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DAMAGE FEATURE OF SEWAGE PIPES CAUSED BY THE NIHON-KAI-CHUBU EARTHQUAKE OF 1983

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ABSTRACT

Presented are damage featurs of sewage pipes which suffered extensive damage due to the Nihon-kai-chubu, Japan, Earthquake in 1983. Precise data on damage of pipes and joint dislodgement were obtained from inspection with use of small TV camera as well as inspection from inside of pipes. From the analysis of the data, it was found that damage rate per unit length decreases as either diameter of pipe or buried depth increases.

INTRODUCTION

Sewage pipes are quite susceptible to damages in the past earthquakes. Although precise damage survey is essential to develop countermeasures for earthquakes, it had not been able to be made after earthquakes because prompt repair made it difficult. After the Nihon-kai-chubu, Japan, Earthquake in 1983, however, precise damage survey with use of small TV cameras, which run through sewage pipes even with small diameter, was made, and sufficient and exact data on damage of sewage pipe could be obtained. This paper presents a damage survey of sewage pipes (refered as pipe in the following) as well as lessons obtained through the damage investigation for preventing seismic damages (Ref.1).

DAMAGE SURVEY OF SEWAGE PIPE

Damage Survey Method Damage of pipes has generally been surveyed by means of inspection from manhole (small diameter pipe) and direct inspection from inside of pipe(large diameter pipe). Because pipe is generally segmented by manhole in each about 50 m interval, damages of the pipe only near manhole can be surveyed by inspection from manhole. However, accuracy of this method is poor. Direct inspection from inside of pipe gives much valuable informations. Precise location of pipe and joint which suffered damage can be surveyed. However even in this method informations on crack width and amount of joint dislodgement could not be generally obtained.

After the Nihon-kai-chubu Earthquake of 1983 (Earthquake Magnitude 7.7), in addition to the two methods, small TV cameras as shown in Fig.1 were used for damage surveys. They are installed in water proof case placed on sledge, and are pulled by strings from manhole. Self-crawing TV cameras were also used. By rotating the lens, some camera can inspect side wall of pipe as well as forward

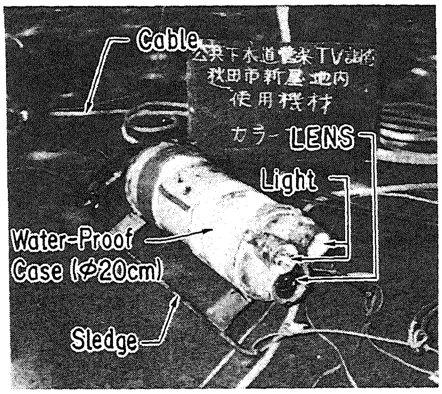


Fig. 1 Small TV Camera Used for Inspection of Pipe Damage

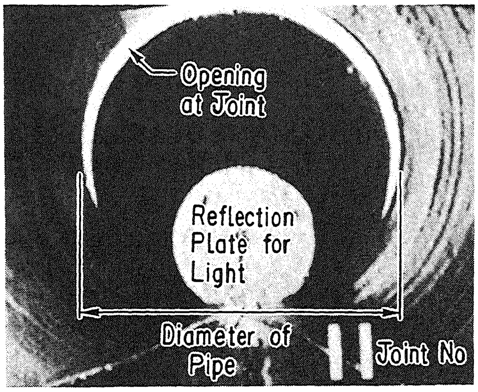
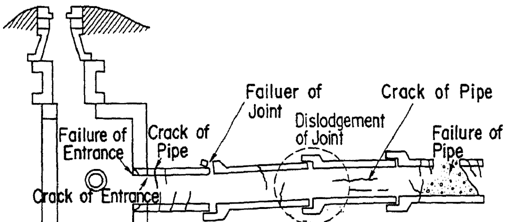


Fig. 2 Dislodgement Detected by TV Camera

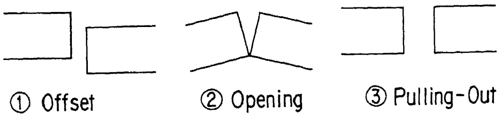
direction. Fig.2 shows an example of damage detected by TV camera. Damage of pipes and joints can fully be surveyed. One more advantage of the inspection by TV camera, which had never been achieved, is a measurement on precise amount of dislodgement of joint. Because diameter of pipe and distance between the lens and the point of interest are known, an amount of dislodgement can be estimated geometrically.

TV camera could also be used to measure levelling of pipe where water from outside was stored. Taking the water level as reference of height, levelling of the pipe could be detected.

<u>Definition of Damage</u> Fig.3 represents typical damage of pipe as well as manhole. Damage occures at pipe itself and at joint. Damage of pipe itself in a form of crash, cut and crack is defined here as "damage of pipe". The damage of pipe can further be classified into "damage of mainbody of pipe", "damage of joint" and "damage at connection with manhole". Damage degree was divided into "failure (significant damage)" and "crack (moderate damage)". Dislodgement at joint is also defined as "offset", "opening" and "pulling-out" (refer to Fig.3).



(a) Pipe Damage



(b) Dislodgement of joint

Fig. 3 Definition of Pipe Damage and Dislodgement at Joint

<u>Pipe Damage Studied</u> Table 1 shows the pipe length surveyed after the earthquake. Excluding the inspection from manhole, which gives only poor information for analysis, data on pipe damages of about 16 km in the Akita city and of 9 km in the Noshiro city, which were obtained from either inspection from inside of pipe or inspection by TV camera, were used for the analysis.

Table 1 Sewage Pipe Length Surveyed after the Nihon-kai-chubu Earthquake

Diameter ϕ	Inspection Method	Akita City	Noshiro City	Total
$\phi \geqq 650$ mm	Inspection from Manhole	88,350 m	3,250 m	91,600 m
	Inspection from Inside of Pipe	2,200 m	2,88 m	5,080 m
	TV Camera	—	370 m	370 m
$\phi < 650$ m	Inspective from Manhole	174,360 m	6,280 m	180,640 m
	TV Camera	13,800 m	6,280 m	20,080 m
	Total	278,710 m	19,060 m	297,770 m

DAMAGE RATE OF PIPE PER UNIT LENGTH

From the data obtained by inspection from inside of pipe and inspection by TV camera, number of damaged point was studied. They were summalized in a form of cross table. Because the pipe length surveyed can also be summalized in a form of cross table, damage rate per unit length can be calculated as shown in Table 2 by dividing the number of damaged point by the pipe length surveyed. Only the result for the Akita city is presented here because damage rate of the Noshiro city exhibits the similar results. Diagonal of Table 2 represents the effect of each factor considered in this analysis (refer to Fig.4). It is summalized from Fig.4 as :

1) Damage rate of dislodgement at joint is 134.1 point/km, which is much pronounced than the pipe damage, i.e., damage rate of failure and crack of pipe is 9.1 point/km and 10.6 point/km, respectively. Summing up these damage rate as well as the damage rate of pipe at connection with manhole, total damage rate of pipe becomes 23.8 point/km, which implies that the pipe in the Akita city suffered one damage at about 40 m interval.

2) Damage rate of clay pipe, which is of earthware, is much pronounced than that of hume pipe and chloroethylene pipe.

Table 2 Cross Table of Damage Rate per Unit Length (Point Damaged/km)

Items			Damaged Type						Type of Pipe			Diameter of Pipe				Buried Depth				Site Condition			
			Joint		Pipe		Pipe at connection with Manhole		H.P	C.P	V.P	D_1	D_2	D_3	D_4	H_1	H_2	H_3	H_4	S.S	C.S	G.S	R.G
			Dislodgement	Damage	Crack	Failure	Crack	Failure															
Damage Type	Joint	Dislodgement of Joint	134.1	—	—	—	—	—	117.8	543.6	17.9	226.1	113.2	37.2	35.7	250.4	172.7	29.5	7.2	139.4	63.3	212.4	31.9
		Damage of Joint		4.5	—	—	—	—	4.6	7.3	—	3.9	3.2	—	9.7	10.2	2.4	3.9	7.2	4.4	8.2	3.0	—
	Mainbody of Pipe	Crack			10.6	—	—	—	10.7	19.4	—	11.7	14.5	—	1.3	12.8	4.0	7.0	33.9	11.8	7.0	4.6	8.0
		Failure				9.1	—	—	9.7	7.3	—	2.1	2.2	37.2	33.1	6.0	7.5	24.9	2.2	8.2	1.2	31.9	—
	Pipe at Connection wth Manhole	Crack					0.6	—	0.7	—	—	1.1	0.5	—	—	—	1.1	—	—	0.3	1.2	3.0	—
		Failure						3.5	3.0	4.9	10.2	2.8	1.6	3.4	9.1	6.0	1.6	8.5	2.9	3.8	2.3	3.0	—
Type of Pipe	Hume Pipe (H.P.)								146.5	—	—	205.1	136.7	77.7	89.0	234.0	174.5	86.3	53.3	147.8	83.2	258.0	39.8
	Clay Pipe (C.P.)									582.5	—	810.9	270.1	—	—	769.2	468.8	—	—	582.5	—	—	—
	Chloroethylene Pipe (V.P.)										28.1	50.6	12.9	—	—	54.3	46.9	5.1	—	28.1	—	—	—
Diameter of Pipe	$200 \leqq \phi < 400$ mm (D_1)											247.8	—	—	—	417.0	240.3	83.1	55.0	272.4	219.0	155.4	20.0
	$400 \leqq \phi < 700$ mm (D_2)												135.2	—	—	167.7	148.8	57.7	107.9	143.0	30.0	168.4	53.0
	$700 \leqq \phi < 1000$ mm (D_3)													77.7	—	—	77.7	—	—	77.7	—	—	—
	$1000 \leqq \phi < 1350$ mm (D_4)														89.0	—	291.2	83.0	20.1	47.2	13.2	674.8	—
Buried Depth	$H < 1.5$ m (H_1)															285.3	—	—	—	295.0	151.9	—	—
	$1.5 \text{ m} \leqq H < 2.5$ m (H_2)																189.3	—	—	187.1	136.7	258.0	20.0
	$2.5 \text{ m} \leqq H < 3.5$ m (H_3)																	73.8	—	108.3	13.2	—	53.0
	$3.5 \text{ m} \leqq H$ (H_4)																		53.3	53.3	—	—	—
Site Condition	Sandy Sail (S.S.)																			167.8	—	—	—
	Clayey Soil (C.S.)																				83.2	—	—
	Gravel Soil (G.S.)																					258.0	—
	Reclaimed Ground (R.G.)																						39.8

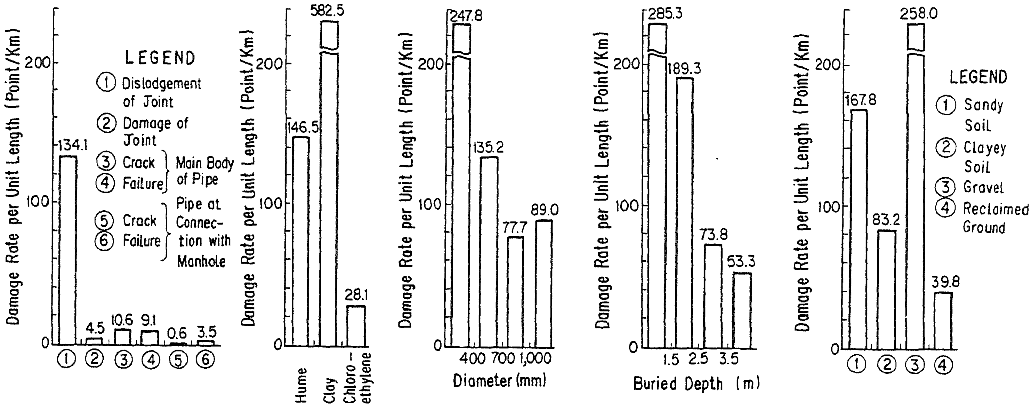


Fig. 4 Damage Rate per Unit Length

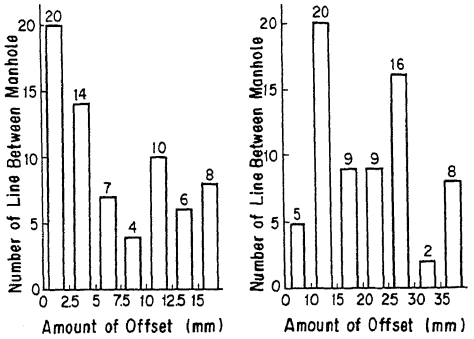
3) Damage rate decreases as either the diameter or the buried depth increases.

4) Damage rate takes the highest value at the gravel site followed by sandy soils. It should be noted that estimation of the soil condition may have some error. Because boring data were limited, it was estimated based on informations either from city officials or surface geological map. It should be also noted here that the "gravel" defined in Fig.4 should mostly be regarded as sandy soils with gravel. High damage rate at the gravel and sandy soil sites may be attributed to liquefaction and soil movement due to liquefaction (Ref.2), which was developed widely in the city.

DAMAGE FEATURE DETECTED BY TV CAMERA

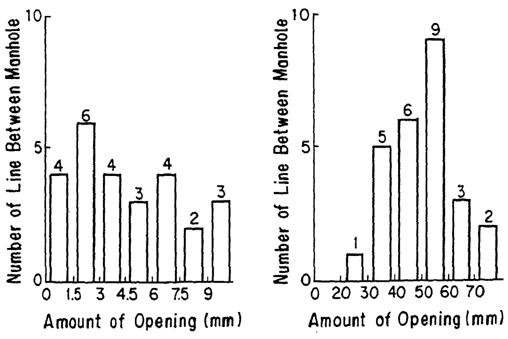
Dislodgement at Joint Amount of dislodgement (offset, opening and pulling-out) was estimated with use of TV camera film for total length of 3.2 km. Pipe surveyed consists of 82 lines, in which a line is defined as a segment divided by manhole at both ends. Number of line in which dislodgement of joint was developed was used in the following as a reference value to count number of the damage.

Figs.5,6 and 7 show an amount of offset, opening and pulling-out, respectively, in which mean and the maximum dislodgement over each line are presented.



(a) Mean Value (b) Maximum Value

Fig. 5 Mean and Maximum Offsets Developed in Each Line



(a) Mean Value (b) Maximum Value

Fig. 6 Mean and Maximum Opening Developed in Each Line

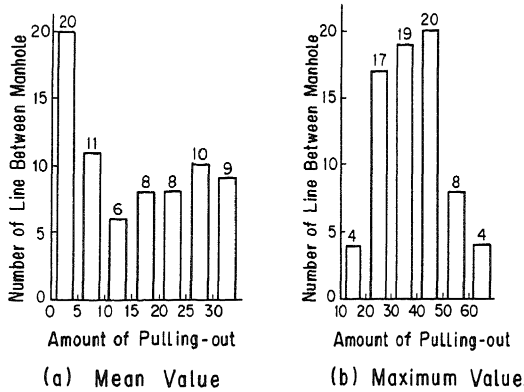


Fig. 7 Mean and Maximum Pulling-out Developed in Each Line

Although there are considerable scatters depending on the line, the maximum dislodgement is 30 - 35 mm (offset), 60 - 70 mm (opening) and 60 - 70 mm (pulling-out). Because such dislodgement at joint was most likely developed due to deformation of subsoils, a finite ground strain(Ref.3) may be estimated as $\Delta\ell/\ell$, in which ℓ and $\Delta\ell$ represent one pipe length (equals 2.4 m for hume pipe) and amount of dislodgement. From the maximum offset and pulling- out, one can compute the maximum finite shear strain of ground of $(1.3 \sim 1.5) \times 10^{-2}$ and the maximum finite axial strain of $(2.5 \sim 2.9) \times 10^{-2}$. Development of $1 \sim 2$ % of ground strain is required to be considered for design of sewage pipe installed near the ground surface.

Fig.8 shows gradients of each pipe determined from a difference of levelling at both pipe ends. Such inclination was most likely developed by the ground settlement. The gradient of as large as 8 % was developed. This corresponds to a difference of levelling of about 20 cm between both ends for hume pipe with length of 2.4 m.

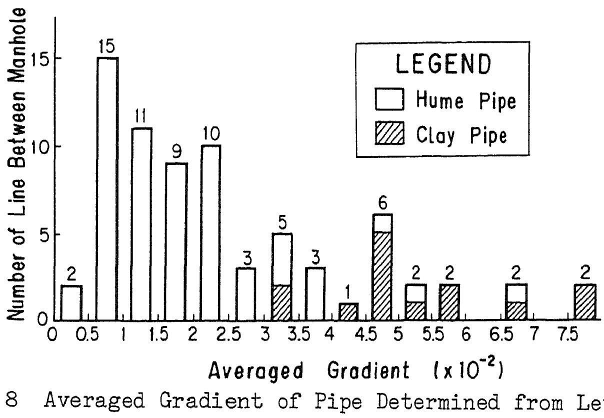


Fig. 8 Averaged Gradient of Pipe Determined from Levelling

Pipe Damage It was found from the inspection by TV camera that most of the pipe damage was cracks and/or failure in circumferential direction, and there were few cracks and/or failure along pipe axis. Fig.9 shows where pipe damage was developed, in which joint number is counted from manhole. It is obvious that the pipe damage concentrates at the first joint, i.e., at the connection with manhole. Different structural response between pipe and manhole resulted in large relative displacement at the connection.

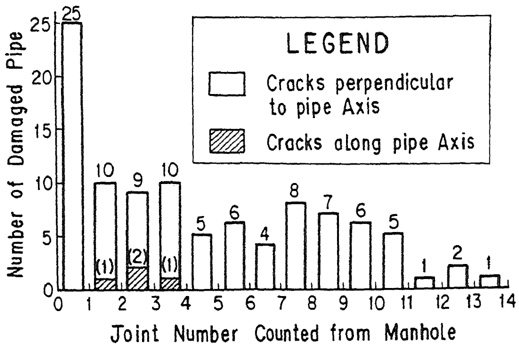


Fig. 9 Joint Where Damages Were Developed

CONCLUSIONS

Precise damage survey was made on sewage pipes at the Akita city as well as the Noshiro city, which suffered damage by the Nihon-kai-chubu Earthquake of 1983(M = 7.7). Damage inspection by small TV camera provided with valuable information on damages of pipe. From the study presented here, the following conclusions may be deduced :

1) Damage rate of dislodgement at joint is 134.1 point/km which is much more pronounced than the damage rate of failure and crack of pipe of 9.2 point/km and 10.6 point/km, respectively.

2) Damage rate of pipe and dislodgement at joint decreases as either the pipe diameter or buried depth increases.

3) The maximum amount of offset, opening and pulling-out is 35 mm, 70 mm and 70 mm, respectively. Assuming that such dislodgements were developed by ground strains induced during the earthquake, the ground strain is estimated as 2 - 3 %. The maximum gradient of pipe computed from the levelling is about 7%.

4) Pipe damage concentrated at the connection with manhole where significant difference of structural response between pipe and manhole was developed.

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