LESSONS FROM THE GREAT HANSHIN EARTHQUAKE: TOWARDS TRANSPORTATION INFRASTRUCTURE IMPROVEMENT

FUMITOSHI MIZUTANI
Regulatory Policy Research Centre, Hertford College,
31-33 Westgate , OXFORD OX1 1NZ, UK

Kobe University
School of Business Administration
2-1 Rokkodai, Nada, KOBE 657-8501, JAPAN

KENICHI SHOJI
Kobe University
School of Business Administration
2-1 Rokkodai, Nada, KOBE 657-8501, JAPAN

Abstract

The Great Hanshin Earthquake occurred on January 17, 1995, causing tremendous damage and killing more than 6000 people in Kobe and the surrounding areas. The purpose of this paper is to look at the transportation system itself, especially focusing on the transportation infrastructure and what we learned from the great disaster for transportation planning and management. First, we will summarize the damage to transportation infrastructure caused by the earthquake. Second, we will explain the traffic situation during the emergency period and discuss the gap between reality and transportation policy. Third, we will critically analyze the transportation infrastructure improvement policy, attempting to determine effective policy.

INTRODUCTION

At 5:46 a.m. on January 17, 1995, an earthquake measuring 7.2 on the Richter scale struck the city of Kobe, one of Japan's most highly populated urban areas. This quake, dubbed the Great Hanshin (or Kobe) Earthquake, took the lives of more than 6000 people and injured 40,000 more. Adding to the devastation caused by such casualties, the severance of most utilities and the damage to infrastructure made the lives of survivors difficult in the weeks following the quake. Gas, electricity, water, sewage, garbage collection, and communications became unavailable to most city residents. Getting from one place to another became time-consuming if not impossible in most cases, as roads, railways, and port facilities suffered severe damage in the earthquake. In losing the utilities and services that had been taken for granted before the earthquake, survivors were shocked to realize how indispensable these were to maintaining modern life.

Engineers and architects were also shocked at the severity of the damage to structures throughout the city. As for the transportation system, regarding the earthquake experience as a lesson, various issues are being debated from the "hardware" of infrastructure to the "software" of management, from the short-term to the long-term. Reconstruction plans are affected by wider regional plans and other programs related to the area, including local and urban plans, as well as predicted socio-economic climates. In this paper, based upon both real experience of the great earthquake and several reports on the earthquake, we will discuss policy issues related to traffic during the emergency period as well as draw lessons from the earthquake toward the development of a better transportation system.

SCALE OF THE EARTHQUAKE AND DAMAGES

Scale of the earthquake and damages

The epicenter of the quake was about 15km west of the center of Kobe city, on the northern part of Awaji Island (N34.36, E135.03), 14km below the earth's surface. With a magnitude of 7.2 on the Richter scale, this earthquake was almost equivalent to the most disastrous in Japanese history, the Great Kanto Earthquake of 1923, which had a magnitude of 7.9 and killed 99,000 people in the Tokyo area. Most severely damaged in the Great Hanshin Earthquake were Kobe city and the surrounding cities and towns. Especially hard hit both physically and economically were Kobe, Awaji Island and the Hanshin area, a mature residential area between Osaka and Kobe.

Kobe and the Hanshin area are part of the greater Osaka metropolitan area (GOMA), which is commonly known as the Keihanshin metropolitan area. With a population of about 18 million, 15% of the total population of Japan, it is important economically, accounting for about 16% of Japan's GDP in 1984 and 16% of total sales of manufacturing industry in 1985. Kobe, one of the central cities along with Osaka and Kyoto in the GOMA, has a population of about 1.5 million, making it the sixth largest city in Japan. Kobe and Hanshin together have a population of about 3 million. The largest port city in Japan, Kobe has emerged as a desirable residential area in the GOMA, along with the Hanshin cities of Ashiya, Nishinomiya and Takarazuka. Because of the geographical constraints imposed by the Rokko Mountains to the north and Osaka Bay to the south, Kobe and Hanshin have developed as a long strip of urbanization, 5km wide at most in the north-south direction, and about 30km long in the east-west direction. Most housing, economic activity, and transportation are concentrated in this narrow corridor.

Striking this highly populated area of economic importance, the Great Hanshin Earthquake caused enormous damage. As of March 31, 1996, total deaths were calculated at 6,279, with 2 missing and 34,900 injured. More than 415,659 houses were completely or partly destroyed. Human casualties were highest in the three cities of Kobe, Nishinomiya and Ashiya. For example, in Kobe, the hardest hit area, for every 1000 people, 3 died, 10 were injured, and 163 were evacuated. The timing of the earthquake in the early morning (5:46 am) meant that most people were asleep at home. According to the Land Planning Agency (1995), housing collapse accounted for most deaths and injuries, or about 88%, with the second largest number caused by fire at 10%. As for casualty by age, deaths of under 20 year-olds and of age 20 to under 60 accounted for about 10% and 37% respectively, but deaths of those over 60 accounted for about 53%. Most of the elderly people who died lived near the downtown areas of large cities, where housing is old and densely packed.

The earthquake also destroyed the physical basis of various economic activities. According to Takayose (1996), the total amount of damage to public facilities, infrastructure and private buildings reached about 9,963 billion yen. The Land Planning Agency (1995) put the estimated amount of damage at 9,600 billion yen, 6,300 billion yen for housing, building and factories, 2,200 billion yen for transport infrastructure, 600 billion yen for public utilities, and 500 billion yen for others. The total loss accounted for about 0.8% of Japanese fixed capital.

Damage to transportation infrastructure

The earthquake not only crippled the transportation network in Kobe and the Hanshin area, but it also halted fundamental urban activities when it severed electricity, water and gas supplies, and electric communication lines. Table 1 shows a summary of the damage to transport infrastructure.

Table 1 - Damage to transport infrastructure

Mode	Major Description
Railway	13 rail operators damaged. Operation which could not be resumed on the day of the quake amounted to 638 route-km.
Roads	Highways such as Chugoku Expressway, Hanshin Expressway (Kobe Route, Wangan Route), National Highway No.2 and No.43 became snarled.
Airports	At Osaka International Airport, damages occurred such as cracks on runways and collapse of outer walls of the passenger terminal building. At Kansai International Airport, cracks were caused to walls of the passenger terminal building, railway station and the multi-story parking garage but the damage did not interfere with airline services.
Ports	Facilities at 24 ports in Hyogo, Osaka and Tokushima Prefectures.

(Note):
This table was made by the authors based on several sources.

First, as for the railway system, thirteen rail operators were unable to operate rail service after the earthquake. Operation which could not be resumed on the day of the earthquake amounted to 638 km, with severe damage concentrated in nine rail operators in the Kobe area. For example, JR West, which operates both the Sanyo Shinkansen and regular commuter lines, suffered damages such as the collapse of elevated tracks and the destruction of station facilities. It took about two and a half months to restore regular JR lines and the Sanyo Shinkansen. Other private railways had similar damage.

Although we mentioned that the damage to transport infrastructure was about 2,200 billion yen, the damage figures increase if we consider transport related facilities. According to the Ministry of Transport, the amount of damage to transport related facilities was estimated at about 15,540 billion yen, which can be divided into 2,550 billion (railway-related), 10,400 billion (port-related), 330 billion (road and vehicle-related), 400 billion (maritime transport related), 670 billion (warehouse and physical distribution), 460 billion (shipbuilding related), 20 billion (airport related), 660 billion (hotel related), 50 billion (others). This was about 3.2% of Japan's GNP in 1995.

Table 2 - Damage in major railway operators

Operator	JR West (Shinkansen)	JR West (Regular)	Hankyu	Hanshin
Route-km which could not be operated	86km	43km	52.8km	19.7km
Damaged elevated tracks	n.a.	2.2km	1.6km	2.0km
Damaged pillars	1,938	950	656	657
Total input labor to rebuild (thousands)	162	230	260	300
Rebuilding cost (billion yen)	49	67	55	58

(Note):
This table was made by the authors based on several sources.

Restoration of transport infrastructure

As Table 3 shows, it took more than two months after the quake to restore most rail services. As of mid-March, 1995, the main artery comprised of three urban railways connecting Osaka and Kobe and the Shinkansen (the bullet trains) was still severed. The Tokaido line of JR was reopened on April 1 and the Sanyo Shinkansen on April 8, but other private railways still had some incomplete sections. Though limited service was resumed on the man-made Rokko and Port Island in May, the two lines of Kobe Shin Kotsu in effect are suspending service in the entire system. Hanshin and Hankyu rescheduled reopening their service for two months earlier than the planned March reopening. However, overall damage remains serious.

Table 3 - Speed of restoration in railway

Operator	Ownership	Fully Restored	Time of Restoration
JR West (Sanyo Shinkansen)	JR	April 8, 1995	81 days
JR West (Kobe Line)	JR	April 1, 1995	74 days
Hankyu	Private	June 12, 1995	146 days
Hanshin	Private	June 26, 1995	160 days
Sanyo	Private	June 18, 1995	152 days
Kobe Dentetsu	Private	June 22, 1995	156 days
Hokushin Kyuko	Private	January 18, 1995	1 days
Kobe City (Subway)	Public	February 16, 1995	30 days
Kobe Shin Kotsu (Portliner)	Quasi-Private	July 31, 1995	195 days
Kobe Shin Kotsu (Rokkoliner)	Quasi-Private	August 23, 1995	218 days
Kobe Kosoku	Quasi-Private	August 13, 1995	208 days

(Source): Kobe City (1997), p.13
(Note): The Daikai station of Kobe Kosoku was reopened on January 17, 1996, one year after the earthquake.

The main trunk and other roads were also deprived of their function on almost all sections. Despite reconstruction efforts, the Kobe Route of the Hanshin Expressway, Harbor Highway, Hamate Bypass, and Rokko Island Bridge (the Wangan Route of the Hanshin Expressway) were still interrupted. Only a limited number of lanes were used on the Chugoku Jukan Expressway, Meishin Expressway and Route 43 of the National Highway. Also with vehicle-height controls and traffic regulations for private cars on the roads under reconstruction in effect, traffic volume is far from normal, with a decrease to below the 40% level of the pre-temblor road capacity in eastern Kobe (Higashi-Nada and Nada wards).

Running vehicle volume drops sharply in accordance with reduced road capacity. In the area near the border between Kobe and Ashiya cities, for instance, the average traffic of more than 250,000 vehicles per weekday on trunk roads before the earthquake dropped to 30% in mid-February, one month after the disaster and remained at 40%, or 100,000 vehicles, even in mid-April. Moreover, any significant increase is not observed in the traffic volume, when compared with the pre-temblor level, in the inland Mukogawa area which holds the main detours for the Hanshin coastal districts, National Highway Route 176 and Chugoku Jukan Expressways. These situations indicate a smaller traffic of cars, considering that the overall traffic includes a large volume of reconstruction-related fleets to transport debris, construction materials, heavy-duty equipment and workers.

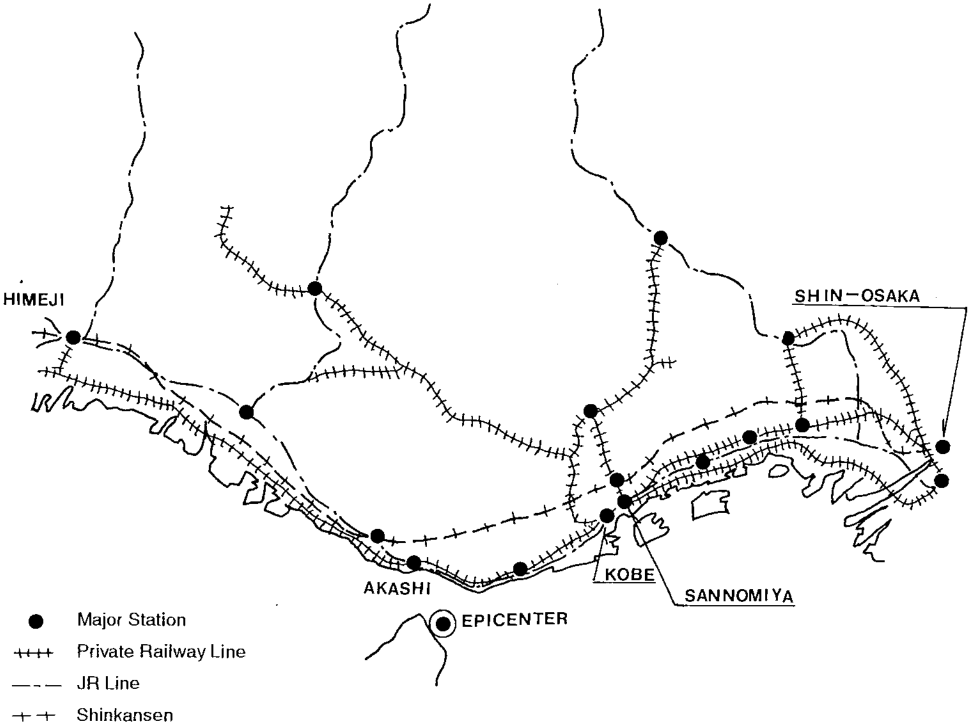
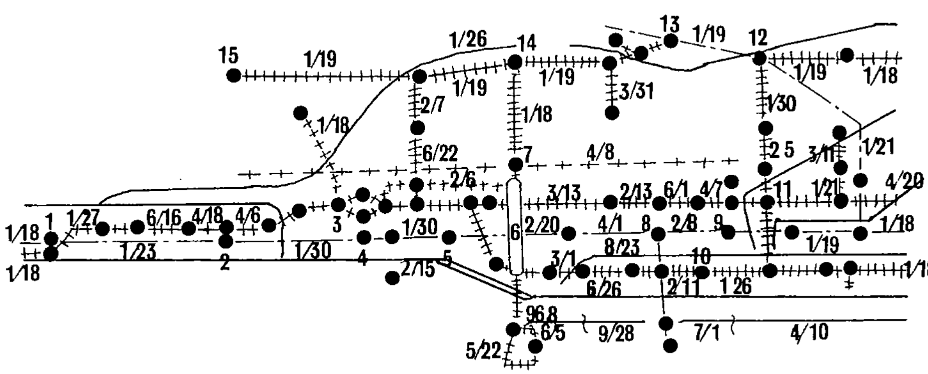


Figure 1 - Major railway network



Major Railway Station

1: Akashi	2:Suma	3: Itayado	4: Shin-Nagata	5: Kobe
6:Sannomiya	7:Shin-Kobe	8: Sumiyoshi	9: Ashiya	10: Ogi
11: Nishinomiya Kitaguchi		12: Takarazuka	13: Sanda	14: Tanigami
15: Ao Main Road				

Private Railway
JR Line
Shinkansen
Main Road

Figure 2 - Reconnection of transportation network

TRANSPORTATION IN THE SHORT-TERM AFTER THE SHOCK

Situation after the earthquake

For several hours after the earthquake, Kobe seemed to be in a stupor. Most Kobe residents did not realize the scale of the disaster or the location of the hardest hit areas. When action finally did occur, it was chaotic. Because almost all public transportation was suspended, in the cities most people had to depend on private autos, motorbikes, or bicycles. Another obvious alternative was to walk. Railway operations were suspended due to damaged tracks and collapsed facilities. Bus operations were also impossible because roads were blocked and operators could not reach their bus storage spaces. Survivors rushed to telephone relatives, but almost all parts of Kobe had disconnected phone lines, compelling survivors to travel by motorbike or car to relatives' homes in order to confirm their safety or to rescue them.

Main roads in cities were severely damaged in many sections. Bridges collapsed and elevated city highway systems were turned on their sides. Numerous cracks appeared in road surfaces. In many cases, regular streets, too, became impassable, due to collapsed electricity poles, houses and buildings. Some few roads were available for use, but drivers had no way of knowing which roads these were, so that previously direct routes took on somewhat of a maze-like quality. Too many cars on too few roads led to the expected result--congestion, causing the dangerous situation of emergency vehicles such as fire engines and ambulances being unable to rescue victims. We have insufficient data about how many people died because of emergency vehicles' delay among the congestion of private vehicles, but there is the possibility that some people would have been saved if such congestion had been avoided.

Even though people were aware of the congestion and of the difficulty of traveling by car, it was necessary for them to continue to use cars because of the immobilized transportation system. Having had water supplies cut off immediately following the earthquake and soon consuming whatever food they had stored in their homes, with supplies unable to reach them speedily because of the collapsed system, people seemingly had no choice but to use their cars even several days after the earthquake.

For several days after the earthquake, roads were congested with private autos by commuters and with vehicles for repair and reconstruction. The earthquake forced people to change their normal patterns of travel, shifting their trip modes or using bypasses due to interrupted travel lines, or shifting their origin or destination due to collapsed homes or offices. The suspension of railway service at JR, Hankyu and Hanshin was one of the biggest factors affecting people's movement. Many Kobe residents commute to Osaka by train. Before the earthquake, commuters to Osaka by railways accounted for 87% in Kobe city and 52% in cities between Kobe and Osaka based on the Person Trip Survey in 1990. Before the earthquake, a total of about 2,700 trains per day were operated between Kobe and Osaka.

Some of the pre-earthquake rail traffic shifted to private cars, motorbikes and bicycles, but traffic congestion and parking problems at destinations became so severe that strict limits were enforced on the use of private cars. Some main roads such as National Route 2 and Route 43 were restricted to only authorized autos. Although sales of two-wheeled vehicles reportedly increased immediately after the earthquake in Kobe, the mode represents a relatively small portion of the total transport volume in the area. In fact, two-wheeled vehicles were effective and convenient to use on roads which were blocked by collapsed buildings and housing, but as an alternative mode to railways, motorbikes and bicycles were insufficient to absorb all traffic.

Soon after the earthquake, buses substituted for railways as the main transport mode. For example, Kobe city restored its bus service in part of the urban area on January 21, four days after the earthquake. Three private bus companies also resumed operations to replace railway service between Osaka and Kobe on January 23 (Monday). Thus, the bus played an active role as a valuable mode in the quake-hit region relatively early. However, two problems which limit use of the bus were reconfirmed: its vulnerability to traffic congestion and its restricted transport capacity. The longer the service distance, the more likely buses were to be delayed by traffic jams. A typical case was the special direct bus service which was installed temporarily connecting Himeji and Shin-Osaka, about 100 km apart, only one and a half hours by bus under normal conditions. On the first day of service after the earthquake, however, January 27 (Friday), the trip took more than six hours, resulting in immediate decisions to suspend the service from the following day and to reduce the distance to a section between Himeji and Sanda (about 15 km north of Kobe).

Substitute buses for urban railways started January 23, connecting Kobe and Nishinomiya. The substitute buses remained far below the capacity of railways, at the beginning with a transport volume of at most 30,000 passengers per day, due to traffic congestion. Exclusive priority lanes for substitute buses were introduced on January 28 after Hanshin Railway service was extended to Ougi (eastern Kobe) on January 26. Organization of the substitute bus system was improved daily, so that by February 1, nearly 120,000 passengers were transported, a number in inverse proportion to the amount of rail service being cut. About 220,000 persons per day were being transported by March 8, when Hankyu resumed service between Mikage and Oji Koen (both in eastern Kobe) making travel possible between Osaka and Kobe by a combination of walking and transfers among JR, Hanshin and Hankyu. However, when compared with the pre-earthquake rail traffic volume of 650,000 passengers per day of three railway operators (JR West, Hankyu, and Hanshin) from Kobe's city center Sannomiya in the direction of Osaka, the transport volume by bus was not remarkably large as an alternative mode.

Because Kobe is also a port city, alternative routes were available by marine transportation. A temporary marine route was opened to connect downtown Kobe (Harbor Land) and Osaka as early as January 20 (Friday). Intercity transport routes to link Himeji, Awaji Island, Kobe, Nishinomiya, Osaka, and routes to connect Port Island, Rokko Island, central Kobe, and Osaka and Kansai Airports were introduced, or existing service increased. However, this transportation mode, again, played only a limited role because of its restricted transport capacity. Unlike buses, ships have a large transport capacity, but the problem is low frequency. Problems arise in time required for boarding and alighting, as well as in the limited number of ships available for service. Waiting time for passengers unable to board overcrowded ships made many see marine transport as an unattractive alternative.

Issues and lessons

Traffic controls and regulations

After the Great Hanshin Earthquake roads were overcrowded with emergency vehicles such as ambulances and fire engines as well as with cars driven by people transporting the injured, taking refuge, or heading for damaged areas to confirm the safety of their families. Even several days after the earthquake, vehicles carrying emergency supplies often became immobilized on roads packed with private cars. How can space for public emergency vehicles be secured without traffic signals or controls by policemen? In order to relieve traffic congestion, governments did not stand idly by. In fact, special traffic controls based on the Basic Law for National Disasters (Saigai Taisaku Kihonho) were enforced in the areas along the Seto Inland Sea in Hyogo prefecture on January 19, but it took time, trial and error, and people's cooperation to facilitate and establish the controls. TV, radio and newspaper were used to provide information about roads but turned out to be not very effective in alleviating traffic congestion.

One reason may be that citizens had no choice but to depend on their cars since public transportation services such as railways and buses were suspended. Another reason that should not be disregarded is that there was a lack of information about what controls had been imposed on which roads or routes. It is necessary to inform citizens of usage of roads in order to clarify what types of vehicles will be allowed to travel during emergencies, but no such information is widely known. Shizuoka prefecture already has a road classification system whereby first priority roads are strictly limited to emergency vehicles when a severe earthquake occurs. Although Shizuoka prefecture has already publicized this information, it is unclear how widely known the information really is, both among residents and among nonresidents who would be traveling into the area in rescue or support vehicles. It is therefore necessary to make the road classification system as simple as possible to assure wide understanding of it.

One option is to indicate emergency usage of roads by visual signs, perhaps using a color code. For example, roads with red signs would restrict traffic in principle only to public vehicles in an emergency, yellow would allow both public and privately owned but authorized vehicles, and non-colored would be all inclusive. If such a simple system were to be put into effect nationwide, with a program for educating the public, much confusion could be avoided during emergencies, and help would arrive to those in need with more speed and efficiency. Also, we must emphasize that private cars played an important role in emergency activities after the earthquake, and it is very hard to tell which vehicles are emergency vehicles, especially just after an earthquake.

The substitute bus

The traffic capacity of buses is limited. Queueing is inevitable when vehicles with a capacity of 70 replace railway cars capable of transporting more than 2500 people per train of eight cars. Another problem with buses is boarding and alighting time, at least three-odd minutes if a bus is to be fully packed, even with smooth boarding. Therefore, the maximum number of buses available is computed to be only 20 per hour if each bus is deadheaded to a bus station where boarding and alighting zones are separated. In order to secure 100 buses per hour (the total capacity of which is still less than that of three trains), simultaneous boarding on more than one bus might work, but this would require a spacious road (or terminal) able to accommodate five buses and a walkway for waiting people. It is worth noting, however, that there would an increase in air pollution if we operated this number of buses, and indeed air pollution became a serious problem after the earthquake. Despite this, a better alternative to substitute buses could not be found, making clear the necessity of reestablishing rail service as soon as possible after a disaster.

Time of restoration

The most important lesson of the earthquake from the point of view of transportation was that speed of restoration is vital. Delay in restoration causes not only problems for rail users, who must switch to more time-consuming and less efficient buses, but it also causes financial problems for the rail companies themselves, which obviously lose more revenues the longer rails are out of service. Moreover, railways delaying restoration are in danger of being eclipsed or having part of their rail share taken by rail companies which reopened lines sooner. For example, JR West resumed its entire service before Hanshin and Hankyu, as a result increasing its passenger share by 10 to 20% on some lines.

THE REBUILDING OF TRANSPORT INFRASTRUCTURE

After the earthquake, there were many proposals, both official and unofficial, related to easing damage or protecting infrastructure. These proposals are classified into several categories: 1) technology and R&D; 2) transport network; 3) revitalization of existent infrastructure; and 4) assistance programs for infrastructure.

Technology and R&D

The cost of safety and who bears it

After the earthquake, there was an outcry that more money should be spent on building safe infrastructure (e.g. Asahi Newspaper, 1996), and we agree that safe infrastructure is certainly desirable in a society. The important question, however, is whether a consensus can be reached about how much safety is desirable in a society, because any level of safety has a cost, and it is unlikely that any society would be willing or able to bear the cost of a 100% level of safety, if such a thing were possible. It would certainly be expensive to enforce stricter shock-resistant standards, and even if they were adhered to, there would be no guarantee of 100% safety. As Takada (1995) stated, it is not easy to obtain a balance between economics and safety in infrastructure. As a result, a line must be drawn somewhere between citizens' needs for safety and the cost of attaining it.

Second, citizens' consensus should be acquired after publicizing information on how much it would cost to reinforce safety standards and enforce shock-resistant requirements for structures. After a cost is judged as acceptable, then, cost sharing should be clarified. For example, when the cost of risk can be distinguished from the cost of the expressways and railways in " normal time," consensus will be needed over whether the total cost will be borne by the users or whether the society as a whole will assume the burden of the risk cost.

So far, information about the cost of safety is very limited and the public has not been educated as to the reliability of safety levels. Thus it is impossible to make well-informed judgments about what safety level is acceptable and who should bear the cost of it. We believe this is an important area of study whose results could benefit society by showing that safety is sometimes not as expensive as it seems. For example, along the Hanshin expressway, concrete pillars were reinforced with steel wrappings. According to some sources, the project cost about 20 million yen. Assuming the reinforced cost of structure is depreciated by 10 years, the extra cost share becomes about 50 yen per car. If this number is accurate, it would seem that consensus among car users could be easily attained, with drivers agreeing to spend the extra fifty yen for the added safety of reinforced pillars. This is a rough example. Of course, we need more precise information about the reinforcement cost and the safety level.

Earthquake prediction vs. disaster-prevention management system

There is much research being done in Japan and abroad with the hope of someday being able to predict an earthquake's size and location. Not only have scientists been unable to develop a system for predicting the physical aspects of earthquakes, but there is also a great deal of uncertainty in predicting the social consequences of earthquakes. At any rate, many problems must be overcome before a useful earthquake prediction system can come into effect. As an example of a disaster prevention management system, JR West has considered introducing an Early-Detection System of Earthquake Wave. The system informs trains on the track before the earthquake wave arrives in order to stop the trains before serious damage occurs. However, this system does not help at all if the earthquake occurs very close to the rail tracks, and its effectiveness surely depends on the type of the earthquake.

Traditional railway technology has focused on how to prevent accidents, and in fact has helped to achieve a very high standard of safety in railway operation. The accident rate in 1993 was only 0.93 per million train kilometers. However, compared with accident prevention technology, technology for reducing accident damage has not yet been well developed. When the Great Hanshin Earthquake occurred, thirteen out of eighteen trains were derailed. Because the earthquake occurred so early in the morning, human casualty was almost nil, but if the earthquake had happened at peak, certainly deaths and injuries would have been staggering. It is clearly necessary to develop technology that would reduce damage even if trains are derailed by earthquakes. Some of the funds going toward the government's expensive research and development programs concentrating on earthquake prediction should be funneled into programs dealing with post-earthquake issues related to minimizing damage and facilitating restoration of impaired services.

Transport networks

Improvement of road network

One important lesson is that the alternative route must be built at some distance from the existing main route, though we cannot postulate the size and area of the earthquake beforehand. Second, it is also necessary to combine east-west routes with north-south routes. Because Kobe and the Hanshin area are bordered by mountains to the north, historically there has been a lack of capacity of the north-south roads. Improvement of the north-south traffic systems will be required to respond to need in disasters. This checkerboard-type road networking, needless to say, requires systematic functions of the road (for example, activating the coastal route as a main trunk road and the mountain route as a collector road) and space improvement befitting each function. The width of each axis supporting the checkerboard should be changed with the function of the road in mind. The effect of such improvement would be beneficial not only to lessen the effect of calamities, but also to reduce trip costs and to reduce loads on the existing trunk roads by allowing access to destination via roads with more traffic capacity, and not depending solely on the crowded east-west trunk roads running through urban districts.

The Earthquake also reminds us of the importance of the ordinary street network. Because Japanese cities were built before motorization, the number of streets in cities is smaller and streets are narrower than in US cities. A street improvement program called the City Planning Roads has been introduced but the street capacities remain insufficient. Most likely, other Asian cities have the same problem as Japanese large cities have: street capacity is quite limited relative to city size. The issue is how to improve streets. Considering the extensive ownership of personal automobiles in recent years, roads related mostly to livelihood should also be provided with more space by widening to a certain extent selectively and wisely. From the viewpoint of socio-economic activities in the whole area, the City Planning Roads, especially those with more intensified needs, should be promoted, but with a focus on environmental issues and, in some cases, area-wide improvement.

Linkage of transportation systems

Linkage of all transportation systems is extremely important. There are two important points arising from the earthquake experience. First, if the linkage between transportation systems is strong enough, we should be able to use an alternate transportation mode when one mode is suspended by a disaster. Second, the linkage points of different transportation systems could be important areas during an emergency: the distribution base of necessities such as food and clothing. For example, in Kobe's case, maritime transportation routes were not affected heavily by the earthquake. However, the mode by sea does not effectively function unless terminal facilities like quays and access roads to the inland (and railways in some cases) are not secured. A vessel of the Marine Safety Agency left Hiroshima immediately after the earthquake to supply drinking water but wasted valuable time at the port in the quake area because no water trucks were available for supply work inland. The Port of Kobe has assumed and probably will play a significant role for the local economy, but without trunk roads networking urban districts, its influence will decline both in the region and in all of Japan.

Improvement of the green-walkway network

The experience of the Great Hanshin Earthquake made us reconfirm the importance of the walk and the bicycle as transportation modes of evacuation at the time of emergency. We also noticed the robustness of firmly-rooted roadside trees against calamities. Therefore, it will be useful to improve the network of green walkways to secure evacuation passage and transportation of various emergency supplies in the restoration phase. Regular roads are extremely dangerous to use as evacuation paths because of tilted buildings, electric poles or wires blocking passage. Especially if a large-scale fire broke out, vehicles occupying roads due to traffic congestion would help spread fire.

Unfortunately, large Japanese cities have not provided green-walkways including cycling roads. Most likely, other highly populated Asian cities have the same problem. However, walkways and parks could prove to be very helpful when a disaster occurs. For example, it would be beneficial to study a plan to improve parks in urban districts so that they could be used as shelters and link those parks with the green-walkway network. If this network were equipped with bicycle roads, they would also be used for the transport of food, medical and other supplies in the restoration phase. Parks integrated with elementary schools would be opened as shelters where local residents would be provided with food. Rebuilding and improving overpopulated old urban districts, widening roads there in conjuncction with the campaign for the green walkway, would allow more space for the control of emergency vehicles in disasters.

The green walkway can be used as a local amenity space during normal time. It is expected to function as a pleasant promenade to allow enjoyment of urban districts, which might also generate a favorable effect on tourism. Promenades could increase the use of bicycles for commuting to offices or schools and, thus, contribute to relieve traffic congestion. This green walkway has both characteristics of public goods: non-rivalry in consumption and non-excludability. It is a classic example of what a government should provide.

Reconsideration of other infrastructure and natural resources

One important lesson is revitalizing existing infrastructures including natural resources such as rivers and canals. In Kobe's case, as there are many small- and middle-size rivers running north to south from the Rokko mountains, these river banks could be utilized as emergency roads to supply foods and necessities. Second, the allocation of public facilities is also an important factor in creating safe cities. Although planning for public facilities such as police stations, fire stations and hospitals must take into account accessibility for residents, it is not clear whether or not accessibility during emergencies has been considered. After the earthquake some public facilities, though themselves operable, could not function because citizens could not gain access to them.

For example, after the Great Hanshin Earthquake, the municipal hospital on Port Island could not accommodate the injured because sole access to the island, the Kobe Ohashi Bridge, was impassable. For the same reason, top police officers could not assemble at the Hyogo prefecture police headquarters on Port Island, and instead had to establish temporary headquarters at the Ikuta police station in the center of Kobe. This was unfortunate for the Hyogo prefecture police, as they had set up headquarters on Port Island only temporarily while their old office was being renovated. However, in either case, questions remain why such important public facilities were located in a place with only one access. At least two independent routes should have been secured before finalizing the location of these facilities. Many outcomes may have been different if the tunnel under construction(before the Earthquake) had been completed, offering a second route to Port Island.

A massive area in Nagata ward was burned down. There were multifaceted adverse conditions such as simultaneous fires in many districts, along with other types of destruction. The fact that the old streets (with city planning fixed at the time when they were built) were equipped with inadequate disaster-preventive measures from the present point of view, that redevelopment had been only slowly implemented and that fire hydrants and water tanks were not in good repair at the time all combined to make a bad situation worse. However, if the water tanks had functioned well, could the fires breaking out in various areas have been extinguished? Fire stations were too few and inappropriately located to serve the areas crowded with old wooden houses and plastic shoe factories. Public facilities should be reviewed from the viewpoint of functionality in an emergency.

Organization of the transport sector and subsidies

Organization and cooperation of operators

One important lesson from the earthquake was that organization size is an important factor in rebuilding transport infrastructure. Smaller transport organizations faced both financial and organizational (e.g. human resources) difficulties in rebuilding transport infrastructure. For example, the rebuilding costs of railway infrastructure were estimated to be 2 to 10 times annual profits for large rail operators and 6 to 50 times of annual profit for small rail operators. (Shoji and Kondo, 1995) Furthermore, in the Japanese rail industry, among private railways it can be expected that rail fare revenues cover all rail costs so that in a case such as the Hanshin Earthquake, where infrastructure was lost, rail operators must lose fare revenue until rail operations are restored, and such railways certainly do not have the cash to replace infrastructure without great difficulty. In an extreme case, a private railway risks bankruptcy.

Public railways or quasi-private railways are not immune to difficulties. For example, Kobe Shin-Kotsu, which belongs to the quasi-private sector, was very slow to restore rail operation. The main reason was that the organization lacks the ability to rebuild infrastructure by itself, being essentially a facility management corporation with infrastructure provided by the public sector (Kobe city). Kobe city, too, lacked the human resources to support Kobe Shin-Kotsu because it was busy restoring its own transport systems. Kobe Shin-Kotsu is a typical case but other small private rail operators more or less faced difficulties in restoring their operations. Although JR West also suffered severe damage to its tracks, it was able to restore service quite rapidly, probably due to the large size of its operation, which held room for slack. Thus, although it is necessary to do more research to determine optimal size, it seems true that small organizations cannot cope as well as large ones during an emergency.

Another lesson from the experience of the earthquake is that it is useful for transport operators to cooperate. We propose a cooperation agreement among operators in different regions to provide each other with human resources, for example. Many cases of support organizations were evident in the wake of the great Hanshin Earthquake. For example, other cities sent engineers and administrative officials. In the transport sector, JR groups such as JR East supported JR West by sending engineers and equipment. Thus, agreement among similar organizations serving different regions could be a useful option. This is one method of reducing the cost of risk by sharing it.

Time-limited reconstruction subsidy program

We think time-limit restoration subsidies for railway operators are necessary. Generally most Japanese transport infrastructure is constructed and managed on the "self-support principle," which means that infrastructure is not constructed with full-fledged public support but with user charges. Railway construction is a typical case. Railway subsidies are limited to the construction of public railways. While it is considered that unlimited availability of subsidies might cause wasteful cost escalation, it seems true that very limited subsidies could help achieve efficient management among operators. In the case of the Great Hanshin Earthquake, rail companies would certainly have faced huge difficulties had they been required to complete restoration with no help whatsoever in the form of subsidies.

Indeed, the government took action to extend subsidies to rebuild infrastructure. For example, national government subsidies for general road works reached 80 % of the cost in severely damaged areas. Subsidies were also granted to port facilities operated by public corporations and to the Hanshin Expressway Public Corporation for 80 percent of the reconstruction costs of urban express roads (Shoji and Mizutani, 1995). Compared with these, subsidies for rail operators are very limited. Government support provided 50 % of total reconstruction costs, equally shared by the national and local government, and disaster reconstruction loans by the Japan Development Bank (JDB), which are not true subsidies but rather low-interest loans. Seven railway operators, except for JR West and Hankyu, applied for government subsidies and eleven railway operators including JR and Hankyu decided to obtain the JDB loans. However, these measures will be insufficient, taking into consideration the size of damage and urban residents' dependence on railways. The damage to railways is not limited to the costs of reconstruction of tracks and facilities. As we mentioned before, decrease in fare revenue during the suspension of rail operation was not negligible. Furthermore, additional expenses were incurred during the suspension of rail operation, such as the cost of substitute bus service.

The 50 % subsidies and JDB loans are time-honored programs, and though the requirements for application to the subsidies have been slightly relaxed, no major change in these programs has been made. In this sense, they cannot be regarded as special measures to accommodate the size of damage caused by the Great Hanshin Earthquake, and the Railway entities are not in effect acknowledged by the government to have been severely damaged. Technically, government grants to private railways or non-public corporations may not be appropriate in normal time from the point of view of traditional Japanese public policy. And local governments have little power, responsibility and money in Japan. However, for all practical purposes, the government has been providing subsidies to the private sector in, for example, agriculture. Without sufficient government support, the financial burden may eventually be forced on railway users in the form of fare raises, decreasing ridership and declining rail companies' profits. After prompt damage estimation, railway operators, regardless of ownership, should have access to time-limited subsidies for reconstruction work.

CONCLUDING REMARKS

The kind of damage Kobe experienced is certainly different from what Tokyo will experience with its next major quake or other Asian-Pacific cities might face in future. Despite the differences in kinds of damage to be expected, many issues that the Great Hanshin Earthquake raised should be explored by other large cities with circumstances similar to Kobe's. For example, three years after the Earthquake, many former residents of downtown Kobe remain in rapidly constructed prefab aluminum housing(so-called shelters) scattered throughout the area, In central cities, small businesses are still struggling to reconstruct. Thus, although improvement of the transportation system is only one of many issues raised by the earthquake, it is vitally important to sustaining the life of a city.

Having the elderly living and working downtown constitutes a social issue, and social issues as well as the seemingly more technical issue of traffic infrastructure improvement are important. Disaster prevention measures often involve controversial decisions based on one particular view of a city's future, and naturally consensus is rarely achieved. Almost all measures are disruptive to some degree, such as appropriating private land for green-walkways that would serve as escape routes or even thinning out dense inner cities by encouraging residents to move elsewhere. Such preventive ideas necessarily take time to realize, but in the case of a disaster such as the Great Hanshin Earthquake, it is necessary to make speedy decisions and act upon them immediately in order to return society to a functional state, making consensus even less likely to be achieved. Perhaps a city should agree beforehand that immediately after a disaster, attempts should be made to recover its previous state, its basic equipment, with the condition of removing what has been reconstructed after a mandatory review ten years later.

If a decision is to be under mandatory review, however, it sounds like a tentative decision, and tentative decisions often lead to a waste-of-cost subsistence bound by vested interests. To avoid such a case, time-limited legislation should be enacted to mandate reviewing the present policies, decisions, and structures, empowering the government to take final responsibility. Nonetheless, it is not easy to alter policies once made or buildings once constructed, even if the environment has changed. It may cost more to review and tear down structures than to build completely new and better facilities from the outset. On the other hand, it is difficult to decide, especially under the pressure to recover quickly from a disaster, what would be a suitable facility in the distant future. Therefore, any additional cost for review or demolition should be justifiably borne by society and may in fact be relatively small when considering what it really pays for--quick recovery and avoidance of the risk of a faulty long-term decision.

ACKNOWLEDGMENTS

We would like to thank the Kansai Energy Foundation for financial support to this research.

REFERENCES

Asahi Newspaper, Osaka Science Department (1996) **Science of Urban Collapse (Toshi Hokai no Kagaku).** Asahi News Paper, Tokyo (in Japanese).

Kobe City (1997) **The Great Hanshin-Awaji Earthquake Statistics and Restoration Progress.** Kobe City, Kobe.

Land Planning Agency (1995) **The Annual Report on Disaster Prevention (Bosai Hakusho).** Ministry of Finance, Printing Bureau, Tokyo (in Japanese).

Ministry of Construction (1995) **The Annual Report on Construction Economy (Kensetsu Hakusho).** Ministry of Finance, Printing Bureau, Tokyo (in Japanese).

Ministry of Transport (1996) **The Annual Report on Transport Economy: Sammary (Fiscal 1995).** Ministry of Finance, Printing Bureau, Tokyo.

Shoji, K. and Kondo, K. (1995) The earthquake disaster and the transportation system (Shinsai to kotsu taikei). **Annual Report on Transportation Economics 1995 (Kotsugaku Kenkyu 1995)**, 35-50 (in Japanese).

Shoji, K. and Mizutani, F. (1995) Rebuilding of transport infrastructure (Kotsu infura no saikochiku). **Business Insight 10**, 8-21 (in Japanese).

Takada, S. (1995) Proposal toward a less-disaster city (Saigai keigen toshi heno teigen). **Hyogo for 21 Century (21 Seiki Hyogo) 65,** 2-5 (in Japanese).

Takayose, S. (1996) **The Great Hanshin Earthquake and Reaction of Local Governments (Hanshin Daishinsai to Jichitai no Taio).** Gakuyo Syobo, Tokyo (in Japanese).