DAMAGE REPORT ON THE 1994 HOKKAIDO-TOHO-OKI EARTHQUAKE

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ABSTRACT

An M8.1 earthquake hit the eastern part of Hokkaido late Tuesday night, October 4, 1994. The epicenter was located off the eastern shore (Toho-Oki) of Hokkaido about 150 km in the Pacific Ocean. It was the third earthquake which affected Hokkaido in less than two years; others being the Kushiro-Oki earthquake on January 15, 1993, and the Hokkaido-Nansei-Oki earthquake of July 12, 1993. Four reconnaissance surveys were made by ERS. Members of the 1st team were Prof. Meguro and Dr. Tong on October 6 and 7; the 2nd team, Dr. Kumazawa and Messrs. Kusu and Komae on October 7-9; the 3rd team, Prof. Tamura and Messrs. Mikami, Katagiri, Xiu and Ito on October 8 -12; and the 4th team, Prof. Yamazaki and Mr. Horiuchi on October 15-17. This is an updated quick look report on the earthquake based on INCEDE Newsletter, Special Issue[1].

INTRODUCTION

The Pacific coast of Hokkaido is prone to large earthquakes. Between 1918 and 1973, there were eight earthquakes with magnitudes greater than 7 (***Figure 1***). The 1993 Kushiro-Oki earthquake with a deep focus of about 100 km is considered to be of a different type. After the M7.4 event in 1973 filled the seismic gap in this area, it has been generally considered that the area had finally entered a quiescent period.

However, Hokkaido seems to be doomed to damaging earthquakes. An M7.8 earthquake occurred near Kushiro on January 15, 1993. Six months later, on July 12, 1993, another M7.8 earthquake off the southwestern coast of Hokkaido triggered devastating tsunamis which took more than 200 lives on Okushiri Island. After fifteen months, an even larger earthquake hit its eastern part.

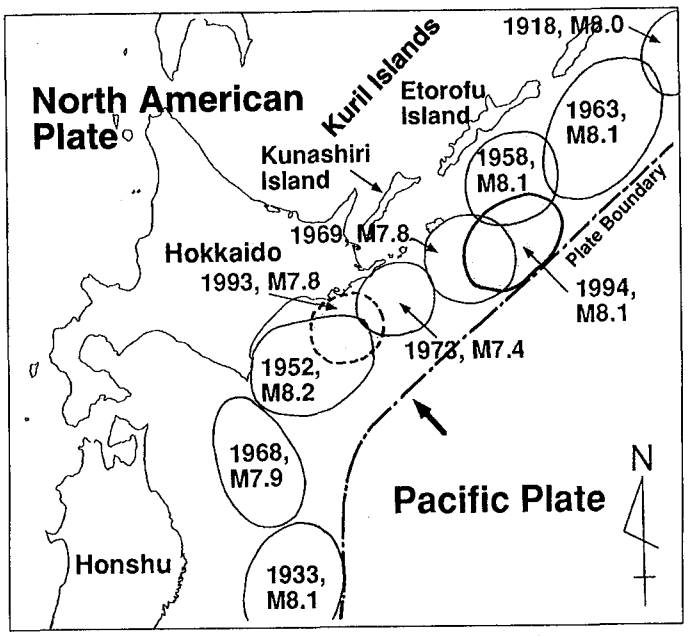

Figure 1 Seismic activities have been very high around the area

The earthquake occurred at 10:23 p.m. (Japan Standard Time) on Tuesday, October 4, 1994. Its magnitude tentatively reported by the Japan Meteorological Agency (JMA) as 7.9 was revised to the official number of 8.1 on October 11. The epicenter was located at 43° 22'N and 147°40'E,

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about 150 km in the ocean off eastern Hokkaido. The focal depth was 30 km, and the focus was supposed to be within the Pacific tectonic plate which descends below the North American plate on which Hokkaido is located. This earthquake was unique because most of the major earthquakes in the region occurred where these plates overlap (***Figure 2***).

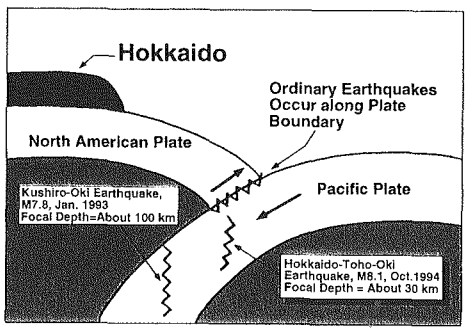


Figure 2 Mechanism of the earthquakes

Figure 3 shows the number of aftershocks recorded at the JMA Kushiro station. According to the Meteorological Agency, 47 aftershocks had been recorded by 1:00 p.m., October 5. By 7:00 p.m., October 12, the number of earthquakes felt in Nemuro and Kushiro reached 107 and 78, respectively. The largest aftershock of M7.3 occurred at 4:56 p.m., October 9, causing intensity 4 ground shaking in Kushiro. The distribution of the epicenters indicates that the causative fault was 130 km long and 70 km wide (***Figure 4***).

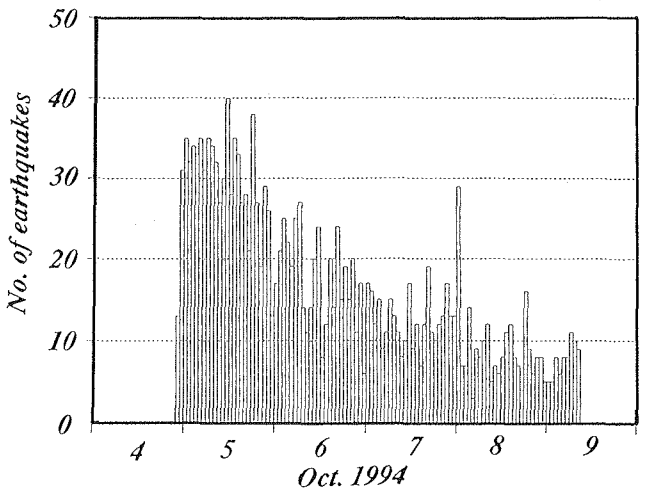


Figure 3 Distribution of the number of aftershocks

INTENSITIES, GROUND MOTIONS, AND TSUNAMIS

The earthquake registered 6 on the Japanese intensity scale of 7 in Kushiro and Akkeshi, and 5 in Nemuro, Nakashibetsu, Hiroo, and Urakawa, all of them in Hokkaido. The earthquake was rather strongly felt as far as Tokyo, Yokohama, and neighboring cities in the Kanto region, with intensity 3 (***Figure 5***).

During the January 1993 Kushiro-Oki earthquake, a very large peak acceleration of 0.94g was recorded at the JMA Kushiro station. During the 1994 Hokkaido-Toho-Oki earthquake, a very large ground acceleration of 1.08g was again recorded at Akkeshi sta-

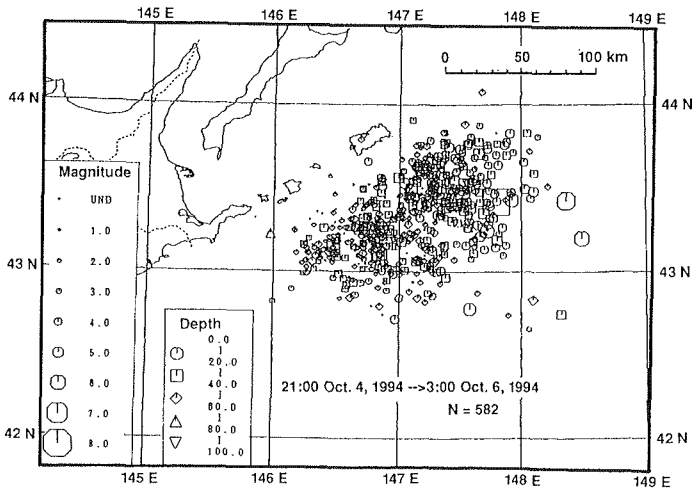


Figure 4 Distribution of aftershocks

tion of Japan Railway (JR) Nemuro Honsen Line (***Figure 7***). After the 1993 Kushiro-Oki earthquake, a group of scientists and engineers were interested in this strong-motion accelerogram and installed seismometers at 23 sites in Kushiro City. About 80% of them were reported to have successfully recorded the October 1994 event.

Two of the records (by courtesy of Prof. K. Kudo, Earthquake Research Institute, The University of Tokyo) show extremely interesting properties. At the two sites, 1.5 km apart and with almost equal epicentral distance of 270 km, horizontal peak accelerations were found to considerably differ; about 370 cm/s/s for one and 170 cm/s/s for the other. However, the velocity time histories were similar with their peak values being approximately the same (***Figure 8***).

The JMA issued tsunami warnings for the Pacific and Sea of Okhotsk coasts of Hokkaido at 10:28, five minutes after the earthquake. Milder tsunami warnings were issued for the Pacific coast from Ibaraki Prefecture all the way to Shizuoka Prefecture.

The first high waves reached Kushiro and Nemuro, both in eastern Hokkaido, at around 11 p.m. Tsunamis as high as 173 cm were reported at Hanasaki Port in Nemuro at 11:04 p.m. and 60 cm in Kushiro at 11:13 p.m. Tsunamis 72 cm high were observed in Miyako, Iwate Prefecture, Honshu. The highest 97-cm waves in Kushiro were recorded at 3:02 a.m., Wednesday, about four and a half hours after the earthquake (***Figure 9***).

The wave heights recorded in Hokkaido and northern Honshu were smaller than those estimated by the JMA. The epicenter was far, 150 km to the nearest part of Hokkaido. More important, however, may be the effect

Figure 5 Seismic intensities in eastern Japan (top) and Hokkaido (bottom)

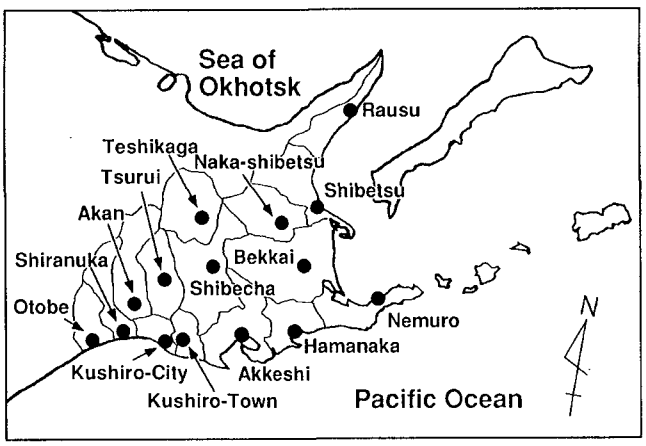


Figure 6 Cities and towns in eastern Hokkaido

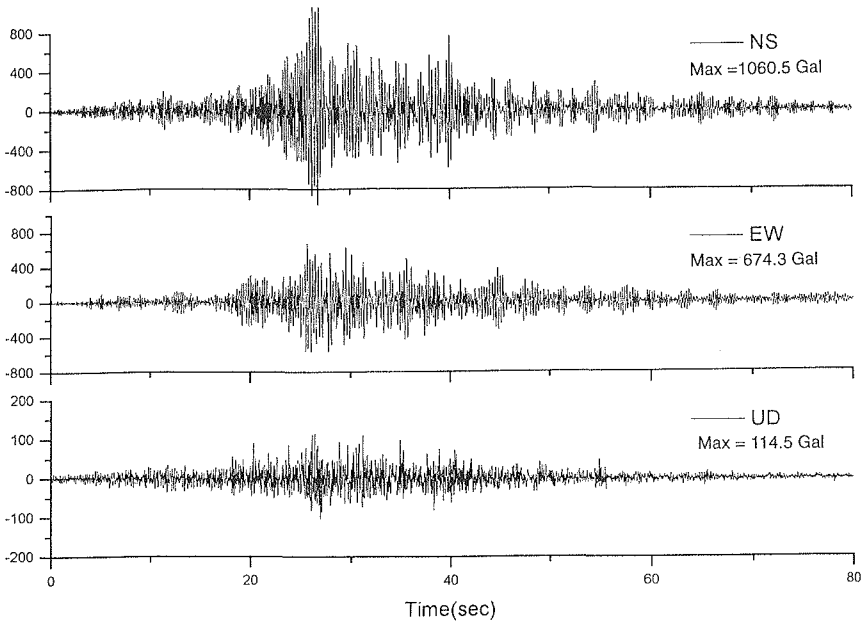


Figure 7 Strong ground acceleration recorded at JR Akkeshi station of Nemuro Honsen Line with epicentral distance of 233 km[2)]

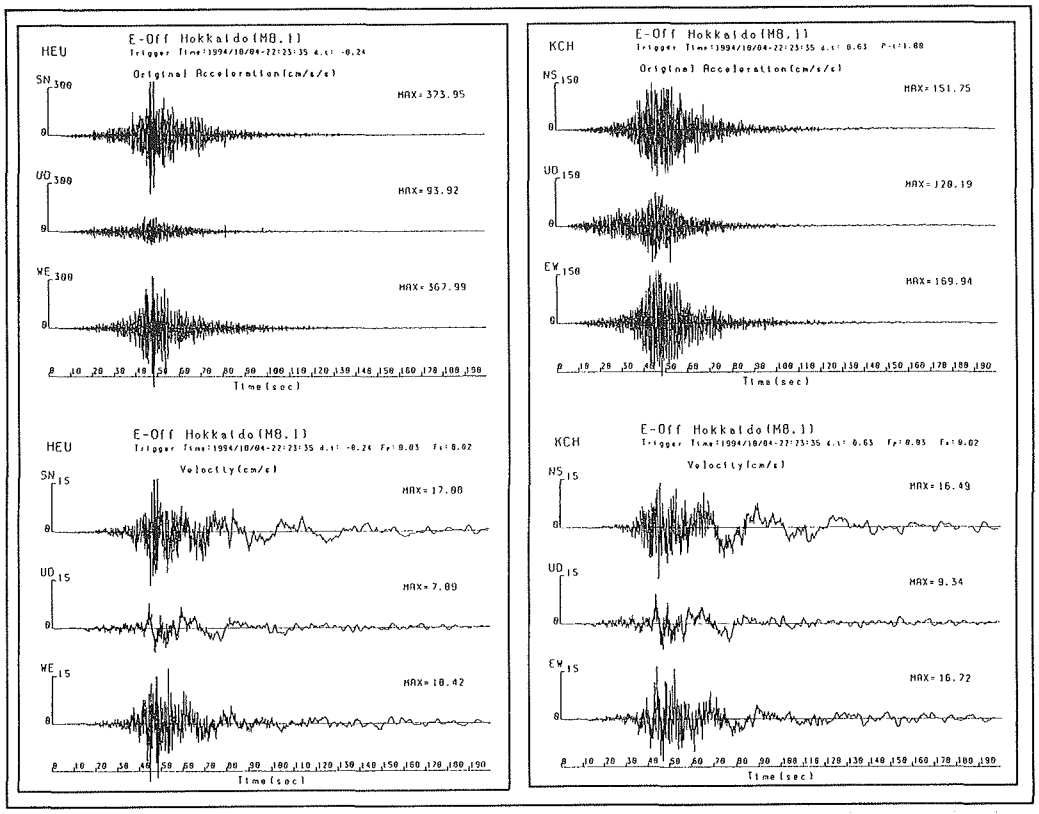


Figure 8 Strong ground motions recorded at two different sites with almost equal epicentral distance of 270 km: Although peak accelerations are different, velocity time histories look very similar

of the direction of the causative fault. Hokkaido is situated in the extension of the longer axis of the oval epicentral area and tsunami energy is usually small in this direction.

An estimated 25,000 people in about 30 cities and towns in Hokkaido were evacuated as a safety precaution in light of the tsunami warnings, mostly in Kushiro, Akkeshi, and Nemuro. The JMA lifted tsunami warnings at 5:55 a.m., Wednesday.

LANDSLIDE AND LIQUEFACTION

Geo-related damage such as landslide and liquefaction was observed in many locations in eastern Hokkaido. The geo-related dam-

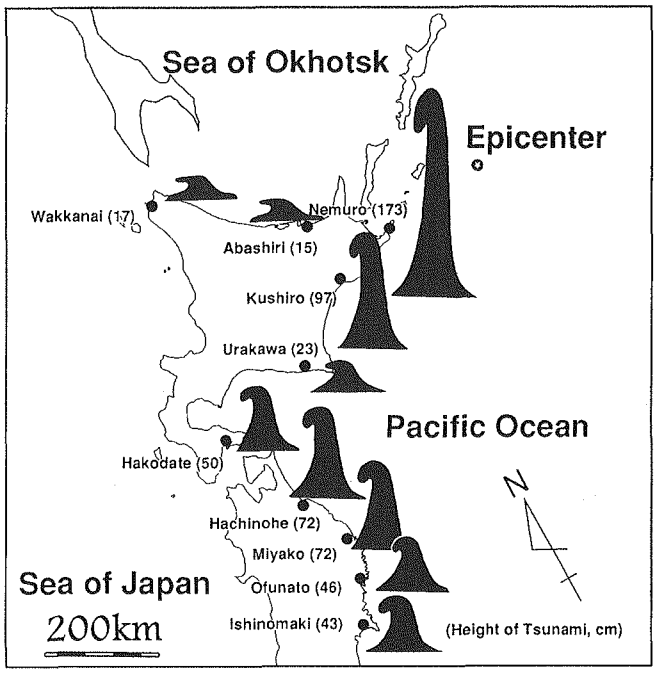


Figure 9 Tsunamis as high as 173 cm were reported in Nemuro (From Asahi Shimbun News)

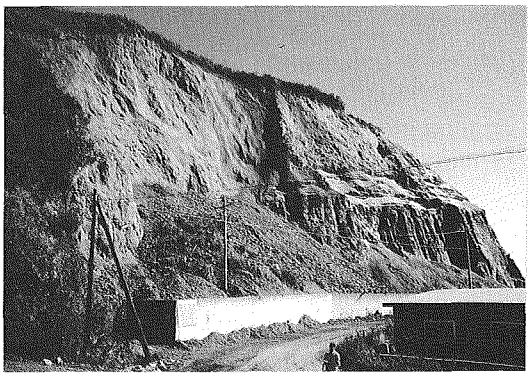


Photo 1 Landslide at Hanasaki Port

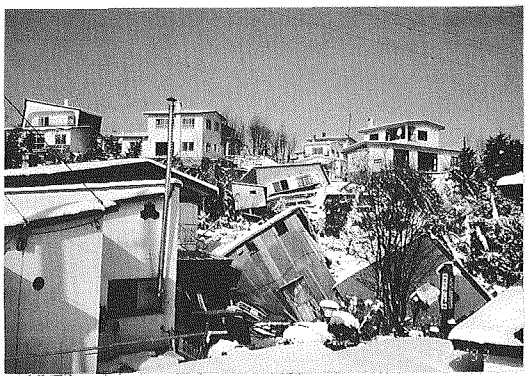


Photo 3 Tank floated up to the surface due to soil liquefaction (Hanasaki)

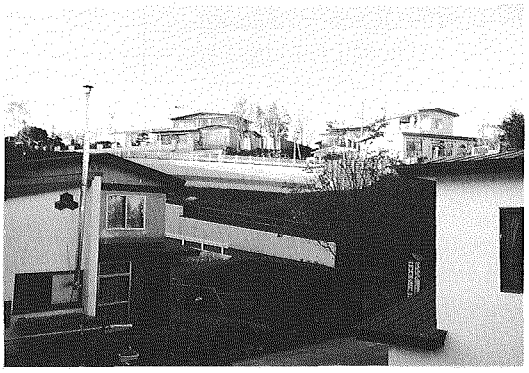


Photo 2 Landslide (Top: due to the 1993 Kushiro-Oki earthquake, Bottom: due to the 1994 Hokkaido-Toho-Oki earthquake)

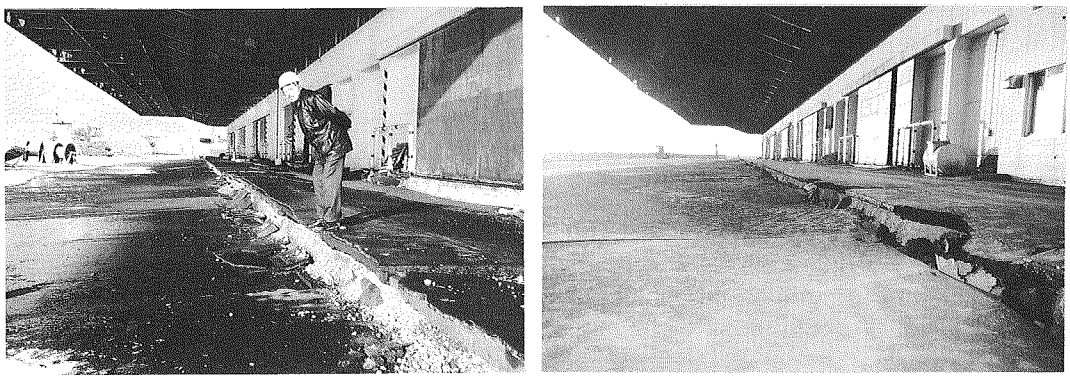


Photo 4 Liquefaction caused similar damage at Kushiro Port (Left: 1993 Kushiro-Oki earthquake, Right: 1994 Hokkaido-Toho-Oki earthquake)

age was one of the main causes of damage to houses/buildings and civil infrastructures. ***Photo 1*** shows the landslide observed at Hanasaki Port. ***Photo 2*** shows the slope at Midorigaoka, Kushiro City, during this earthquake and during the 1993 Kushiro-Oki earthquake (upper photo) where houses collapsed. In this earthquake, no failure occurred because of reinforced reconstruction of the slope. A tank that emerged above the ground surface due to the liquefaction of the sand fill around the tank is shown in ***Photo 3***. Liquefaction caused various damage to port facilities and lifeline systems. ***Photos 4*** and ***5*** show the damage due to liquefaction similar to that by the 1993 Kushiro-Oki earthquake. Although Kushiro Port was restored, it sustained similar structural damage after the 1994 Hokkaido-Toho-Oki earthquake (***Photo 4***). People made a manhole that surfaced due to liquefaction during the 1993 Kushiro-Oki earthquake as a monument to the earthquake disaster. Manholes near the monument again emerged above the ground due to liquefaction during the 1994 Hokkaido-Toho-Oki earthquake.

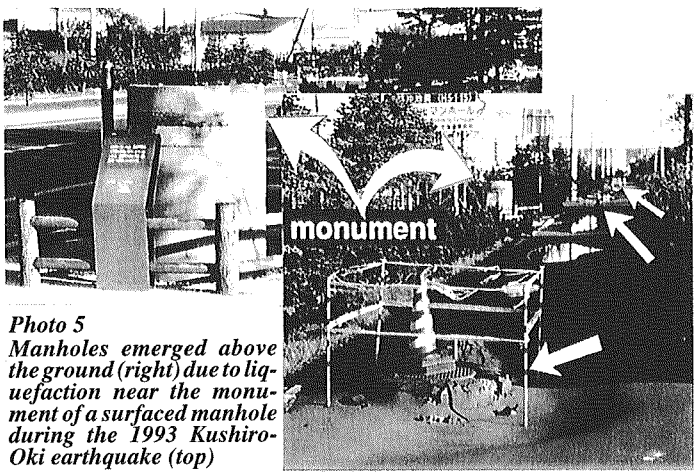


Photo 5 Manholes emerged above the ground (right) due to liquefaction near the monument of a surfaced manhole during the 1993 Kushiro-Oki earthquake (top)

Table 1 Damaged Houses, Buildings and School Buildings

Prefecture / City	Hokkaido			Others	Total
	Nemuro	Kushiro	Others		
Damaged Houses and Buildings					
Collapse	38	23	0	0	61
Severe	286	46	16	0	348
Medium	5,532	1,525	38	0	7,095
Flood	4	11	0	169	184
Total	5,860	1,605	54	169	7,688
Damaged School Buildings					
Primary	42	43	16	9	110
Junior High	30	17	8	5	60
High	6	11	5	7	29
Others	12	3	2	2	19
Total	90	74	31	23	218

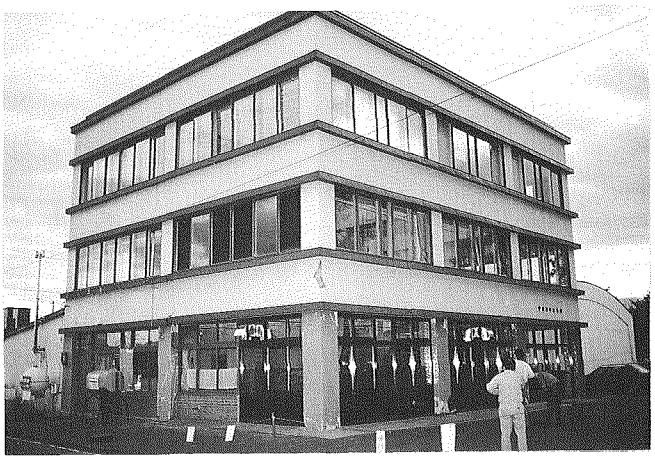


Photo 6 Overview of Nakashibetsu Citizen's Hall

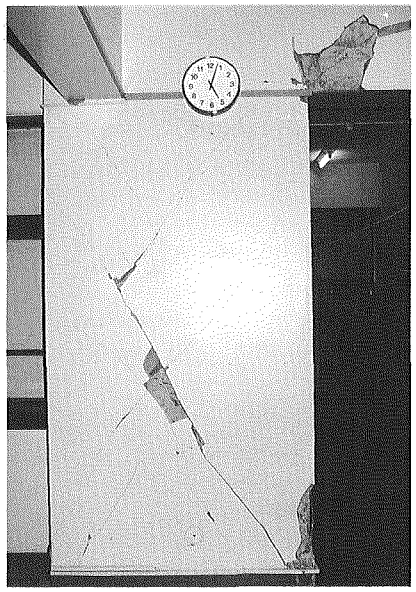


Photo 7 Shear failure of column with wall and shear failure of beam (Nakashibetsu Citizen's Hall)

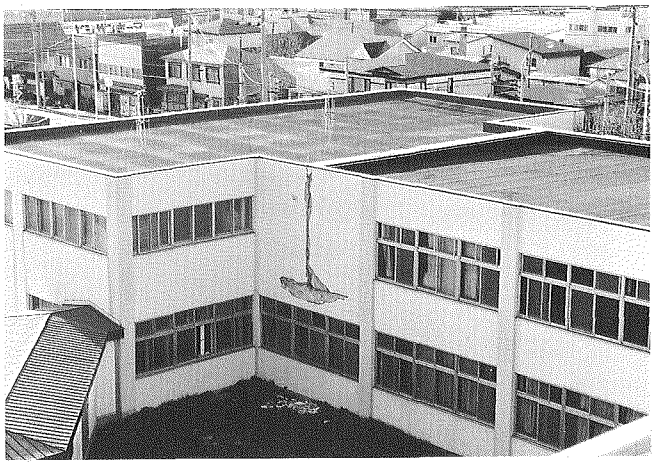


Photo 8 Failure at joint of low-rise parts (Nemuro Hospital)

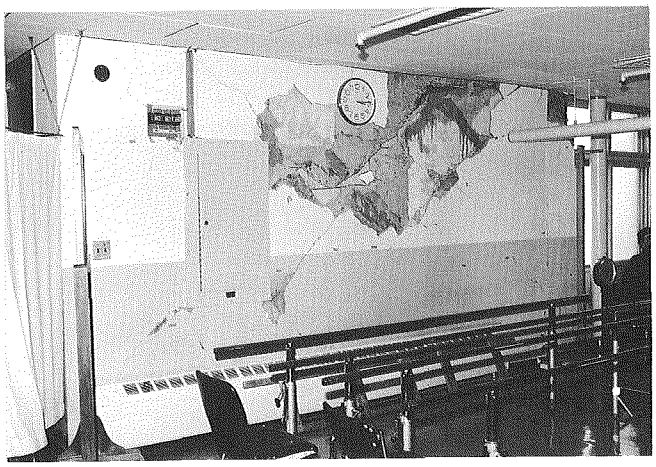


Photo 9 Shear failure of shear wall (Nemuro Hospital)

Photo 10 Shear failure of column (Nemuro Hospital)

Photo 11 Overview of Nakashibetsu Hospital

Photo 12 Shear crack of column (Nakashibetsu Hospital)

DAMAGE TO HOUSES AND BUILDINGS [3, 4]

Damage to houses and buildings totaled officially on February 28, 1995, is shown in ***Table 1***. One of the field survey teams, headed by Dr. F. Kumazawa, visited the eastern part of Hokkaido to investigate the damage, mainly to reinforced concrete public buildings, on October 7-9, 1994. The team investigated eighteen structures in Nakashibetsu Town, Nemuro City and Kushiro City. The typical damage to these structures is described as follows:

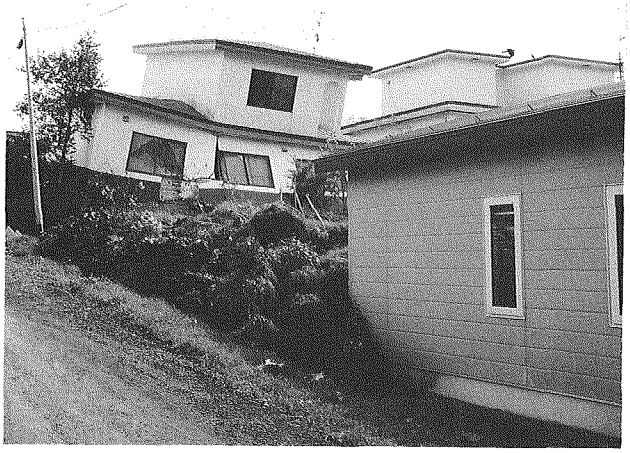


Photo 13 Wooden houses collapsed due to land failure

Nakashibetsu Citizen's Hall and Nemuro Hospital, which were constructed in 1962 and 1958, respectively, were severely damaged by shear failure of the columns on the first story (***Photos 6-10***) Many shear cracks on columns were also observed at Nakashibetsu Hospital that was constructed in 1968 (***Photos 11*** and ***12***). Many wooden houses on reclaimed land were damaged due to

Photo 14 A wooden house with its foundation displaced horizontally by 3.5 m and vertically by 1 m

land failure (***Photo 13***). ***Photo 14*** shows a house that was slightly damaged but the foundation was destroyed. Threat to people's lives does not come only from destruction of structural elements. Many people could have been injured or killed by damaged nonstructural elements if the earthquake occurred in daytime. In an event hall of the Nemuro Cultural Center constructed in 1992, about 200 seats were buried under fallen ceiling panels as shown in ***Photo 15***. Also, a nonstructural wall collapsed in Koyo

Photo 15 Fallen ceiling on about 200 seats in a large event hall (Nemuro Cultural Center)

Photo 16 Collapsed nonstructural wall (Koyo Junior High School in Nemuro City)

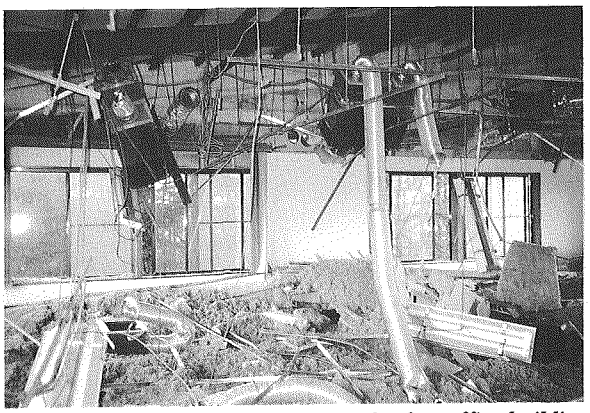


Photo 17 Damage of interior materials of an office building (Top: Outside, Bottom: Inside)

Photo 18 Books fell down from shelves (Higashi-Nakashibetsu Elementary School)

Junior High School constructed in 1964 in Nemuro City (***Photo 16***). A steel structure office building shown in ***Photo 17*** has slight structural damage. However, its ceiling panels and air conditioners installed on the ceiling fell down, completely burying the floor inside. ***Photo 18*** shows the scattered books that fell from the shelves which were bolted to the wall at Higashi-Nakashibetsu Elementary School.

Lessons learned from the investigation of damage to houses and buildings are as follows:

1) Many houses and buildings on reclaimed land were damaged due to deformation of soil, i.e., landslide, crack and/or liquefaction. It is very important to estimate the seismic capacity of the structures considering soil conditions.
2) Structural damage was observed in buildings that were designed before 1971, i.e., before the seismic design code was revised. It is necessary to strengthen these buildings as soon as possible, especially public buildings, as a countermeasure against seismic disaster.
3) Nonstructural damage causes casualties according to time and circumstances. It is essential to estimate the seismic performance of buildings, especially those used by many people, and of the nonstructural elements.

There seems to be only one confirmed structural fire after the earthquake. A two-story building with several eating and drinking establishments caught fire. Fortunately, the fire did not spread.

Photo 19 National and local highways are damaged at many locations

DAMAGE TO CIVIL INFRASTRUCTURES[5]

Damage to roads and bridges

National and local highways were damaged at many locations due to the Hokkaido-Toho-Oki earthquake. Embank-

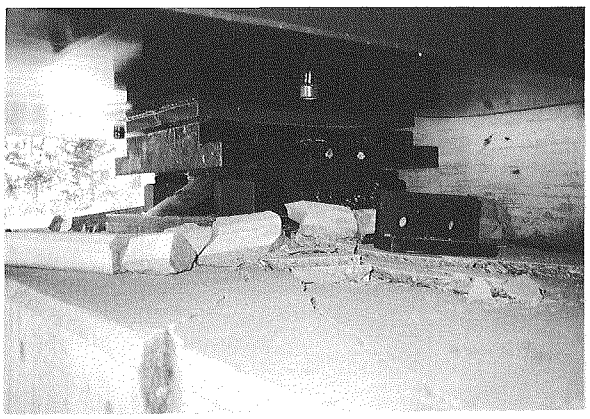


Photo 20 Damaged shoe and anchorage of pier of Rindo-Ohashi bridge

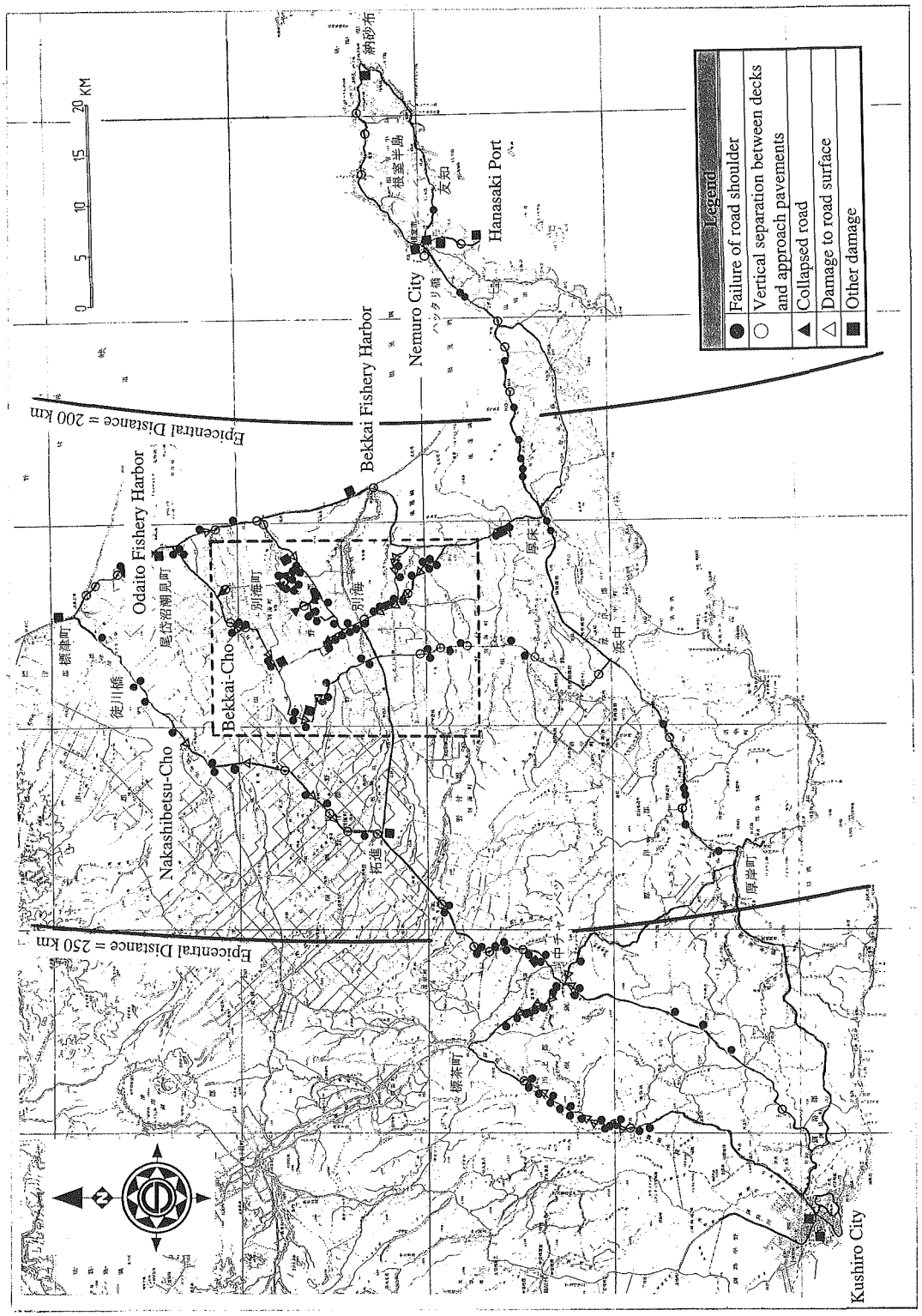


Figure 10 Distribution of damage to roads in eastern Hokkaido

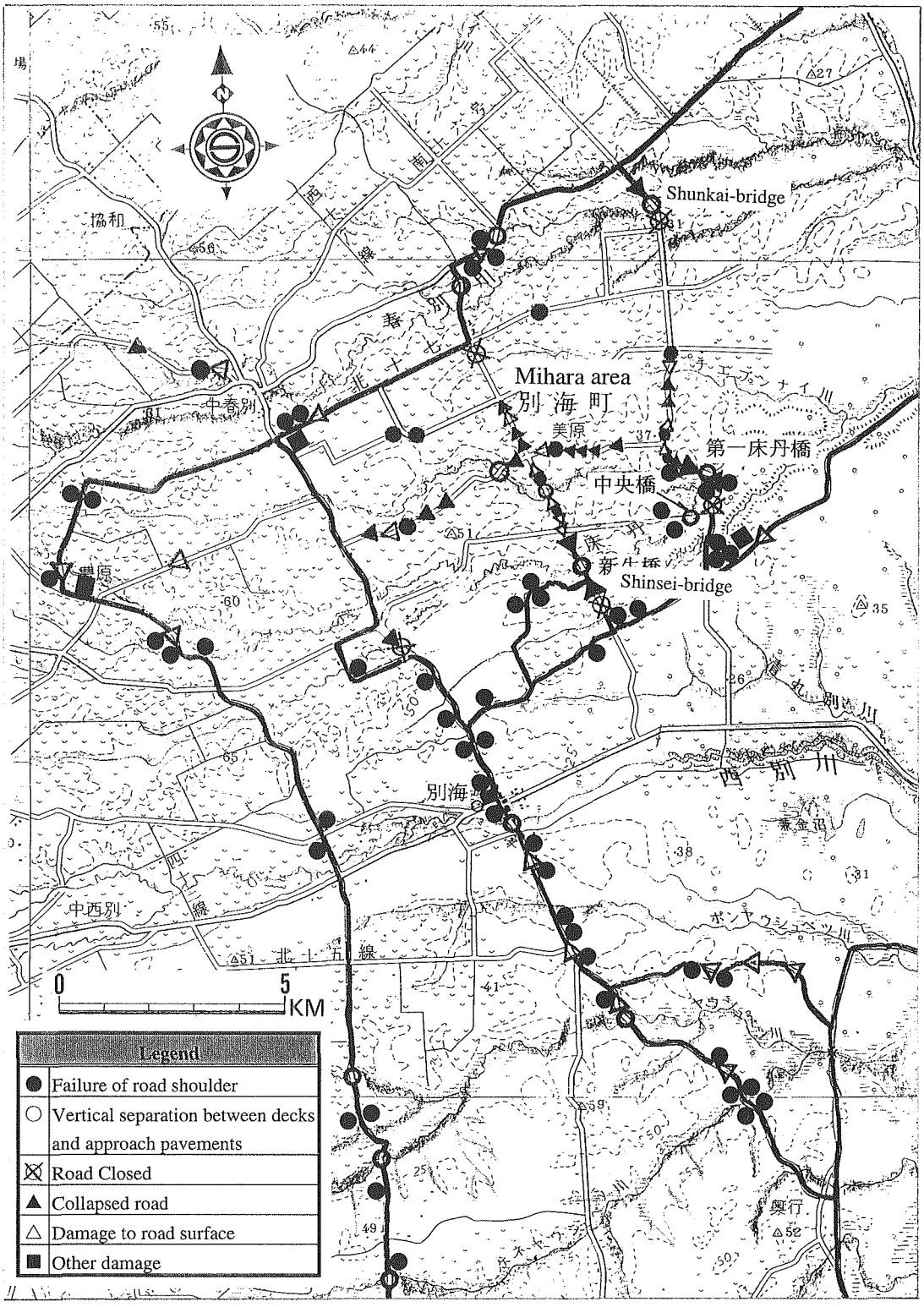


Figure 11 Damaged roads in Bekkai Town
(Enlarged figure of the dashed line area of the previous figure)

ments subsided and slipped at numerous locations, forming large cracks (***Photo 19***). Since roads sustained especially heavy damage, extensive investigations were conducted in eastern Hokkaido.

As of early Wednesday morning, October 5, traffic was paralyzed at about 40 locations along more than 30 national and local highways in Hokkaido. This number was reduced by about a half within 3 days. All national highways had been opened by the evening of October 9. Thirty bridges were reported to have been damaged (***Photo 20***).

Figure 10 shows the distribution of damage to roads in eastern Hokkaido. Representative damage to roads can be classified as follows:

1) Vertical separation between bridge deck and approach pavement: The most common disruption at bridge sites was settlement of approach fills due to compaction of embankment materials. These settlements produced vertical separations between the approach pavements and the bridge decks as shown in ***Photo 21***.
2) Damage at the section between hills: Significant road damage was observed at the valley section between hills or mountains, often with a river flowing through the valley or with high underwater level (***Photo 22***).
3) Damage at fill section beside the cut: Fill sections beside the cut were often damaged due to the different motions between these sections (***Photo 23***).

Bekkai Town is famous for its large-scale dairy farming. Therefore, damage to roads greatly inconvenienced the farmers. ***Figure 11*** shows Bekkai Town and the damage to roads in Bekkai Town investigated by the Konagai Laboratory. As shown in the figure, the Mihara area suffered the heaviest damage to roads from the earthquake. Many rivers flowing in this area,

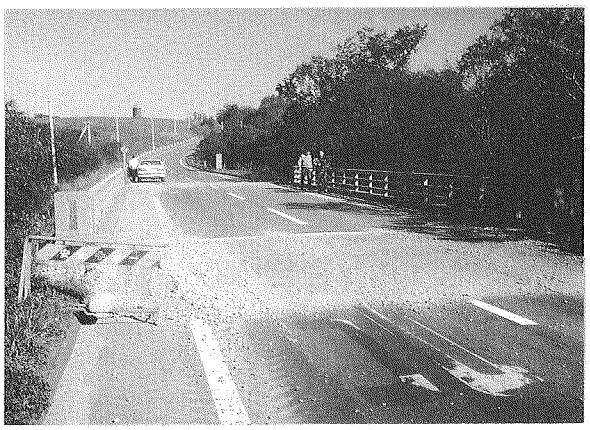


Photo 21 Vertical separation between deck and approach pavement

Photo 22 Damage to road at the section between hills

like the Tokotan and Syunbetsu, cross the trunk line between Bekkai Town and its northern neighboring town. Significant road damage was found at these crossings as shown in ***Photos 24-25.*** The most common disruption at bridges was the collapse of approach fills due to sliding or compaction of the embankment materials. The bridges themselves had almost no damage.

The topography of this area called Konsen plateau might be one reason for the heavy damage. The Konsen plateau is less than 200m-high, and is poorly drained. Peat and bog are widespread and the lack of sunshine and the balmy temperatures help maintain the saturated state year-round.

Photo 23 Damage to road at the fill section beside the cut

Photo 24 Failure of approach pavement of Shinsei bridge

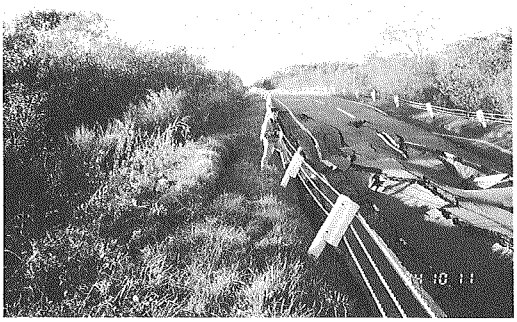
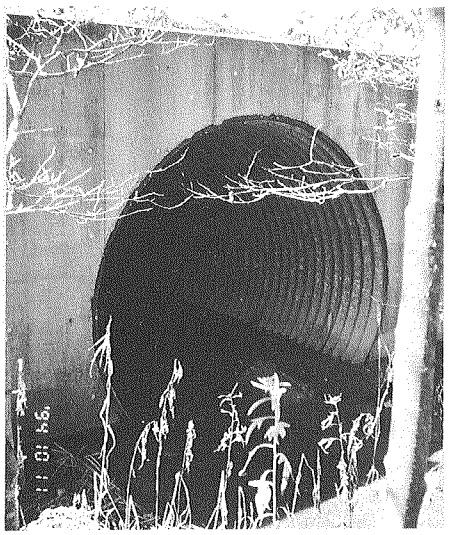


Photo 25 Subsidence of approach fills of Shunkai bridge

Photo 26 Damage to road diagonally above a corrugated culvert



Damage to ports and harbors

Port facilities suffered extensive damage from liquefaction and subsidence of the underlying soils. Fishing is one of the region's main industries and damage to the port facilities had a significant impact on this area.

A tsunami about 173 cm-high hit Hanasaki Port but there were no casualties. ***Photo 27*** shows a tide barrier against tsunamis. It did not perform during this earthquake because ground motions caused the barrier to slip out from the rail. Damage to the quay walls and quay surfaces was also visible in this port as shown in ***Photo 28***.

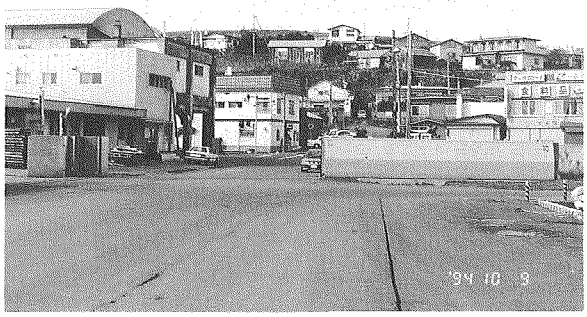


Photo 27 Tide barrier at Hanasaki Port

At Odaito fishery harbor, the soil behind the sheet pile-type quay wall liquefied and the concrete plates of the quay surface inclined as shown in ***Photo 29.*** Damage to this port was estimated at about 1.7 billion yen.

Bekkai fishery harbor is an estuary harbor of the Nishibetsu river. Sheet pile-type quay walls moved toward the sea (***Photo 30***). Cracks were found on the ground surface 6 m behind the quay walls. Damage to this port was estimated at about 0.4 billion yen.

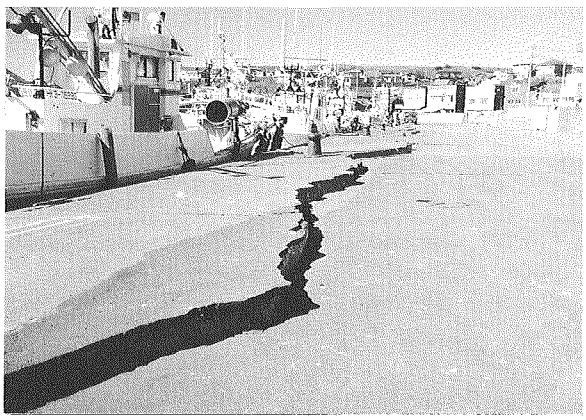


Photo 28 Cracks on quay surface at Hanasaki Port

LIFELINE DISRUPTION

Hokkaido Railway Co. stopped all trains in Hokkaido immediately after the earthquake. As of Wednesday morning, three lines were not running because of subsidence of tracks and loss of supporting soil (***Photo 31***). Two lines most heavily damaged in Nemuro and Kushiro regions were closed for several weeks.

A total of 16 gas leaks were reported in Kushiro, of which six were repaired by Wednesday morning. The rest was eventually found undamaged. Damage to the city gas system in Kushiro was generally light compared with that inflicted by the January 1993 earthquake due to the retrofitting work

Photo 29 Damage to quay surface by liquefaction at Hanasaki Port

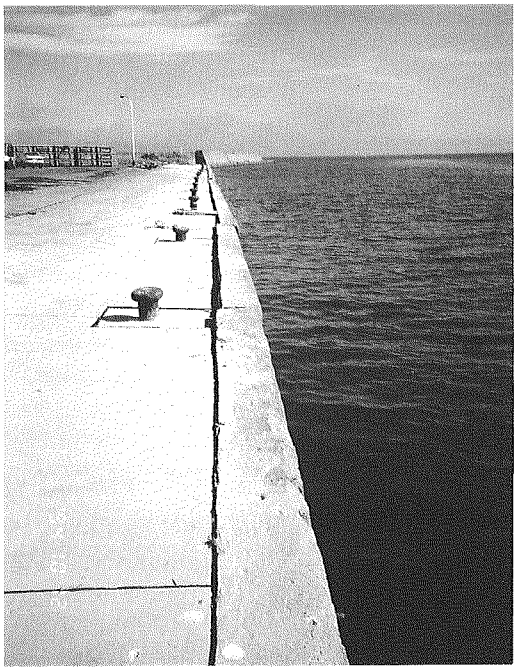


Photo 30 Movement of sheet pile-type quay wall at Bekkai fishery harbor

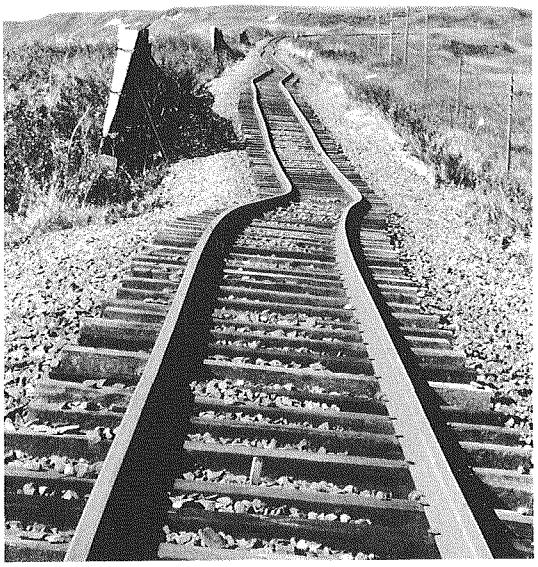


Photo 31 Rails buckled due to subsidence of the embankment at Nemuro Honsen Line

performed after the 1993 event.

Power failure affected about 46,000 households in Hokkaido, but power was restored to most areas by midnight Tuesday. The number was reduced to about 1,200 at 9:00 a.m. of the next day (***Figure 12***). However, its effect was serious on some dairy farms remotely located from towns because the blackout hindered the milking of cows.

The most heavily affected were the water supply systems of cities and towns in eastern Hokkaido. Early Wednesday morning, about 15,000 households were without water, mostly in Nemuro (6,000), Bekkai (5,000), Nakashibetsu (2,000) and Hamanaka (1,800). On Thursday morning, about 11,000 were still without water. In Nemuro, the number increased to 6,450, about half of all households in the city. The number of households without water had decreased to about 2,600 by Saturday morning,

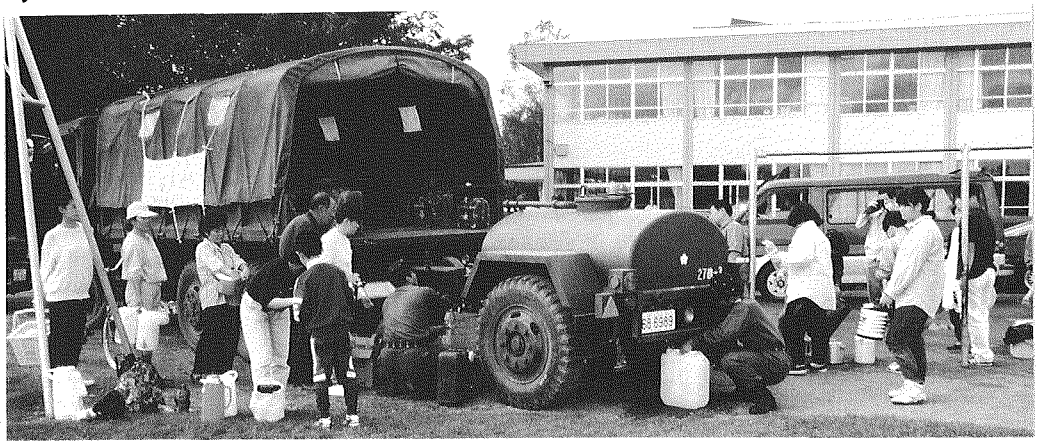


Photo 32 Self-Defense Forces supply potable water to the citizens of Nakashibetsu

ELECTRONIC COMMUNICATIONS SYSTEM AFFECTED
(From "The Japan Times," Thursday, October 6, 1994)

The earthquake severed underground fiber-optic cables, disrupting services at some financial institutions, according to Hokkaido Takushoku Bank.

Bank officials said Hokkaido Takushoku branches in Nakashibetsu and Rausu could not make contact with the main branch on computer lines, causing problems for some depositors who tried to withdraw money.

Six post offices in Nemuro, Nakashibetsu and Bekkai also reported that their on-line systems were out of order all day Wednesday, although this caused no confusion.

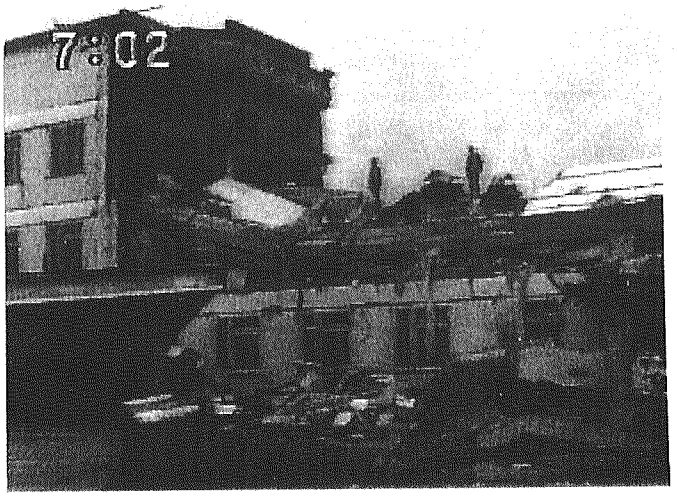
The Hokkaido office of Nippon Telegraph and Telephone Corp. said fiber-optic cables connecting Kushiro and Teshikaga around Shibecha were cut by collapsed roads.

DAMAGE ON KURIL ISLANDS

It is known that damage was far more severe on some of the Kuril islands, but information available at present is fragmentary. Below is a short list of what seemed to have taken place relating to the earthquake damage in the northern islands.

1. *Tsunamis with 2-3 meter wave heights attacked Shikotan and Kunashiri.*
2. *About 40 percent of homes on Shikotan collapsed or were washed away by the tsunamis. The number of houses affected by the earthquake reached almost 90 percent on Shikotan and 50 to 60 percent on Etorofu.*
3. *A 3-story military hospital collapsed in Etorofu, and a military garage, regiment headquarters and a club building collapsed in Kunashiri.*
4. *Ten or eleven people were killed, at least seven in Etorofu and three in Shikotan. Most of the casualties in Etorofu were killed in the collapse of the military hospital.*
5. *Some of the 15,000 inhabitants of the Kuril islands have left their homes devastated by the earthquake. By October 14, about 1,700 residents had left their islands for Sakhalin.*
6. *A government committee set up after the earthquake estimated the damage on the islands at 300 billion rubles ($100 million), two thirds of it being the damage to military buildings and facilities.*
7. *At least about 170 houses/buildings collapsed, affecting about 400 families with 1,500 residents.*
8. *Russia thanked Tokyo for an offer of humanitarian aid, but rejected a Japanese proposal to send rescuers, including troops, to the Kurils. Japan was reported to focus its aid on medical and food supplies, but would not consider any dispatch of aid personnel.*
9. *The first lot of medical and food supplies of about ¥ 10 million arrived in Nemuro port on October 13.*

It was reported after the earthquake that, because of financial difficulty, three earthquake and tsunami observatories on the islands of Etorofu, Kunashiri and Shikotan were closed in October 1993. The Japanese Meteorological Agency, with the assistance of the Ministry of Foreign Affairs, started on October 9 to provide meteorological and seismological information to the Russian government.



A 3-story military hospital collapses in Etorofu (From NHK TV news)

October 8, and to 1,300 by Sunday evening in Nemuro, Bekkai and Nakashibetsu. On October 14, 10 days after the earthquake, water supply was resumed to all the households in Nemuro, the city hardest hit by the earthquake.

DAMAGE ESTIMATES

Preliminary loss estimates were made for Nemuro by the municipal government as follows (October 14):

Ports and harbors	**¥2,943 million**
Residential houses	**1,412 million**
Commerce and industry	**359 million**
Marine product industry	**314 million**
Others	**131 million**
TOTAL	**¥5,159 million**

The Kushiro Office of Public Works estimated the following losses for civil infrastructures in Kushiro and Nemuro regions (October 13):

Fishery ports	**¥2,800 million**
Prefectural roads	**2,000 million**
River works	**300 million**
Quay protection works	**650 million**
TOTAL	**¥ 5,750 million**

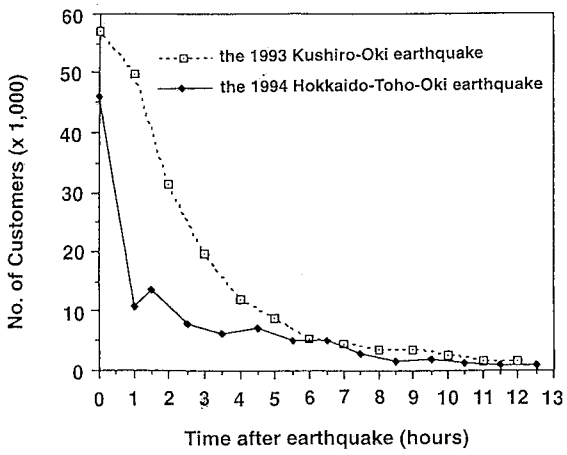


Figure 12 Restoration of power after the earthquake (after the Denki Shimbun News, October 13)

The total loss due to the quake reported by local governments is shown in ***Table 2*** (February 28, 1995).

CONCLUSIONS

The Hokkaido-Toho-Oki earthquake of magnitude 8.1 occurred at 10:23 p.m. (local time) on Tuesday, October 4, 1994. The epicenter was located off the eastern shore of Hokkaido about 150 km in the Pacific Ocean. It was the third earthquake which affected Hokkaido in less than two years. Very large ground motions were recorded at affected sites. At the JR Akkeshi station, an acceleration of 1.08g

Table 2 Damage due to the 1994 Hokkaido-Toho-Oki earthquake
No. of injured people and damaged civil infrastructures, and monetary loss

		Hokkaido			Tohoku (Northeastern part of Honshu)	Total
		Nemuro	Kushiro	Others		
Injured		234	165	37	1	437
Civil infrastructures	Roads	791	853	136	5	1,785
	Bridges	5	14	11	0	30
	Port facilities	2	3	2	0	7
	Others	92	81	45	1	219
	Total	890	951	194	6	2,041
Total monetary loss (billion yen)		38.84	14.99	3.51	1.97	59.31

was recorded. However, severe tsunamis were not oscillated because of the fault type and rupture direction of the earthquake. Despite the large magnitude of the earthquake, human damage was not so severe because of its location. Due to the cold weather in Hokkaido, where it snows heavily and the soil freezes in winter, houses are built on large and strong foundation with thick walls and small windows. A sheet of light metal or of other material is pasted on the roof and thich columns are used as protection from heavy snow. These characteristics of the houses could have helped reduce the damage from the earthquake, sparing the dwellers from injury or death. Most of the damage to structures due to the earthquake was caused by geo-related damage, such as landslide, liquefaction and subsidence. The damage to transportation facilities like roads, bridges, and railway and to ports and harbor facilities was also caused by geo-related damage. Lifeline facilities were damaged, especially the water supply system. The effects of this large earthquake propagated to a wide area, including the neighboring Kuril Islands. Damage on these islands was reportedly much severer than that in Japan. However, not much information could be obtained in Japan. Also, it is not certain how much information, like tsunami warning, from Japan could be obtained on the islands. This emphasizes the need for and importance of continuous information exchange before, during, and after the event.

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