other hand, the number of parked trucks nearly doubled from 435 to 914. On both days, the number of on-street parked vehicles by directions is about the same. About 60% of all these parked vehicles were on narrow roads. Moreover, the number of parked vehicles in the open spaces of evacuation points increased from 812 vehicles (46 points) to 3,671 vehicles (77 points). This means the number of vehicles at these evacuation points on the next day of the quake quadrupled, indicating that many affected residents moved their cars to these evacuation points.

4.2.2 Distribution of parked vehicles

Fig.9 a) and b) show the distribution of parked vehicles on the day of the quake by road type. These lines are drawn in the same way as the distribution of moving vehicles. The thickness of the lines indicates the number of parked vehicles per link length. As shown in this figure, vehicles were parked on almost every trunk road. On narrow roads, parked vehicles were also spread widely on the road network throughout the study area, but few parked vehicles could be seen in sections with road blockages.

Fig.10 shows the distribution of parked vehicles in schoolyards and other open spaces. In this figure, the size of circle indicates the number of parked vehicles on each day. Many of these vehicles were in the eastern part of the study area, where the ratio of damaged houses was higher. Moreover, in most places, more parked vehicles were seen on the 18th than on the 17th; in 37 places, parked vehicles were recognized for the first time on the 18th. It can be, therefore, surmised that these vehicles were brought out to the evacuation places by many affected people on the next day of the quake. The reason why the affected people moved their vehicles there (to evacuation places) was that they used their vehicles as a shelter during the night or to store their personal effects because of the great damage to their houses.

5. INFLUENCE OF ON-STREET PARKED VEHICLES ON TRAFFIC FLOW

5.1 Ratios of road links and blockage or parked vehicles

Fig.11 shows the extent of road blockages and parked vehicles by the road widths. The figure shows that as the road width increases, the percentage of the road with parked vehicles increases too. In addition to road blockages, the existence of parked vehicles on the roads measuring 4 meters or less in width possibly made the passage of large vehicles such as fire engines very difficult. It means that parked vehicles on narrow roads could cause serious problems in the case of emergency.

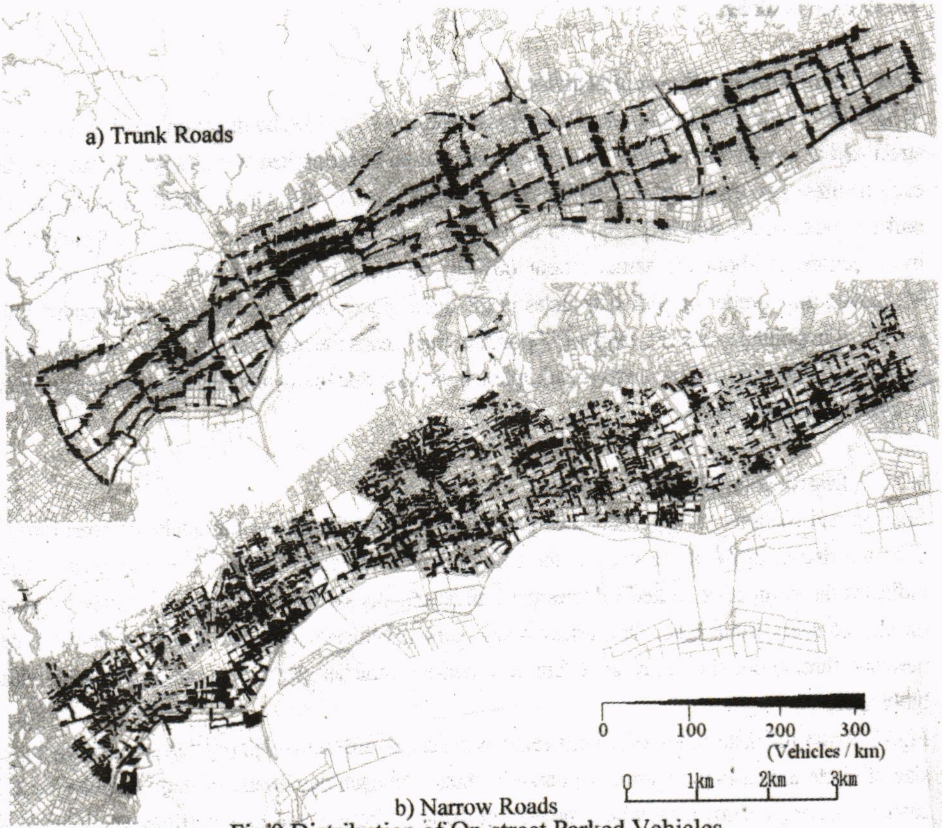


Fig.9 Distribution of On-street Parked Vehicles

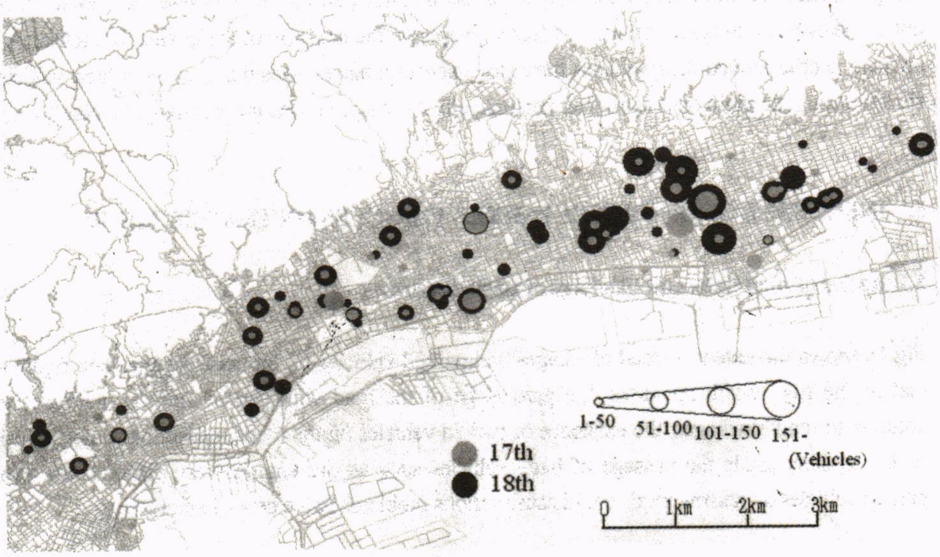


Fig.10 Distribution of Parked Vehicles on Evacuation Points

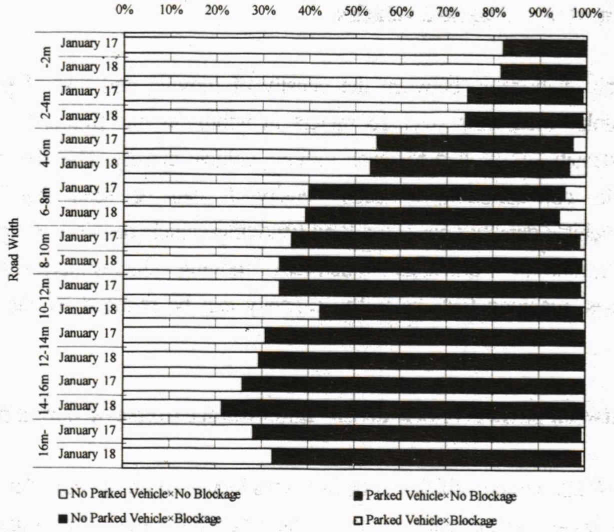


Fig.11 Ratios of Road Links with Blockages or Parked Vehicles

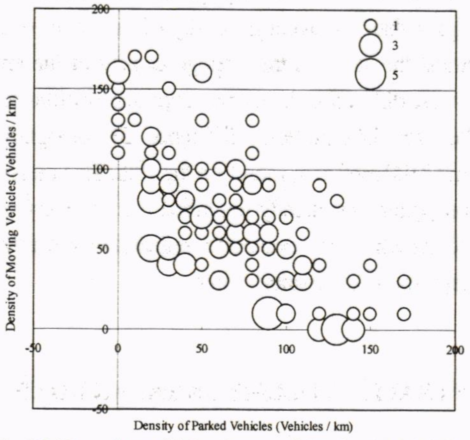


Fig.12 Density of Moving and Parked Vehicles

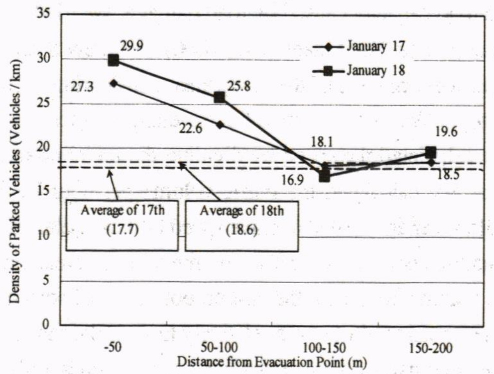


Fig.13 Density of Parked Vehicle by Distance from Evacuation Point

5.2 Density of moving and parked vehicles

Fig.12 shows the relationship between the density of moving and that of parked vehicles on the two-lane road links, measuring over 16 meters in width. In this figure, ten road links with high parked-vehicle density are plotted for each moving-vehicle density. The size of circles indicates the number of links corresponding to each density. It can be seen that the total number of moving/parked-vehicle densities has some limit ((moving-vehicle density) + (parked-vehicle density) $\leqq$ (constant)). Around these limits, as the density of moving vehicles increases, the density of parked vehicles decreases, meaning that the traffic capacity can be reduced by the occurrence of parked vehicles.

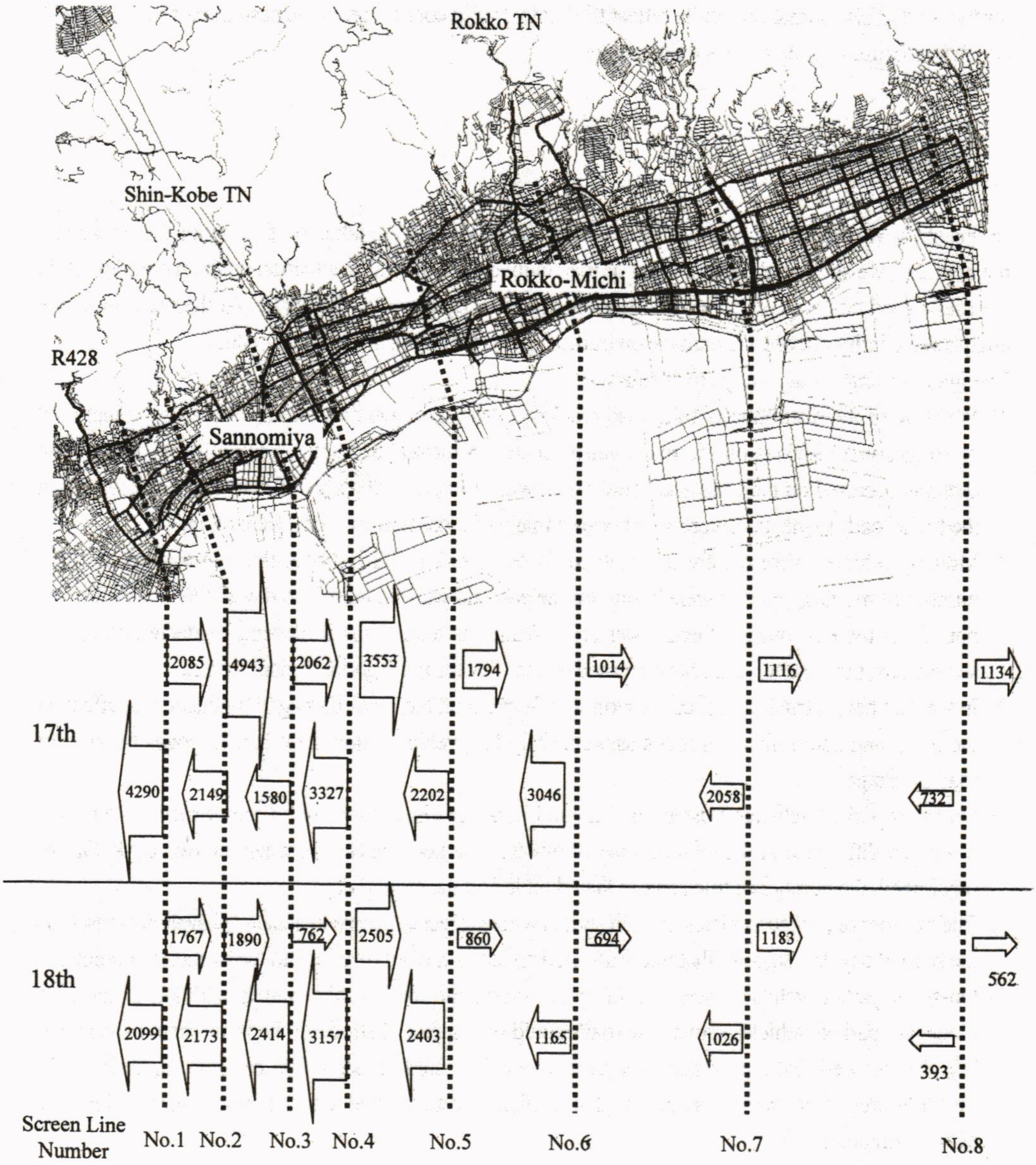
5.3 Relation between parked-vehicle density and distance from evacuation point

As described in 4.2.2, parked vehicles in open spaces increased on the next day of the quake. We then measured the parked-vehicle density on the surrounding narrow roads by distance from the evacuation point. Fig.13 shows the average parked-vehicle density at each link by distance from the evacuation point on these two days. On both days, the average parked-vehicle density less than 100 meters from the evacuation point was bigger than the average density of the entire study area, while the density 100 meters or more was almost the same as the average density of the entire study area. Moreover, we examined whether there were differences in average densities by distance. We found that, although there was no difference on the 17th, the significant difference (5% of significant levels) was seen between "less than 100 meters" and "100 meters or more" on the 18th. This means that parked vehicles tended to gather around evacuation points. As already described before, many residents seemed to move their vehicles to evacuation points when they evacuated, reflecting the behaviour of affected people to park their vehicles on the streets around evacuation points.

6. ESTIMATION OF TRAFFIC VOLUME ON TRUNK ROAD NETWORKS

In the affected areas, serious traffic congestion occurred on the trunk roads running east and west because of the reduced road capacity caused by road damage. We tried to estimate the traffic volume on the trunk roads by aerial photos (See Odani *et al.*, 2000). We drew 8 screen lines on the road networks between the eastern and western ends of the study area, considering access routes to the affected areas from the surrounding ones. We first measured the traveling distances by vehicles from a series of two aerial photos, and then calculated the speed by dividing the traveling distance by the time intervals of these photos. After that, we calculated the traffic volume per hour by the product of the number of moving vehicles per kilometer and spatial average speed of those vehicles.

Fig.14 shows the estimation results of the traffic volume of each screen line on the road networks. There is a clear gap in traffic volume bound for the east on both sides of screen lines 4 and 5. On the western side of these screen lines, traffic volume was relatively high as the traffic density was low and traveling speed was high. On the other hand, on the eastern side of those lines, traffic volume was quite low as the traffic density was high and traffic was not moving. Similar tendency can be seen on the traffic bound



Total Traffic Volume for Both Direction	17th	6375	7092	3642	6880	3996	4060	3174	1866
	18th	3866	4063	3176	5662	3263	1859	2209	955

Fig.14 Estimation Results of Traffic Volumes on Each Screen Line

for the west. This estimation results reflect the heavy traffic congestion in the eastern part of study area, which was caused by the serious road damage.

7. SUMMARY

In this study, through the examination of aerial photos, which were taken on the day of the quake and the next day, we showed the distribution of road damage and the traffic situation on the road network in the established city area of Kobe City near the sea immediately after the quake. At the same time, we analyzed the influence of road damage on traffic flows on both main and minor roads.

The main findings of the study are as follows:

1) We showed the distribution of the road blockages over the wide disaster area, confirming that road blockages were serious on the roads narrower than 8 meters. Moreover, though many impassable sections occurred on the trunk road network, it was difficult for the car traffic to make a detour from the trunk roads to the narrower roads because many of those narrow roads were blocked.
2) Moving vehicles were mostly on trunk roads on Jan.17 and 18. About three fourths of the total number of moving vehicles were bound for the east and west on these two days, 70% of which were bound for the east outside the disaster area. While the total number of vehicles decreased on the second day, the number of trucks increased on that day for relief goods transportation.
3) In the east bound trunk roads, congestion was frequent on the roads damaged by the quake, affecting the north and south direction roads as well. Only few vehicles moved on narrow roads because of road blockages.
4) On-street parked vehicles existed on main and minor roads, but mostly on minor roads. There was not much difference in the total number of on-street parked vehicles between the two days. On the other hand, the number of trucks more than doubled on the second day.
5) The number of parked vehicles in open spaces where affected people evacuated sharply increased on the second day. We surmise that many affected residents moved their cars to the evacuation points.
6) On-street parked vehicles increased in proportion to the road widths, and in addition to the road blockage, parked vehicles on narrow roads could be a factor obstructing the movement of vehicles. We also showed that the existence of parked vehicles could reduce traffic capacity on main roads. Furthermore, there was a tendency that vehicles were parked on the roads surrounding the evacuation point.
7) We estimated the traffic volume on the east and west direction trunk roads along some screen lines in the study area. It became clear that there was a difference in traffic volume between eastern and western parts of the study area on these two days. In the eastern part, traffic congestion was heavy because there were many damaged parts on trunk roads, and the total number of lanes where vehicle could pass through was also limited.

Although aerial photos show the traffic situation of the moment it is taken, this study verified that they might provide very useful data to grasp the degree of road damage and the actual condition of traffic flow at the time of disaster, and also develop future disaster prevention measures. As for road blockages, if they can be automatically identified on aerial photos by image-processing technology, it will be possible to grasp the degree of road damage more quickly. Moreover, as for traffic situation, if aerial photos are taken several times, for example at intervals of several hours, moving vehicles can be automatically identified by the image-processing technology, letting us see the changes of traffic flow. This kind of traffic flow estimation will not be necessary if the traffic control center is functioning. However, the estimation method in this study will be effective in the area where beacons are not installed, such as in mountain areas, or at the time when the traffic control center is paralyzed by the disaster.

Finally, the future subjects of the study are as follows:

1) To grasp the usual traffic situation using the aerial photos taken before the quake, and to clarify a traffic situation peculiar to the time of great disaster by comparing the both traffic situations.
2) To calculate Origin-Destination (OD) traffic volume from traffic volume on the screen lines obtained in this study based on the results of the OD survey of the drivers which the authors carried out after the quake.
3) To develop a model to estimate the number of parked vehicles at the time of disaster, for which the explanation variables include traffic conditions along the road, road widths, and the distances from the evacuation points.

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