RESTORATION OF LIFELINES IN SENDAI AFTER THE DAMAGE CAUSED BY THE 1978 MIYAGI-KEN-OKI EARTHQUAKE

by

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SUMMARY

The northern part of Honshu, Japan, was shaken by a strong earthquake of magnitude 7.4 at 17:14 (JST) on June 12, 1978. In the middle of the hardest-hit area was the city of Sendai with a population of 617,000. This paper briefly describes the restorations of some of the lifeline systems, mainly in Sendai, that followed the damage inflicted by the 1978 Miyagi-ken-oki earthquake.

INTRODUCTION

The Miyagi-ken-oki earthquake of 12th June 1978 originated in the Pacific Ocean at a point about 100 km east of Sendai. The intensity in the Sendai area was V by the Japan Meteorological Agency scale, which roughly corresponds to VIII on the Modified Mercalli scale. The peak horizontal acceleration recorded on the ground surface or in building basement in Sendai and its surrounding area generally varied between 200 and 300 cm/s^2.

The overall damage has been estimated at some ¥200 billion, and more than sixty percent of this was sustained in Sendai, where some 700 homes were damaged beyond repair. Several reinforced concrete and steel frame buildings were wholly collapsed, and damage to highway and railway structures was also extensive. However, the immediate concern after the earthquake was directed to the disruptions of urban utility systems, which included electric power, water supply, sewerage and city gas systems.

Figure 1 schematically shows the flows in these four systems. The portions enclosed by dotted lines indicate those most responsible for the disruptions of the systems. It is seen from Fig.1 that buried distribution pipelines in water supply and city gas systems, substations and distribution facilities in electric power system, and pumping stations and main sewers in sewerage system were accounted for the disruptions of service in this particular earthquake.

ELECTRIC POWER SYSTEM

Prior to the occurrence of the earthquake, the Tohoku Electric Power Company was delivering some 4,900 megawatts of electricity to the northern

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part of Honshu as shown in Fig.2. An estimated 681,600 customer power services were affected by the power outages caused by seismic damage to power system facilities and by the operation of relays triggered by the earthquake. Figure 2 also shows the distribution of the areas where power outages occurred. Generating facilities generally sustained only minor damage, although two steam power plants (525 MW and 950 MW; shown as A and B in Fig.2) serving most of the customer load in the Sendai area sustained some equipment damage, which caused shortage of power supply and necessitated curtailment of customer load for several days. There was no major failure of overhead and underground transmission lines.

The primary cause for the extensive power outages in the Sendai area was severe damage to electrical equipment at two of the key bulk power substations (C and D in Fig.2) which disrupted the company's artery 275-kv transmission line. Damage was most severe at the 275-kv Sendai Substation (C in Fig.2), where three transformers including two primary 275-kv transformers, twelve circuit breakers, three disconnecting switches, thirteen porcelain-clad current transformer, three capacitance potential devices and eight lightening arresters suffered damage. Most of the equipment damage was associated with failures of porcelain components and damage due to inadequate anchorage was small.

Early restoration by 275-kv lines was judged impossible because of the damage to the Sendai Substation, and emergency service was recovered by connecting intact lower voltage (154 and 66-kv) lines. As shown in Fig.3, service was restored to about 90 percent of the customer within the same day of the earthquake occurrence, and all distribution substations in the Sendai area received power supply during the early hours of June 13. However, power outages to about 80,000 customers remained on the following morning mostly in the city of Sendai and several surrounding cities. Emergency restoration was completed within about 38 hours after the occurrence of the earthquake.

As shown in Fig.4, it has been reported that in all restoration required some 19,400 man·day and ¥3.22 billion. It is interesting to note from Fig.4 that there are basically two types of seismic damage involved in the power supply system. In the case of the damage to substations, for example, the cost of restoration was high but the work required a relatively small amount of man power. On the contrary, the damage inflicted on distribution facilities such as poles and pole-clad transformers did not cost much in terms of money but their restorations required a large amount of man power.

CITY GAS SYSTEM

A total of some 136,000 customers in the city of Sendai and several surrounding cities were supplied with city gas by the Sendai City Bureau of Gas from the Bureau's two factories, one of which, however, produced more than 90 percent of the total supply. The equipment damage at the larger factory was generally light although all of the three production units stopped due to power outages. Service to customers was maintained for nearly an hour after the earthquake by using the reserved gas in holders. However, a number of calls were received from customers informing gas leakage during this period, and supply was eventually down at 18:15 to all 136,000 customers. This was the first instance in recent years in

Japan that service to such a large number of customers was closed down at one time.

Figure 5 shows the schematic flow of the restoration work of the city gas system in Sendai. By the morning of June 13, valves at all 141 distribution regulator stations had been shut down. Damage survey was first made for medium-pressure (1∿10 kg/cm^2) transmission lines. Damage to these some 200-km section of mostly arc-welded steel pipes was slight, and repairs had been completed by the noon of June 14, some 40 hours after the earthquake occurrence.

During the afternoon of July 13, the first restoration program was established by employing six subisolation areas. On June 16, this program had to be altered to adopt eight subisolation areas since the original program was found inadequate as the distribution of damage was eventually disclosed. Leakage surveys and repairs began on a full scale from June 16 for some 1,200 km distribution lines. Four days beginning from June 15 were also needed to close customers' meters. As surveys and repairs progressed, however, damage in several newly developed residential districts was found much heavier than earlier estimated. The details of the buried pipeline damage are presented elsewhere (1,2). Several subisolation areas had to be further divided into smaller areas to efficiently facilitate the location and repair of leaks. In all 38 subisolation areas had to be employed with number of customers varying from 77 to 21,638. Distribution mains had to be cut and bulkheaded at 155 locations in order to establish these subisolation areas.

Figure 6 summarizes the progress of restoration work for the city gas of Sendai and the number of men employed during this period. The first 400 customers had service restored by June 16. Accumulated percentages restored were 30 percent by June 22, 50 percent by June 24, 70 percent by June 26, and 90 percent by June 28. It was about four weeks after the earthquake that all restorable meters were returned to service.

Figure 6 clearly shows four distinct phases of restoration. During Phase I from June 12 to 15, all supply was closed down. Damage survey was made for key facilities, such as production facilities and transmission lines. Transmission lines were repaired and the original restoration program for distribution lines established. During Phase II from June 16 to 21, surveys and repairs of distribution lines were initiated according to the original restoration program. Uncertainty involved in the damage estimate made in Phase I necessitated revision of the program including subdivision of subisolation areas. Work efficiency is seen to fluctuate during this period. From June 22 to 29 (Phase III), restoration progressed smoothly with stable and high work efficiency. Then in Phase IV, surveys and repairs in most heavily damaged areas were made, and consequently efficiency of restoration work became very low.

Generally speaking, however, the progress of restoration seems to differ according to the size of the utility. Figure 7 shows the summary of restoration in the service area of the Shiogama Gas Company with a number of customers of approximately 6,000. Although the pipeline damage in Shiogama was heavier than that in Sendai, the restoration curve in Fig.7 is much smoother than that of Sendai. This seems to indicate that, the larger

a utility system is, the more important its disaster-preparedness becomes.

The total cost of restoration for the city gas system of Sendai has been reported to be some ¥850 million.

WATER SUPPLY SYSTEM

The Sendai City Bureau of Water Supply provided potable water to some 200,000 customers with a total population of 620,000 from its three treatment facilities having a maximum daily capacity of 320,000 m^3. The fourth treatment facility was under expansion work and not in full operation at the time of the earthquake. Facilities for collection, storage, transmission, and treatment work came through the earthquake without any substantial damage. The Sendai water supply network uses gravity flow for most of its service area, and standby generators were able to supply power needed at treatment facilities. The three treatment facilities received normal power supply at 0:15, 0:35 and 7:30 on June 13.

Minor distribution pipings sustained considerable damage (1,2). Damage was most severe in some of the newly developed residential districts where large-scaled cut and fill had extensively altered the original ground profile.

The emergency operations immediately following the earthquake were primarily concentrated on stopping any uncontrolled flows of water from broken mains. Consequently, about 7,000 services were without water on the following morning. The restoration of water service in Sendai was generally fast and the number of customers without water decreased to 800 by June 15, during which normal service was restored except for several newly developed residential districts where the stability of fills and slopes had become a grave concern.

A total of some 650 man·day was required for restoring the water mains in Sendai, and additional 1,100 man·day for repairing facilities on customers' premises. Over 4,000 breaks to service connections, meters and domestic pipings were reported to the Bureau during June. The overall damage to the Sendai City Bureau's facilities has been estimated at some ¥255 million.

Table 1 summarizes the emergency water supply operations in four of the larger water utilities in the affected area. Figure 8 shows the relation between the number of days required before the complete recovery of the system and the extent of damage to buried distribution pipes for the 29 water utilities. The wide scatter of the data points in Fig.8 seems to indicate that the extent of pipeline damage is not the single decisive factor for the disruption of water service after an earthquake. In the case of Ishinomaki, for example, the power outage at the city's only water-supply source was responsible for the 20-hour complete suspension of supply. In Shiogama, complete suspension of water supply continued for some 61 hours because the city's major 20-km transmission line was damaged at five locations.

SEWERAGE SYSTEM

The sewer system of Sendai serves to approximately 60 percent of the city's total population. The major portion of the system is designed as combined sewers for both sewage and storm water. The length of sewers amounts to about 700 km with diameters varying from 250 mm to 2,200 mm. There are eleven main pumping stations where sewage is boosted to a treatment plant. A daily amount of about 260,000 m^3 of sewage is treated and discharged to the Pacific Ocean.

Buried pipelines and manholes were extensively damaged. It was fortunate, however, that no major sewer line completely collapsed. The single most important seismic effect was the disablement of several pumping stations caused by power outages. Table 2 summarizes the seismic effects on the eleven pumping stations. Normal operation continued at only two stations without interruption by using standby power units. At the rest of the pumping stations, sewage had to be temporarily discharged to rivers or other waterways, and in one case to the adjacent down-stream station. It is particularly important to note that standby power units at five stations were disabled by shortage of cooling water supply. Most of the disabled pumping stations resumed normal operation within two days after the earthquake. At one of the stations, however, where equipment damage was most severe, discharge of untreated sewage to river continued for eleven days.

In spite of the damage described above, waste disposal from house sewers was never restricted during the post earthquake period. The overall damage to the Sendai's sewerage system has been estimated at some ¥370 million.

CLOSING REMARKS

Although the damage to the city of Sendai caused by the 1978 Miyagi-ken-oki earthquake was not devastating, numerous have been obtained from this experience, especially on the seismic effects on lifeline utility systems in a modern urban area.

The importance of predisaster planning including an adequate damage estimate was strongly recognized. It was also felt that emergency planning should be made for several different levels of seismic disasters. The level experienced by Sendai during and after the Miyagi-ken-oki earthquake seems to be one of the typical levels to be considered.

REFERENCES

1. Katayama, T. (1979): Damage to lifeline systems in the city of Sendai caused by the 1978 Miyagiken-oki earthquake, Bulletin of the New Zealand National Society for Earthquake Engineering, Vol.12, No.1, 49-58.

2. Kubo, K., and R. Isoyama (1980): Damage to buried utility pipes in the 1978 Miyagiken-oki earthquake, to be presented at the 7th World Conference on Earthquake Engineering, Istanbul, Turkey.

Table 1. Summary of Emergency Water Supply Operations.

Item \ Utility	Sendai	Ishinomaki	Izumi	Shiogama
Number of Customers	201,400	33,200	17,800	19,900
Period of Complete Suspension of Water Supply (hours)	0	21	16	61
Total Number of Customers Affected (customer·day)	14,640	1,023	51,167	50,540
Total Number of Trucks Employed (truck·day)	149	37	91	245
Total Number of Men Employed (man·day)	394	74	297	1,497
Total Amount of Water Delivered (ton)	702	54	695	2,071
Average Amount of Water Delivered per Customer per Day (litres)	49	54	14	41

Table 2. Damage to Pumping Stations in Sendai.

Pumping Station	Drainage Area (ha)	Capacity (m^3/s) Sewage	Capacity (m^3/s) Storm Water	Effects of the Earthquake: Power Outages	Suspension of Water Supply	Faults in Emergency Power Units	Faults in Electrical and/or Mechanical Systems	Damage to Discharge Pipes	Damage to Inlet Pipes	Damage to Buildings and Other Equipment	Amount of Sewage Discharged into Waterways (m^3)	Normal Operation Resumed at
A	55.84	0.134	0.860	○						○	Normal Operation Continued	
B	16.60	0.014	-	◎							Negligible	0:30 on June 13
C	243.54	0.510	-	○	◎→○			△			2,000	1:30 on June 13
D	158.78	0.067	-	○					◎		2,000	16:00 on June 14
E	920.00	0.419	7.687	○			○	◎		○	450,000	16:25 on June 23
F	121.52	1.007	3.620	○		◎	◎	△		○	10,000	17:30 on June 14
G	139.30	0.135	-	○	○→○			◎	○	○	5,500	10:00 on June 14
H	168.00	0.149	-	○	◎→○						Negligible	10:00 on June 13
I	320.42	0.236	2.118	○					△	○	Normal Operation Continued	
J	53.96	0.033	-	○	◎→○						*	10:00 on June 13
K	108.00	0.151	-	○	○→◎	○				○	3,000	9:00 on June 13

* Discharged to Station K by gravity flow.

◎ Main cause(s) for malfunction of pumping station.

△ Damage discovered about one month after the earthquake.

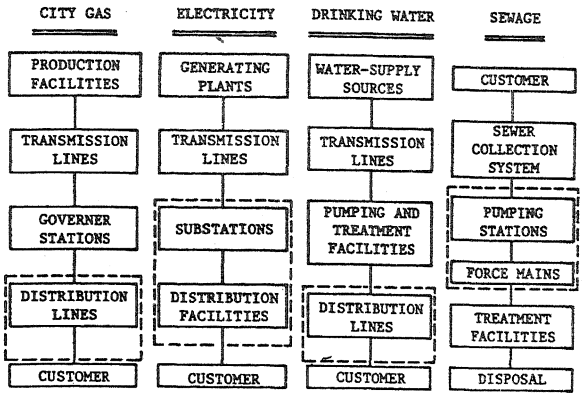

Fig.1. Schematic Flows of Utility Systems Investigated.

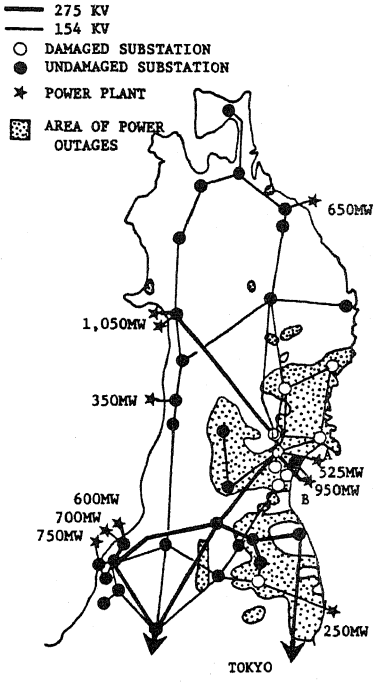

Fig.2. Transmission Network and Affected Area in the Tohoku Electric Power Company's Service Area.

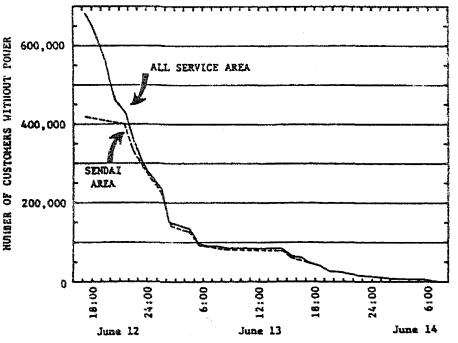

Fig.3. Number of Customers Affected in the Tohoku Electric Power Company's Service Area.

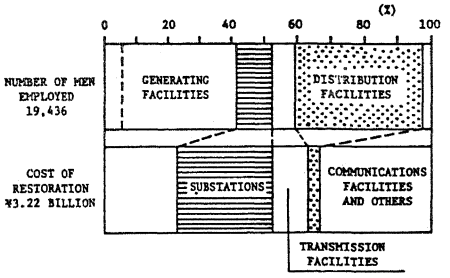

Fig.4. Breakdowns of Men Employed in and Cost of Restoration of Electric Power System.

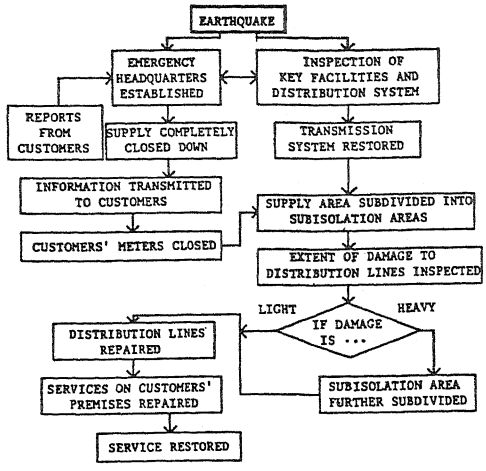

Fig.5. Flow of Restoration Work of City Gas System.

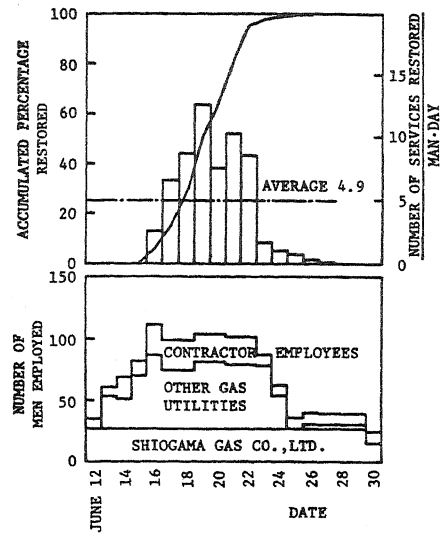

Fig.7. Progress of Restoration of City Gas in Shiogama.

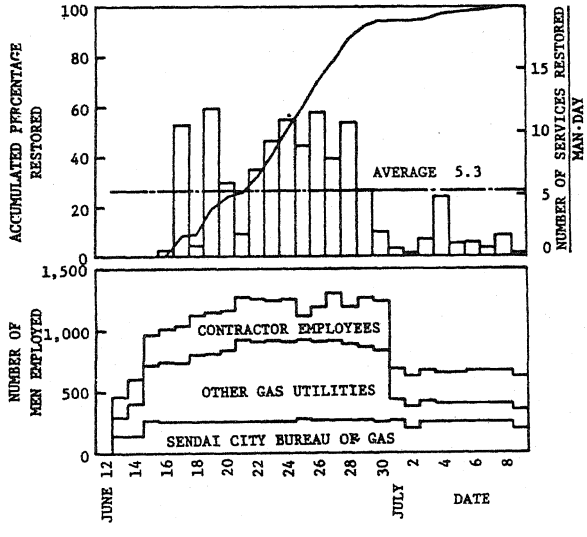

Fig.6. Progress of Restoration of City Gas in Sendai.

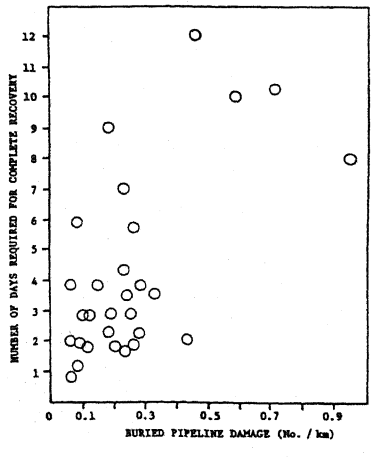

Fig.8. Number of Days Required for Complete Recovery of Water System and Extent of Damage to Buried Pipelines.