FUNCTIONAL DAMAGE AND REHABILITATION OF LIFELINES IN EARTHQUAKES

by

Eiichi KURIBAYASHI[I], Tadayuki TAZAKI[II], Takayuki HADATE[III] and Ryoji HAGIWARA[IV]

SUMMARY

The Miyagiken-oki (i.e. Off Miyagi Prefecture) Earthquake of June 12, 1978 with 7.4 of Magnitude brought many disasters to Sendai City of about six hundred thousand at population and its adjacent area. It killed 28 people and the property loss amounted 276 bil. yen (1.1 bil. dollars). The disaster was supposed as one of the biggest earthquake disasters since the Kanto Earthquake of 1923. After then such earthquake disasters in modernized prefectural metropolises had been experienced in the Fukui Earthquake of 1948 and the Niigata Earthquake of 1964. However Sendai City was urbanized than Fukui and Niigata at those days.

This paper discusses the functional damage and rehabilitation of lifeline systems.

FUNCTIONAL DAMAGE TO LIFELINE FACILITIES

General Description

After the earthquake, Sendai City and its adjacent area experienced suspension of electric power, water and gas supply, sewarage, railway operation, traffic signals and telecommunications. They brought an inconvenience in urban activities.

Lifeline facilities perform their function when they are operated as a network. The experiences through the past earthquakes show us the possibility of the functional paralysis of whole lifeline systems caused by the partial damage. In this earthquake, the "bottleneck" was the electric power facilities. Traffic signals and some of the water pumps for water supply operated by electricity did not work due to the electricity outages. The electricity-relied urban life was obliged to stop for a few days.

Transportation Facilities

Roads

After the earthquake at 5:14 p.m. of June 12, the automatic control system for traffic signals at Sendai Central Police Station did not work due to electricity outages. Two hundred sixty traffic signals in Sendai could not be operated. That was just at rush hours in the evening so that the traffic became confused. Owing to the recovery of electricity at 8 p.m., policeman's hand signal for traffic control and the temporary electric-power supply to traffic signals by portable generators, traffic congestion was gradually dissolved.

I) Director, Earthquake Disaster Prevention Department, Public Works Research Institute, Ministry of Construction, Tsukuba Science City, Ibaraki-ken 305, Japan

II) Senior Research Engineer, Earthquake Engineering Division, do

III, IV) Research Engineer, do

The traffic on major roads was restricted by structural damage to national and prefectural highways and Tohoku Expressway.

Railways

After the earthquake, all the railways under the control of Sendai Railway Control Bureau JNR were suspended. Many commuters and travelers were deprived of means of transportation. As a result of inspection and temporary restoration, Tohoku Main Line south of Sendai and Joban Line (both connecting Tokyo and Sendai) reopened on June 14, and north part of Tohoku Main Line on June 15. Local lines in and around Sendai reopend on July 8.

Harbors

Ishinomaki Industrial Harbor, Sendai Harbor and other harbors in Miyagi Prefecture suffered such damage as cracks in aprons, breakdown of loading machines, etc. But by emergency measures, the function of the harbors was mostly secured.

Airport

Sendai Airport suffered slight damage of cracks on runways. Taking-off and landing of planes were suspended for a while. But normal operation was soon resumed.

Water Supply Facilities

Water supply facilities were damaged at 54 cities, towns and villages. In Sendai water supply was suspended at about 7,000 houses after the earthquake. The number of houses suspended decreased to 2,000 on June 14 and to 700 on June 15. Water supply was suspended at all 16,000 houses in Shiogama City, 15 km east of Sendai, and at 10,500 houses in Izumi City, 10 km north of Sendai. Due to the damage to industrial water supply facilities, more than 20 factories were obliged to be supplied no water for 24-79 hours.

Sewerage Facilities

After the earthquake, sewerage treatment and pump yards in Sendai and some other cities could not work because of electricity outages and structural damage. Under such situations, sewage was obliged to be discharged into a river without full treatment. After the temporary restoration, the function of these damaged facilities was recovered within a few days except for Kooriyama Pump Yard (recovered at 4:25 p.m. of June 23) in Sendai.

Medical Facilities

Medical activities after the earthquake were more or less impeded because of electricity outages and the damage to equipments and fittings at hospitals and clinics. However accidents of patients were prevented by emergency measures. Serious confusion of medical activities did not come about by means of the cooperation among the hospitals with slight or no damage.

Energy Supply Facilities

Electric Power Facilities

Total demand of electric power in Tohoku District (northern part of Japan) was 4,900 MW just before the earthquake. After the earthquake the demand for electric power reduced by 1,500 MW, and the supply reduced by 1,000 MW owing to the damage of both facilities of customers and the electric power company.

The number of electricity-failed houses reached 681,600 (419,100 in Miyagi Pref., 103,000 in Fukushima Pref., 95,800 in Yamagata Pref., 59,000 in Iwate Pref.). Owing to the temporary restoration it decreased to 280,000 at the end of June 12, and to 12,000 on June 13. The function of electric power facilities was completely recovered on the early morning of June 14.

Gas Supply Facilities

The earthquake caused the damage to gas supply facilities in four cities of Sendai (including Izumi and Tagajo), Shiogama, Furukawa and Ishinomaki. There was slight damage in the latter three cities. The function of gas supply facilities was completely recovered on June 13 in Ishinomaki, on June 16 in Shiogama and on June 18 in Furukawa.

However, in Sendai gas production facilities at Minato and Haramachi Plants were damaged. A cylindrical gas holder in Haramachi Plant with the capacity of 17,000M^3 caught fire and what was worse, gas pipes were damaged at 533 places. The gas supply in Sendai was wholly suspended by such serious damage. With the temporary restoration gas supply was resumed in some part of Sendai on June 16. After the accomplishment of inspection and restoration of all gas pipes, from main pipelines to twig pipes inside every house, gas supply resumed block by block. It was on July 9 that gas supply was resumed to every house.

Areal propane-gas supply through pipes was also suspended at 7,861 among 16,266 customers in Miyagi Pref.. The supply to 4,444 houses was resumed on June 14.

Telecommunication Facilities

3,845 telephones of 1,738,000 subscription telephones in four affected prefectures were damaged by snapping of wires, the damage to telpehone sets, etc. They were entirely restored on June 20. As for long-distance transmission lines, 4,000 circuits into, out of and through Sendai were down by the damage to coaxial cables, inclination of microwave antennas, etc. All the circuits were restored on June 14. Short-distance transmission lines were slightly damaged, but all the circuits were soon recovered on June 13. As many telephone calls poured into Sendai immediately after the earthquake, extraordinary congestion of calls took place until June 14.

Public telephones were unusable for several hours by electricity outages. Telegraph was not able to be serviced at Sendai Central Telegraph Office by the damage to transmission lines. Their functions were soon recovered. In three days after the earthquake sixtyfour thousand telegrams reached Sendai, that is 20 times more than usual.

Wireless facilities for emergencies connecting the prefectural government office and local communities were slightly damaged in Miyagi Prefecture. There was only one town that could not communicate by wireless.

As for broadcasting, TV and radio stations could not broadcast for a while after the earthquake by the electricity outages and the damage to microwave circuits. Their functions were recovered within less than an hour.

CHARACTERISTICS OF THE DAMAGE AND ITS REHABILITATION

Relationships among Damage, Topography and Geology

The sites where structures suffered damage approximately correspond to the areas of topographically or geologically poor conditions. For instance the razed houses are concentrated to alluvium, eastern suburb of Sendai, and to the hilltop, northern and south-western suburb of the city. The latter area also suffered slope failures. The distribution of the damage roughly coincides with that of the water supply facility and of the gas supply facility.

Through the experiences of past earthquakes, we have learned that structures on the alluvium are likely to suffer greater damage than those on the diluvial layer. The earthquake proved that the experience was fairly true.

The hills in the western part of Sendai and the western part of Natori are covered with 5M thick loam layer at the top and with 10-20M thick gravel layer underneath. The Tertiary of sandstone spreads beneath them. N-value of the loam layer at 2.5M beneath the surface and of the gravel layer are on the average 5 and 20-30 respectively. Midorigaoka District, Sendai where residential lots had been developed in late '50s through early '60s and many slope failures took place, has the same geological conditions. The residential lots had been developed by cutting the hilltops and filling the valleys. There were the fills more than 10M thick and whose N-value was less than 10. Slope failure and settlements occurred mostly at these fills due to the earthquake, which caused the damage to residential houses, water supply and gas supply pipes.

In the residential lots of northern part of Sendai and Izumi there are no loam and gravel layers. Hard rock and soft rock lies alternately. The residential lots had been developed by using bulldozers attached by the ripper. Fig. 3 shows the damage distribution of water supply and gas supply pipes at Nanko-dai Housing Complex, Izumi. The damaged sites concentrate to the areas where they have used to be swamps and had been artificially filled.

Damage and Function of Lifelines

Table 1 shows the individual loss ratios of lifeline facilities in Miyagi Prefecture. The individual loss ratio is defined as the ratio of the loss caused by the earthquake and the existing assets in the affected area both valued in money. The existing assets can be estimated from the population density.

$$\text{Individual Loss Ratio} = \frac{L\ P}{W\ P_D}$$

where

L : loss valued in money,

W : national wealth,

P : national population and

P_D: population of the quake-affected area.

The data of the national wealth of 1978 was not available, so that the data of 1970 were used.

Table 1 Comparison of Individual Loss Ratios of Lifeline Facilities

	Loss (L) in million yen	National Wealth[*1] in billion yen	$\frac{L_K P}{W_K P_D}$
Highway	10,721[*2]	8,121.5	0.076
Harbor	3,746	2,076.5	0.103
Water Supply	1,733	4,502.2	0.022
Gas Supply	947	867.4	0.063
Electric Power	2,960	8,133.7	0.021
Telecommunication	850	4,857.2	0.010

*1 Referred from the National Wealth Survey of 1970.

*2 Excluding National Expressways.

P : 111,933 thousand

P_D: 1,955 thousand

The individual loss ratio of harbor facility shown in the table is the highest and those of highway and gas supply facilities are also high. Water supply and electric power facilities have relatively low ratios and telecommunication facility has the lowest. The sequence of the individual loss ratios suggests that the ratio represents the extent of damage. It can be used as the index quantifying damage of various kinds of facilities.

The sequence also roughly coincides to that of the functional damage. In Ishinomaki Port, the mostly heavily damaged harbor, the function was maintained after the earthquake by the emergency repair and by utilizing the little damaged warves. As for the facilities themselves, the damage was not minor but the reserved facilities had been well prepared.

Many highways had been blocked due to the earthquake damage since the occurrence of the earthquake. It took more than four months to resume the traffic in one highway section and three highway bridges due to reconstruction works. Many bridges suffered considerable damage which made discontinuity of highway network in Miyagi Prefecture. The gas supply facility suffered great functional damage, as the individual loss ratio was relatively high. It took about one month to completely resume the supply. The area where gas supply stopped after the earthquake encompassed Sendai and adjacent cities. The water supply facility sustained less functional damage than the gas supply, as the individual loss ratio of the water supply was also less. The suspension of water supply in Sendai was over on June 20, eight days after the earthquake. During the suspended period, water wagons supplied water to the residents. Functional damage of the electric power was not severe. The domestic power supply was resumed on June 14. On the other hand the suspension influenced other lifeline facilities. For example traffic signals did not function because they did not have the reserved electric power. It brought traffic congestion in the central Sendai. The Traffic Control Center of Sendai Central Policestation, which had controlled areal traffic signals in Sendai, disordered. Tohoku Electric Power Co. Ltd. asked

industries to reduce the consumption of electric power, until the power plants and transformer stations recovered. It would have influenced the industrial productivity to some extent. The telecommunication facility suffered little functional damage. However the demand for the telephone call increased after the earthquake, which caused difficulties of telephone calls.

As stated above, functional damage and individual loss ratio fairly correlate in each other.

LESSONS FROM THE EARTHQUAKE DISASTER

(1) The loss ratio valued in money represents successfully the extent of damage of lifeline facilities and the functional disturbance.

(2) Gas supply was stopped for about one month after the earthquake. One reason for this was that the gas pipe networks were continuous within the supplying area. The supply could not be resumed until whole damages of pipes were repaired.

Functional damage of the electric power facilities was not big. However it caused the disorder of traffic signals and water pumps of water supply. Functional damage of the electric power facilities had much consequence on other lifelines.

(3) This earthquake revealed the vulnerability of the artificial land, which was developed by cutting and filling a large volume in a swamp or steep slope. Most of the damages were caused not only by ground shaking itself but also by ground failures.

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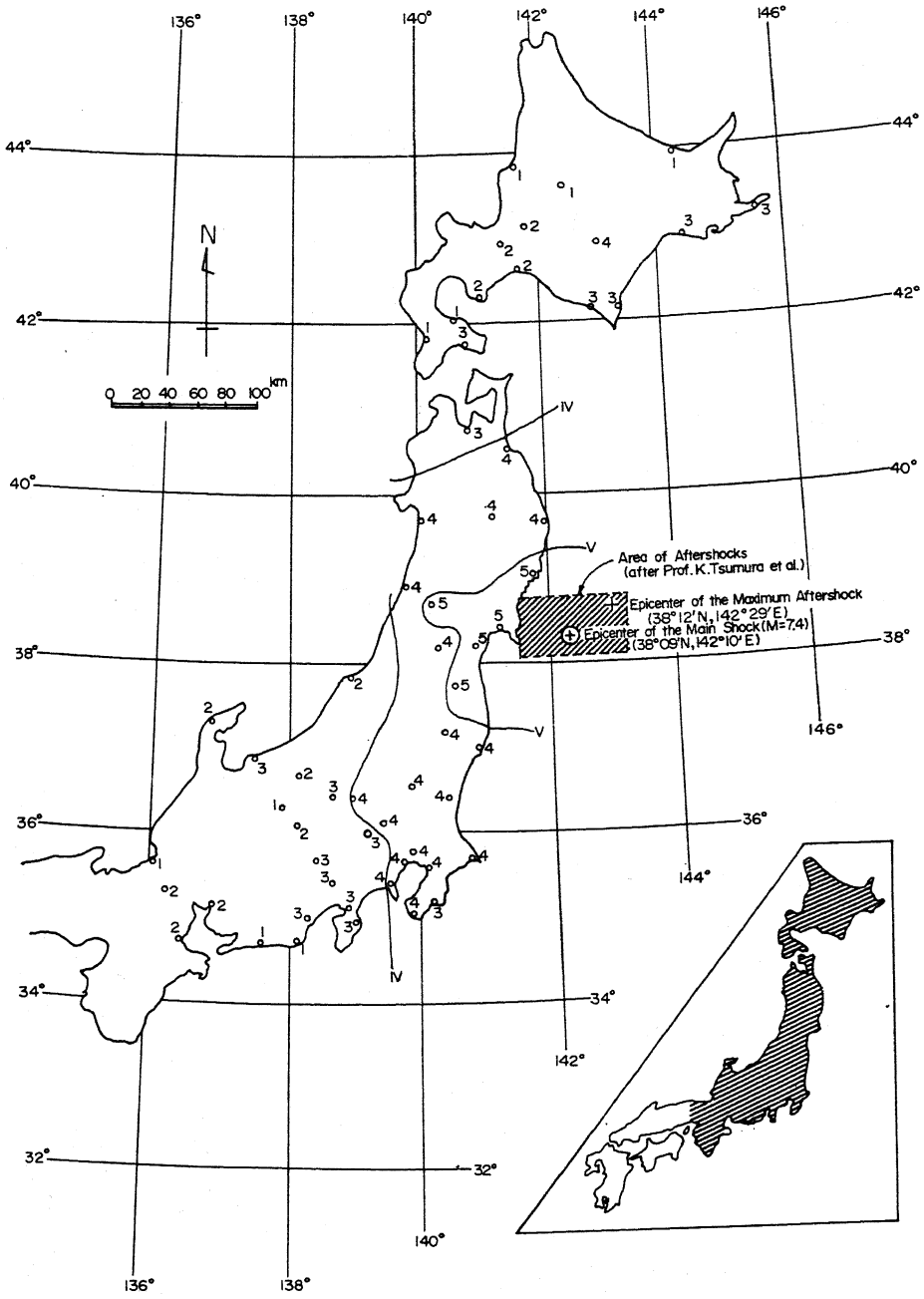

Fig. 1 Isoseismals (in JMA's 7th intensity scale)

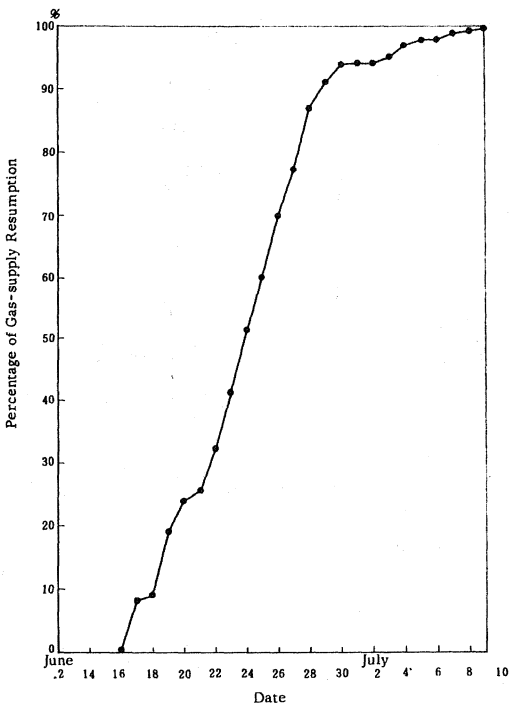

Fig. 2 Transition of Gas-supply Resumption (Gas Bureau of Sendai Municipal Government)

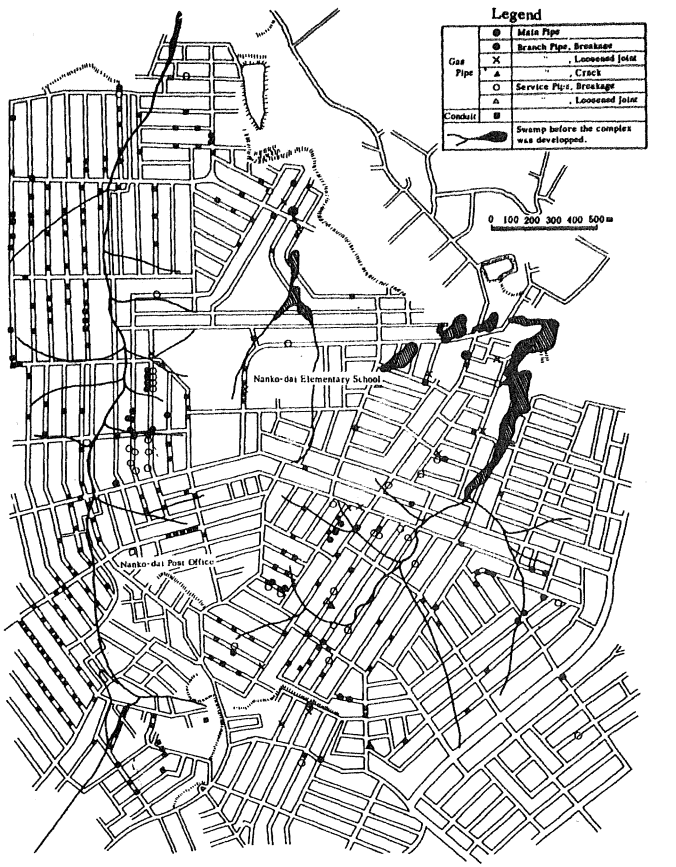

Fig. 3 Damaged Sites Distribution of Conduits and Gas Pipes at Nanko-dai, Izumi City