DAMAGE TO LIFELINE SYSTEMS IN THE CITY OF SENDAI CAUSED BY THE 1978 MIYAGIKEN-OKI EARTHQUAKE

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SYNOPSIS

The city of Sendai with a population of 617,000 was struck by a destructive earthquake of magnitude 7.4 at 17:14 (JST) on June 12, 1978. One of the particular features of this 1978 Miyagiken-Okai earthquake was the damage sustained by various lifeline utility systems. This paper describes the damage to electric power, water supply, sewerage and city gas systems in Sendai, and the processes of their restorations.

INTRODUCTION

A destructive earthquake of magnitude 7.4 struck the northern portion of the Honshu Island at 17:14 (JST) on June 12, 1978. According to the Japan Meteorological Agency, the epicenter was about 100 km to the east of the city of Sendai (142°10'E and 38°09'N) and the focal depth was 40 km. The dimensions of the causative fault plane were estimated as 30 x 80 km, with its longer side approximately in the east-west direction (Seno, T., et al., 1978). Since the reported epicenter is located near the eastern edge of this source area, the shortest distance from Sendai to the source area was 50 to 60 km. The intensity in the Sendai area was V by the JMA scale, which roughly corresponds to VIII on the Modified Mercalli scale. Figure 1 shows the distribution of JMA intensities at various locations. The peak horizontal acceleration recorded on the ground surface or in building basements in Sendai and its surrounding area generally varied between 200 and 300 cm/sec².

Sendai, the 14th largest city in Japan with a population of 617,000 on 237 km², was situated almost at the center of the JMA intensity V area, and a variety of damage was sustained by a number of different structures and systems. The overall damage has been estimated at some Yen 200 billion[#], and more than sixty percent of this was sustained in Sendai, where some 700 homes have been reported to have totally collapsed, some 3,400 homes appreciably damaged and some 74,000 homes had minor damage. Six reinforced concrete buildings and nine steel frame structures have been reported to have wholly collapsed. Damage to highway and railway structures was also extensive. Twenty-eight persons lost their lives (thirteen in Sendai) because of damage caused by the earthquake. It was especially noted that sixteen were killed by collapsing gatepost, masonry or concrete-block walls.

One of the particular features of the 1978 Miyagiken-Okai earthquake was, however, the damage sustained by various lifeline utility systems in the city of Sendai. This paper describes the damage to electric power,

water supply, sewerage and city gas systems in Sendai, and the processes of their restorations.

ELECTRIC POWER SYSTEM

Prior to the occurrence of the earthquake, the Tohoku Electric Power Company was delivering 4,900 megawatts to the northern portion of the Honshu Island. Approximately 1,500 megawatts of demand decreased after the earthquake including the interruption of some 1,130 megawatts of supply. System frequency momentarily fluctuated from 50.00 Hz to 50.58 Hz, then returned to normal in five minutes.

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. These relays were reported to have normally operated and protected the equipment from electrical faults in the system before equipment was structurally damaged.

Generally speaking, generating facilities sustained minor damage. Two steam power plants serving most of the customer load in the Sendai area sustained some equipment damage. The Sendai Steam Plant Nos. 2 and 3 units (each 175 megawatts) and the Shin-Sendai Steam Plant No. 1 (350 megawatts) and No. 2 (600 megawatts) units were hand-tripped because of the severe shaking caused by the earthquake. The Sendai Steam Plant No. 1 (175 megawatts) unit was not running at the time of the earthquake. Damage at these plants was not severe, but it took several days before generating units at these plants resumed running. This caused shortage of power supply in the Sendai area and necessitated curtailment of customer load. The Sendai Steam Plant No. 1 unit was placed in service by June 16. The Shin-Sendai Steam Plant Nos. 1 and 2 units resumed running on June 18 and 19, respectively.

There was no major failure of overhead and underground transmission lines except for some fissuring near footing and minor cracking of retaining walls of transmission towers.

A total of eighteen substations

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\$NZ is approximately Yen 200.

sustained equipment damage to varying degrees, including two 275-kv, seven 154-kv and nine 66-kv or lower voltage substations. There was major damage to nearly every type of electrical equipment (Table 1). However, 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 (275-kv) which disrupted the company's artery 275-kv transmission line. Damage was most severe at the 275-kv Sendai Substation, where three transformers including two primary 275-kv transformers, twelve circuit breakers, three disconnecting switches, thirteen porcelain-clad current transformers, three capacitance potential devices and eight lightning arresters suffered damage. Most of the equipment damage at these substations was associated with failures of porcelain components and damage caused by inadequate anchorage was minimal.

Early restoration by 275-kv lines was judged impossible because of the damage to the two steam plants and the Sendai Substation as described above, and emergency service was recovered by connecting intact lower voltage (154 and 66-kv) lines. 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. Figure 2 shows how the number of customers without power decreased until emergency restoration was completed about 38 hours after the occurrence of the earthquake. It has been reported that in all restoration required some 19,400 man-day and Yen 3.22 billion (Fig. 3).

WATER SUPPLY SYSTEM

The Sendai City Bureau of Water Supply provides 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 m³. The fourth treatment facility was under expansion work and not in full operation. Facilities for collection, storage, transmission and treatment work came through the earthquake without any substantial damage. The Sendai water supply network used gravity flow for most of its service area and pumping facilities were minimal and undamaged. Power required at treatment facilities was obtained from emergency power units and the power outages did not affect service to customers. It has been reported that these three treatment facilities were able to receive normal power supply at 0:15, 0:35 and 7:30 on June 13.

Minor distribution pipings sustained considerable damage. A total of 215 breaks have been reported to have occurred in the water distribution mains having diameters equal to or greater than 50 mm. The summary of damage to distribution pipes with diameters equal to or greater than 75 mm is shown in Table 2. There were 98 breaks in 50 mm pipes whose length is not known. The statistics in Table 2 should be carefully interpreted because damage to buried pipes is strongly related to subsurface site conditions.

Figure 4 shows the general geological setting of the Sendai area (Okutsu, H., 1975). The distinct NE-SW line passing near the center of the map is called the Rifu-Nagamachi tectonic line. The Sendai Plain develops to the east of this line and is bounded by the Pacific Ocean. This alluvial plain is mostly of sand, silt and gravels. Its depth to the Tertiary basement rocks varies abruptly near the tectonic line but is generally between 30 and 60 m. There are several areas in this plain which are covered with 2-5 m thick, very soft peat or mud. The general topography of the area to the west of the tectonic line is characterized by hilly terrain and several levels of terraces. The central part of Sendai including office and business quarters and older residential districts is located on the terrace structure on the north of the Hirose River. The surface deposit of this terrace is loam with this thickness rarely exceeding 2 m. This surface deposit is underlain by gravels or sand and gravels with the standard penetration N-value varying from 20 to 60. The Tertiary basement rocks, mostly of tuff, is usually found at a depth of 5 to 7 m. The hills are either of very hard andesite or agglomerate, or of workable tuff, shale, mudstone or sandstone. At several places, the tops of hills are covered with loam deposits. A number of residential districts have been developed in the last 30 years on the slopes of the hills with softer workable rocks.

Figure 5 shows the distribution of damage to buried water pipes. Note that the lines bounding different site conditions in Fig. 4 are retained so that easy reference can be made. Damage is generally slight in the central part of the city located on the geologically stable terrace. Pipe failures were concentrated in the newly developed residential districts where large-scaled cut and fill have extensively altered the original ground profile. In these areas, because of inherent instability of artificial slopes, insufficient densification of fills, and abrupt changes in subsoil properties between cut and fill, strong seismic shaking easily produced fissures, local settlement, slippage, and relative displacement over short horizontal distances. These were the main causes of buried pipe breaks.

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 in the city of Sendai except for several newly developed residential districts where the stability of fills and slopes was in doubt. Over 4,000 breaks to service connections, meters and domestic pipings were reported to the Bureau during June.

Trucks were used to supply water to the areas which were completely out of water. On June 14, thirty-seven trucks made 213 deliveries to various locations (Table 3). Most of the vehicles were rented ordinary trucks which carried the Bureau's 1 m³ water tanks. It is noted

that an average of 8-10 litres per person was distributed during the days that shortage of water was most acute in a number of localized areas.

A total of some 650 man-days were required for restoring water mains, and additional 1,100 man-days for repairing facilities on customers' premises. The overall damage to the Bureau's facilities has been estimated at some Yen 255 million.

SEWERAGE SYSTEM

The sewer system of Sendai serves approximately 60 percent of the city's total population. The length of sewers amounts to about 700 km with diameters varying from 250 mm to 2200 mm. The system has eleven main pumping stations where sewage is boosted to a single treatment plant. This plant treats a daily amount of about 260,000 m³ of sewage before it is discharged to shore.

Although various types of damage were inflicted upon the sewerage system, the single most important seismic effect was the disablement of several pumping stations caused by power outages. Table 4 summarizes the seismic effects on the eleven pumping stations. Normal operation was continued at two of the stations without interruption by using emergency power units. At the rest of the pumping stations, sewage had to be temporarily discharged to rivers or other water courses, and in one case to the adjacent down-stream station. It is particularly important to note that emergency 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 due to resumption of power and/or completion of emergency repair work. At one of the stations, however, where equipment damage was most severe, discharge of sewage to river continued for eleven days.

When pumping was resumed, it was discovered that no major sewer line was completely collapsed. Damage survey was concentrated on those areas where damage to road, water and gas pipes had been reported. A total of 702 manholes were visually inspected and 299 manholes were found to have been damaged to varying degrees, of which 82 manholes received sufficient damage to warrant some repair. Damage survey of buried pipes was made in those areas where manholes were severely damaged. A total of about 2 km sections of pipes was inspected. About 1.6 km sections were inspected by using television camera and supporting video tape equipment. Based on this damage assessment, some 190 m sections of 250 mm and 300 mm vitrified clay and concrete pipes were replaced. Although the Sendai sewer system has not so far encountered any major trouble since the earthquake, undetected damage is anticipated to cause maintenance problems in the future.

There were several sections of large-diameter sewer mains which had been completed but were not in use at the time of the earthquake. Pipes were of concrete with diameters varying from 1650 mm to 2200 mm. They were buried in the alluvial plain shown in Fig. 4. A total of 62 manholes

and 2,845 joints were visually inspected for the sections of 7.42 km, and 51 manholes and 533 joints were found to have been damaged. Cracks in pipe body were also found, notably in the circumferential direction near the junctions between pipes and manholes. Although it is difficult to generalize this result to uninspected used pipes, there may be many, probably minor, undetected pipe failures in the present sewer network.

The overall damage to the Sendai's sewerage system has been estimated at some Yen 370 million.

CITY GAS SYSTEM

The city of Sendai and parts of several surrounding cities were supplied with city gas by the Sendai City Bureau of Gas. City gas was served to about 136,000 customers from the Bureau's two factories, one of which produced more than 90 percent of the total supply. Damage to production facilities was generally light although an old water-sealed gas holder suffered structural damage and was eventually destroyed by the ensuing fire at the smaller factory. All of the three production units at the larger factory stopped due to power outages but equipment damage was slight. Service to customers was maintained for nearly an hour after the earthquake by using the reserved gas in holders. During this period, however, a number of calls were received from customers informing gas leakage. Supply was closed 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. The numbers of affected customers were some 45,000 and 17,000 after the 1964 Niigata and the 1971 San Fernando earthquake, respectively.

Table 5 summarizes pertinent data on buried pipelines in the Sendai's city gas system. Medium pressure (1-10 kg/cm) transmission lines were mostly of arc-welded steel pipes, and low pressure (less than 1 kg/cm) distribution mains were mostly of screw joint steel pipes or mechanical joint cast-iron pipes. Screw joint steel pipes were also used for service pipes and pipes on customers' premises. High correlations among pipe size, pipe material and type of joint should be noted.

In about 240-km length of arc-welded steel pipes, there have been reported only four minor failures. All of them were associated with loosenings of flange joints in pits caused by the settlement of surrounding soil. It is believed significant that arc-welded steel pipes sustained the stresses of the earthquake remarkably well although substantial portions of these pipes were buried in soft alluvial soil.

A cross tabulation was made of damage to low pressure buried pipes with respect to various items and categories. The low pressure pipes included distribution mains, branches, services and pipings on customers' premises. Damage to medium pressure transmission lines was not included. Six items selected are failure mode, pipe classifica-

tion, pipe material, pipe size, type of joint and type of soil. Each item was divided into two to five categories. For example, failure mode was divided into breaks, cracks, slipping out of joint, loosening of joints, and others. The result is shown in Table 6. A number on the diagonal shows the simple sum of failures under each respective category. A total of 552 failures have been reported in the low pressure pipings. The uppermost diagonal element shows that 409 of them were classified as breaks. The breakdown of these 409 breaks can be seen by tracing the numbers along the horizontal direction. Breaks were mainly observed in small-diameter steel pipes with screw joints used for distribution branches, services and pipings on customers' premises. Breaks at screw joints seem to be the most common type of damage to buried gas pipes.

Another interesting feature to be observed from Table 6 is the effect of site subsoil condition to pipeline damage. The site condition was very roughly classified into three categories, i.e. terrace, alluvium, and cut-and-fill. 397 out of 522 failures were sustained by the pipes buried in newly developed cut-and-fill residential districts. Although Table 6 simply shows numbers of failures which are not normalised, for example, with respect to pipe length, this trend is clearly seen for all the categories in the table. Approximate locations of gas pipe damage are plotted in Fig. 6.

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 transmission lines. Damage to these some 200 km sections of arc-welded steel pipes was slight as described before, and repairs had been completed by the noon of June 14, some 40 hours after the earthquake occurrence.

During the afternoon of June 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 started on a full scale from June 16 for some 1,200 km distribution lines. Four days beginning from June 15 were required to close customers' meters. As surveys and repairs progressed, however, damage in several newly developed residential districts was found much heavier than earlier estimated. 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 create subisolation areas.

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 7 summarizes the progress of restoration work and the number of men working during this period. This figure 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.

The four phases described here seem to be one of the typical restoration processes following seismic damage to lifeline utility systems. The period of suspension of lifelines will be shortened if the length of Phases I and II is minimized. To achieve this, it is important to protect key facilities within the system from an earthquake and to have a well-organized and developed emergency planning for handling seismic disasters. It seems to be particularly important for utilities to be prepared with a macroscopic damage estimate in case of a future earthquake disaster including information on the distribution of damage within their service areas.

The total cost of restoration for the city gas system of Sendai has been estimated at some Yen 850 million.

CLOSING REMARKS

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

It was clearly demonstrated that buried utility pipelines are very vulnerable to seismic effects. Alteration of the original ground profile by large-scale cut and fill was found to produce potential seismic-disaster areas unless proper attention was given to geological and engineering considerations. Shut-down of city gas supply to a large service area causes extremely tedious and time-consuming restoration work. The importance of emergency planning was reconfirmed. Preparation of an adequate damage estimate in case of future earthquake disasters was found important.

It should also be pointed out that emergency planning must be made by assuming several different levels of seismic disaster. The level experienced by Sendai during and after the Miyagiken-Oki earthquake seems to be one of the typical levels to be considered. A moderate level of disaster is expected to occur more frequently than a really

catastrophic disaster. Utilities should be able to deal with such a disaster quickly and efficiently so that the period of inconvenience to human activity in a major metropolitan area is minimized.

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Table 1. Equipment Damage at Eighteen Substations.

Type of Equipment	Number of Damage Sustained by Equipment for			Total
	275-kv	154-kv	66-kv or Lower	
Transformers	4 (2)	3 (1)	6	13 (3)
Gas Circuit Breakers	3 (3)	-	-	3 (3)
Air Blast Circuit Breakers	3 (3)	16 (3)	6 (3)	25 (9)
Porcelain-Clad Circuit Breakers	-	-	3	3
Disconnecting Switches	2 (2)	1	3 (1)	6 (3)
Porcelain-Clad Current Transformers	10 (10)	12 (2)	2 (1)	24 (13)
Capacitance Potential Devices	3 (3)	-	-	3 (3)
Lightening Arresters	6 (6)	8 (2)	-	14 (8)

Numbers in brackets show damage to the Sendai Substation (275-kv).

Table 2. Damage to Water Distribution Pipes With Diameters Equal To Or Greater Than 75 mm (The Sendai City Bureau of Water Supply).

Diameter of Pipe (mm)	Material of Pipe								Total	
	Cast Iron*		Steel		Asbestos Cement		Polyvinyl Chloride			
	Length (km)	Breaks	Length (km)	Breaks	Length (km)	Breaks	Length (km)	Breaks	Length (km)	Breaks
75	18.4	3	1.1	1	7.0	32	114.4	21	140.9	57
100	183.6	15	1.7	0	29.1	5	207.2	22	421.6	43**
150	205.0	4	1.4	0	7.0	0	-	-	213.4	4
200	118.9	2	1.4	0	1.5	1	-	-	121.8	3
250	39.9	3	0.7	0	1.3	0	-	-	41.9	3
300	70.0	2	3.7	0	2.1	1	-	-	75.8	4***
350	2.0	0	0.1	0	-	-	-	-	2.1	0
400	27.6	2	3.5	0	-	-	-	-	31.1	2
450	1.7	0	0.1	0	-	-	-	-	1.8	0
500	20.0	1	6.6	0	-	-	-	-	26.6	1
550~1100	16.3	0	50.2	0	-	-	-	-	66.5	0
Total	703.4	32	70.5	1	48.0	39	321.6	43	1143.5	117

* Including ductile cast iron pipes.

** Including one break of isolating valve.

*** Including one break of hydrant.

Table 3. Data on Emergency Water Service.

Date	Number of Customers Without Water	Number of Persons Affected	Number of Trucks Employed			Number of Men Employed			Number of Deliveries Made	Amount of Water Delivered (m ³)	Service Hours
			Bureau's	Rented	Total	Bureau's	Contractor	Total			
June 12	?	?	5	0	5	20	0	20	7	7	20~24
13	7,000	21,000	7	22	29	50	22	72	165	180	6~23
14	5,800	17,600	7	30	37	60	30	90	213	230	6~22
15	800	2,400	7	20	27	50	20	70	120	130	6~21
16	300	900	7	10	17	40	10	50	60	65	6~21
17	250	750	6	4	10	26	4	30	26	30	6~19
18	200	600	6	4	10	26	4	30	18	20	6~19
19	200	600	5	3	8	15	3	18	18	20	6~19
20	60	200	4	0	4	9	0	9	7	14	8:30~19
21	30	100	2	0	2	5	0	5	3	6	--
Total	--	--	56	93	149	301	93	394	637	702	--

Table 4. Damage to Pumping Stations in Sendai.

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

Pumping Station	Drainage Area (ha)	Capacity (m ³ /s)										Amount of Sewage Discharged into Waterways (m ³)	Normal Operation Resumed at
		Sewage	Storm Water										
A	55.84	0.134	0.860	X				?		X		Normal Operation Continued	
B	16.60	0.014	--	X								Negligible	0:30 on June 13
C	243.54	0.510	--	X	X → X			X				2,000	1:30 on June 13
D	158.78	0.067	--	X						X		2,000	16:00 on June 14
E	920.00	0.419	7.687	X			X	X		X		450,000	16:25 on June 23
F	121.52	1.007	3.620	X		X	X	X		X		10,000	17:30 on June 14
G	139.30	0.135	--	X	X → X			X	X	X		5,500	10:00 on June 14
H	168.00	0.149	--	X	X → X							Negligible	10:00 on June 13
I	320.42	0.236	2.118	X					X	X		Normal Operation Continued	
J	53.96	0.033	--	X	X → X							*	10:00 on June 13
K	108.00	0.151	--	X	X → X	X				X		3,000	9:00 on June 13

* Discharged to Station K by gravity flow.

Table 5. Pertinent Data on Buried Gas Pipes in the Sendai Area.

		Total Length (km)	Material		Size of Pipe (mm)			Type of Joint			
					25~100	125~200	250~500	Welded	Mechanical	Screw*	Bell and Spigot
Medium Pressure	Transmission Lines	195.9	Steel	189.5	13.8	100.3	75.4	189.5	---	---	---
			Cast Iron	6.4	1.7	4.6	0.1	---	6.4	---	---
Low Pressure	Distribution Mains & Branches	1225.1	Steel	644.9	627.2	16.0	1.7	51.2	---	593.7	---
			Cast Iron	580.2	181.5	381.2	17.5	---	530.0	---	50.2
	Services and Pipes on Customers' Premises	320.0	Steel	320.0	320.0**	---	---	---	---	320.0	---
Total		1741.0	Steel	1154.4	961.0	116.3	77.1	240.7	---	913.7	---
			Cast Iron	586.6	183.2	385.8	17.6	---	536.4	---	50.2

* This includes a small number of other types.

** Mostly of 25 mm in diameter.

Table 6. Cross Tabulation of Gas Pipe Failures in the Sendai Area.

		Mode of Failure					Classification of Pipe				Material		Size of Pipe				Type of Joint					Site Geological Condition			
		B	C	S	L	O	M	B	S	D	S	C	D ₁	D ₂	D ₃	D ₄	W	M	S	B	O	A	B	C	
Mode of Failure	Breaks	409	0	0	0	0	3	127	129	150	409	0	276	132	1	0	0	0	408	0	1	45	73	291	
	Cracks		43	0	0	0	1	14	8	20	43	0	29	14	0	0	0	0	43	0	0	2	18	23	
	Slip Out			60	0	0	11	46	2	1	49	11	1	51	7	1	0	11	48	0	1	0	2	58	
	Loosening				13	0	4	5	2	2	11	2	2	11	0	0	0	2	9	0	2	5	2	6	
	Others					27	1	6	7	13	26	1	19	7	1	0	0	0	24	0	3	4	4	19	
Classification of Pipe	Mains						20	0	0	0	6	14	0	11	8	1	0	13	4	0	3	2	6	12	
	Branches						198	0	0	0	198	0	16	182	0	0	0	0	196	0	2	3	14	181	
	Services								148	0	148	0	142	6	0	0	0	0	147	0	1	18	32	98	
	Domestic									186	186	0	169	16	1	0	0	0	185	0	1	33	47	106	
Material	Steel										538	0	327	210	1	0	0	0	532	0	6	55	98	385	
	Cast Iron											14	0	5	8	1	0	13	0	0	1	1	1	12	
Size of Pipe	D ₁	D ₁ < 50 mm											327	0	0	0	0	0	324	0	3	47	73	207	
	D ₂	50 ≤ D ₂ ≤ 100 mm												215	0	0	0	5	207	0	3	9	24	182	
	D ₃	100 < D ₃ ≤ 200 mm													9	0	0	7	1	0	1	0	1	8	
	D ₄	200 < D ₄															1	0	1	0	0	0	1	0	
Type of Joint	Welded																0	0	0	0	0	0	0	0	
	Mechanical																	13	0	0	0	1	1	11	
	Screw																		532	0	0	52	97	383	
	Bell & Spigot																			0	0	0	0	0	
	Others																				7	3	1	3	
Site Geological Conditn.	A	Terrace (Old City Area)																					56	0	0
	B	Alluvial Plain																					99	0	
	C	Cut and Fill																							397

FIGURE 1: LOCATION OF EPICENTER AND JMA INTENSITIES AT VARIOUS PLACES

FIGURE 2: NUMBER OF CUSTOMERS AFFECTED BY THE EARTHQUAKE IN THE TOHOKU ELECTRIC POWER COMPANY'S SERVICE AREA

FIGURE 3: BREAKDOWNS OF MEN EMPLOYED IN AND COST OF RESTORATION OF ELECTRIC POWER SYSTEM

FIGURE 4: GENERAL GEOLOGIC SETTING OF THE SENDAI AREA

FIGURE 5: LOCATION OF RUPTURES IN WATER DISTRIBUTION MAINS

FIGURE 6: LOCATION OF BREAKS AND LEAKS OF GAS DISTRIBUTION SYSTEM

FIGURE 7: PROGRESS OF RESTORATION OF CITY GAS IN SENDAI