The Damage Analysis of Distribution Pipes in Artificial Ground

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ABSTRAUCT

Many water distribution pipes were damaged by the Great East Japan Earthquake that happened on March 11th 2011. These pipes were mainly found at the artificial ground in developed land on hilly area in Sendai City, so it is assumed that the specific land characteristic is related to the damage of pipes. From the viewpoint of ground situation, there are few existing studies between pipe damages and land character such as an earthquake occurrence.
Those factors seem to be linked together, so we have researched following three points. Firstly, we estimate the thickness of cutting and filling ground in developed land by the topographic map surveyed before and after land development. According to the topographic map, we classify the developed land into cutting, filling and boundary area. Secondly, we calculate each damage ratio of the pipes for those three areas. Finally, we analyze the damage ratio for the thickness of land cutting and filling, the pipe kinds, and the land development ages.
According to the study, we conclude as follows. The filling ground has the highest damage ratio. The specific pipe kind has high damage ratio. The filling area developed before 1965 has high damage ratio.

INTRODUCTION

Sendai city has about a million of population and is the central city of Tohoku region. It is located in north area of Japan main land (Figure 1) and surrounded by the Ou Mountains in west and the Pacific Ocean in east. The water distribution area of Sendai is about 363km2 and our four main filtration plants are located in west area. So we supply water for customers with the effective utilization from west to east across Sendai. The water pipes are covered about 4,500km in Sendai and contributed to distribute water to citizens. The Great East Japan earthquake on March 11, 2011 had magnitude of 9.0 and the greatest earthquake ever recorded in Japan. It brought the intense shake and massive tsunami that caused lifelines cutting off over the long period of time. Especially, the tsunami hit the Tohoku and Kanto coast and caused the great damages and casualties.

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In Sendai, the suspension of water supply reached to two hundred thirty thousand houses with five hundred thousand people by those damages. This great damage restored by March 29, 2011 except some heavy damaged area.
Many distribution pipelines were broken and most of them were observed at an artificial ground. It is thought that distribution pipelines are influenced by ground damage. It is also considered that concentration of pipe break mainly was observed within the boundary area between cutting and filling in artificial ground when an earthquake happens. This reason is that strength in artificial ground is affected by backfilling materials and number of compaction at that time, so if the construction was not performed perfectly, strength against a shake in artificial ground is weak relatively. In 1965, Sendai city applied an Act on Regulation of Residential Land Development, the act decides technical standard for the construction. There are some developed areas where constructed for the past several ten years with no application of the construction act to the artificial ground. In addition, there are some distribution pipeline installed at the time of developed area, and they are reaching to service life. Fragility of water pipeline varies with the material and the joint, and the aging water pipelines do not have earthquake resistant performance.
Sendai waterworks bureau needs to replace such pipelines that will be easy to break with priority in keeping mind of installed ground condition. There are some cities in Japan which have the similar situation of Sendai. They will have the possibility of an intense shake of earthquake in the future like we have experienced. In that condition, it is important to analyze damage to pipeline in artificial ground. This analysis clarifies a damage tendency and allows preparing for future earthquake. Although there are some studies and investigations for the pipe breaks caused by the earthquake in Sendai city, they have rarely the focus on the viewpoint of ground condition and pipe materials and joints in detail. Therefore, in this study, to clarify a damage tendency about 409 water pipe breaks judged to be broken by the earthquake, the pipe breaks and the ground situation seem to be linked together, so we have researched the following points to verify the relation. We conduct the methods and procedures below.
Firstly, we estimate the thickness of cutting and filling ground in the developed land by the topographic map surveyed before and after development of land. According to the topographic map, we classify the developed land into three as cutting, filling and boundary area. Secondly, we calculate each damage ratio of the pipes for those areas. Finally, we analyze the damage ratio for the thickness of land cutting and filling, the pipe materials and joints, and the land development ages.

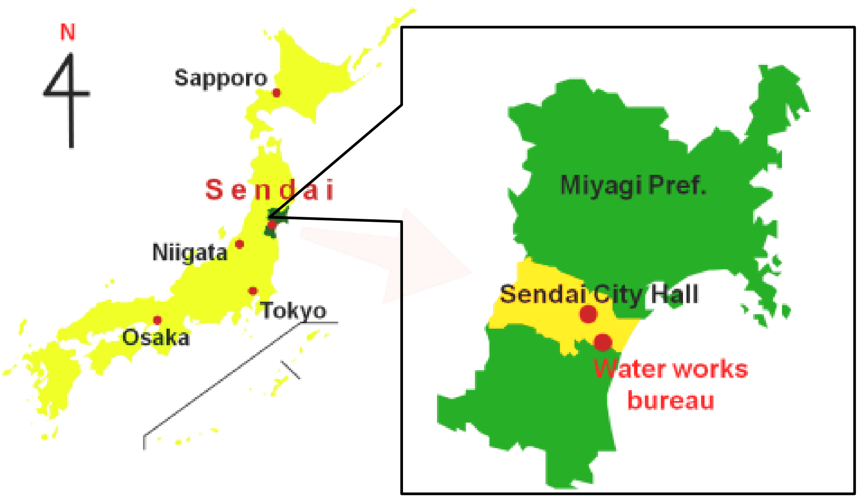


Figure 1　Location of Sendai City

METHODS

Damage Caused to Water Pipeline by the Great East Japan Earthquake

The Great East Japan Earthquake happened on March 11, 2011at 2:46 PM local time of Pacific Coast beside of Miyagi Prefecture. In Sendai City, there were few damages for main four purification plants but significant damages for water distribution pipelines. The number of breaks of the distribution pipelines by the earthquake reached to 409 except the auxiliary equipment broken. The pipe breaks of 317 cases were concentrated in developed artificial land, and it accounts for 80% of 409 pipe breaks.

Drawing up geotechnical map about the thickness of filling or cutting in developed areas

We designated the analyzing areas including the information map of residential land development record of Sendai City and the development land of adjoin Sendai where we supply the water. First, we calculate the surface elevation data before the land development and that of after. Table 1 shows materials for making the elevation data.

Table 1 Data about surface elevation

Item	Name
Before development	1/3000 City Planning Map
	Aerial photographs taken in 1940's
After development	5-m grid digital elevation model
	Data for permission for developed land

Then we estimate the thickness of filling or cutting land by the elevation data. Each data about surface elevation has an elevation error constantly, so the estimation may have an error in height of ±2.0m. Table 2 shows three classifications of ground condition by the estimation. In this table, B indicates the thickness of filling or cutting land.

Table 2 Classification of ground condition

Ground condition	Range of the thickness
Boundary area	Filling $0.0 < B \leqq 2.0$m, Cutting $0.0 \leqq B \leqq 2.0$m
Filling area	Filling $2.0\text{m} < B$
Cutting area	Cutting $2.0\text{m} < B$

Figure 2 shows cross section before and after land development, we classify ground condition into filling, cutting and boundary area by the thickness such as this figure. And we make a grand topography of developed residential land by the thickness as reduced scale about 1/2,500 (Figure 3).

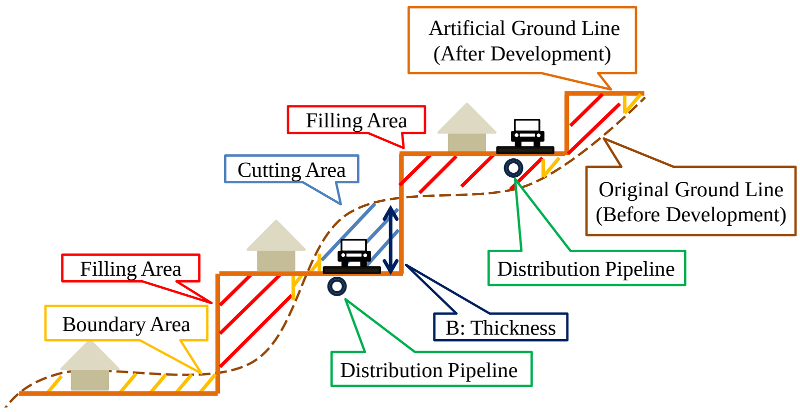


Figure 2 Cross Section before and after land development

Data and Analyzing points

We have researched for damage to pipeline to use the grand topography and below data. Table 3 shows data for using this study.

Table 3 Data

Data	Detail
(1)Damaged pipeline data	409 damaged water pipes repaired by the end of April, 2011.
(2)Pipeline data in Sendai City	Data for transmission, main distribution, distribution small distribution, conveyance and receiving pipe Sendai Waterworks Bureau has.
(3)Land development data	Data made by Fukken Gijyutsu Consultants Co., Ltd.

Table 4 shows classifications of pipe materials and joints. In these classifications, we calculate the damage ratio for distribution pipes with two analyzing points respectively.

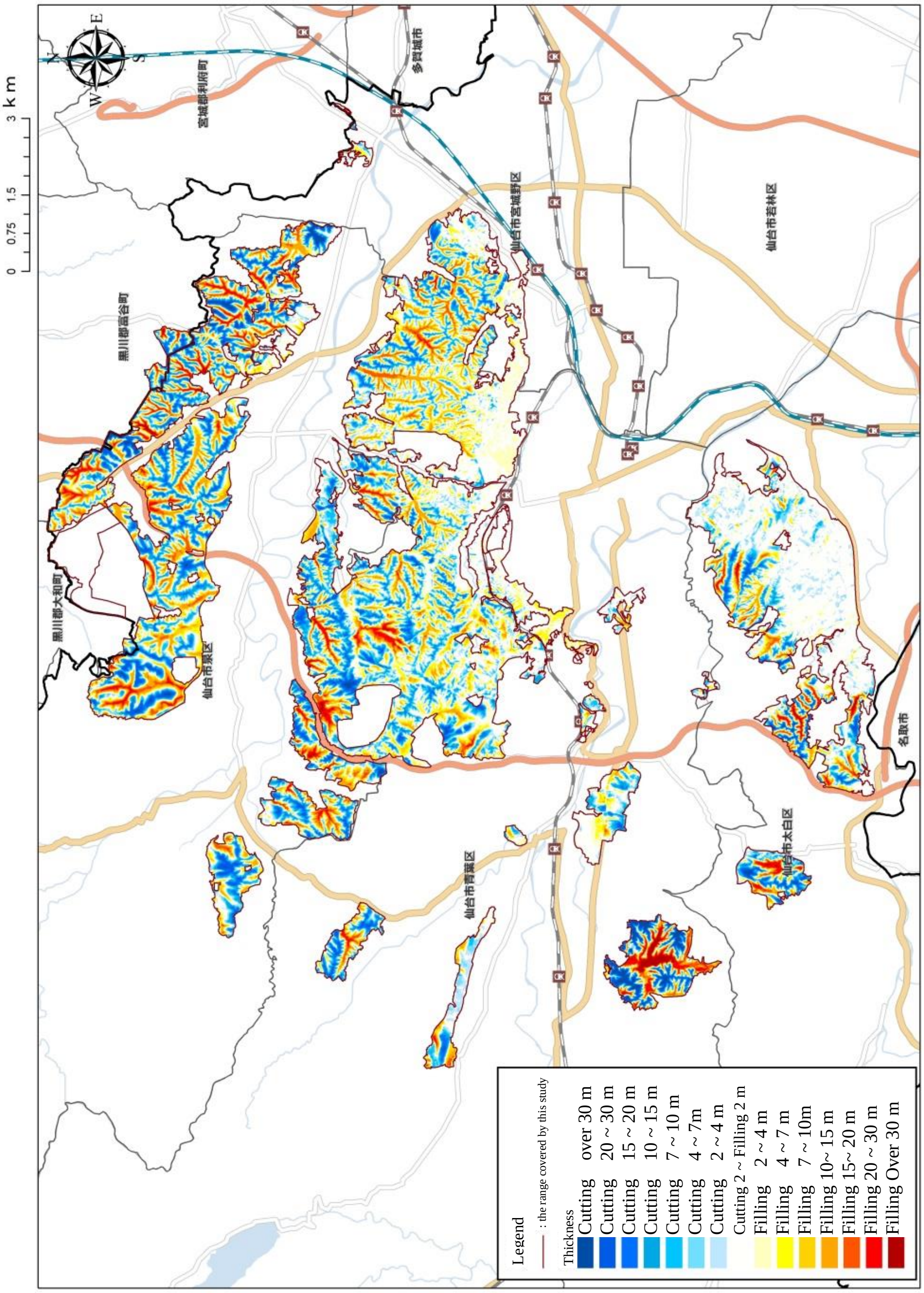
Table 4　Classifications of pipe materials　・　joints

Pipe materials・joints	Abbreviation	Characteristic
Ductile iron pipe（A, F and T type mechanical joint）	DIP (A,　F,　T)	They don't have anchor performance.
Ductile iron pipe（K type mechanical joint）	DIP (K)	Using retainer gland, they have anchor performance relatively.
Ductile iron pipe（KF・NS・S・S II type mechanical joint）	DIP（KF,　NS,　S,　S II）	They have seismic resistant joint and have used general.
Rigid polyvinyl chloride pipe（rubber ring joint）	VP(RR)	The strength is weaker than Metal pipe. This has rubber ring socket but don't have anchor performance.
Rigid polyvinyl chloride pipe（taper socket joint）	VP(TS)	The strength is weaker than Metal pipe. Joint is fixed by taper socket.

Analyzing points:

（1）　Damage ratio for the ground conditions (filling, cutting and boundary area)

（2）　Damage ratio for the land development age



Background map made by ESRI JAPAN Co., Ltd.

Figure 3 The grand topography of developed residential land

RESULTS AND DISCUSSION

Analysis of the damage ratio for distribution pipes in artificial ground condition

Table 5 and Figure 4 show the damage ratio for distribution pipes in cutting, boundary and filling area. The damage ratio is 0.05 in cutting area, 0.13 in boundary area, and 0.36 in filling area respectably. When an earthquake happens, it is presumed that distribution pipelines are influenced by ground damage and broken mainly between cutting and filling area in artificial ground. It is so called the boundary area. However, this study shows a tendency that high damage ratio is cutting, boundary, and filling area in that order. Damage ratio in boundary area and filling area are 2.6 times and 7 times higher than that of in cutting area. Also it shows that the damage ratio in filling area is wholly high, and the highest damage ratio of the filling area is the thickness from 4 to 5 meter. This result shows that the damage to water pipelines varies to subsurface grand conditions even if the same shake happened in developed land. This result implies that filling area is affected with a shake relatively and pipelines installed in filling area were easy to break.

Figure 5 shows the damage ratio for pipelines each subsurface ground condition to different pipe materials and joints. Most pipe materials and joints have a tendency that damage ratio becomes higher in order of cutting, boundary, and filling area. Damage ratio of DIP (A, F, T) and VP (TS) are higher than that of the others. As a result, it is suspected that these pipes don't have earthquake resistant performance like DIP（KF，NS，S，SⅡ）. In addition, the material of VP (TS) is less stronger than the others, so the damage ratio of VP (TS) is the highest. Therefore, it implies that DIP (A, F, T) and VP (TS) installed in filling area have high priority to be replaced by earthquake resistant pipe.

Damage ratio for water pipelines in filling area according to land development age

Figure 6 shows number of pipe breaks and length of pipeline and Figure 7 shows the damage ratio in filling area according to land development age. The damage ratio in filling area is approximately 0.9 (breaks/km) before 1965, it is approximately 0.4 after 1965. Damaged water pipe installed in filling area was not found after 1990. It makes a clear tendency that pipes have lower damage ratio according to land development age. In 1965, Sendai city applied an Act on Regulation of Residential Land Development, the act decides technical standard for the construction. This suggests that strength of subsurface ground condition become higher after 1965, and also the figure shows there are few number of pipe breaks. Therefore, it is necessary to pay full attention to the pipes installed in filling area that developed for the past several years ago. Also, it implies that pipes installed in filling area have high priority to be replaced by earthquake resistant pipe.

Table 5 Damage ratio by the thickness of filling and cutting

Ground Condition	Thickness	Number of Breaks	Length (km)	Damage Ratio(breaks/km)	Summary
Cutting area	Over 21m	0	39.50	0.00	Total number of breaks : 40 Damage ratio : 0.05 (breaks/km) Total length : 735.97km
	20～21m	1	10.39	0.10	
	19～20m	0	12.15	0.00	
	18～19m	1	14.62	0.07	
	17～18m	1	17.17	0.06	
	16～17m	0	20.40	0.00	
	15～16m	0	22.98	0.00	
	14～15m	1	24.99	0.04	
	13～14m	0	27.70	0.00	
	12～13m	1	30.49	0.03	
	11～12m	1	33.89	0.03	
	10～11m	0	38.28	0.00	
	9～10m	2	41.36	0.05	
	8～9m	2	43.62	0.05	
	7～8m	0	48.00	0.00	
	6～7m	1	50.76	0.02	
	5～6m	6	53.56	0.11	
	4～5m	6	59.38	0.10	
	3～4m	4	66.20	0.06	
	2～3m	13	80.56	0.16	
Boundary area	1～2m	8	109.97	0.07	Total number of breaks : 60 Damage ratio : 0.13 (breaks/km) Total length : 459.09km
	0～1m	7	126.51	0.06	
	0～1m	22	119.59	0.18	
	1～2m	23	103.02	0.22	
Filling area	2～3m	27	76.59	0.35	Total number of breaks : 217 Damage ratio : 0.36 (breaks/km) Total length : 595.10km
	3～4m	17	60.64	0.28	
	4～5m	37	53.96	0.69	
	5～6m	16	46.83	0.34	
	6～7m	16	42.78	0.37	
	7～8m	18	38.00	0.47	
	8～9m	10	32.90	0.30	
	9～10m	7	29.87	0.23	
	10～11m	10	27.52	0.36	
	11～12m	13	26.93	0.48	
	12～13m	9	22.96	0.39	
	13～14m	9	20.99	0.43	
	14～15m	4	18.13	0.22	
	15～16m	4	15.25	0.26	
	16～17m	3	12.59	0.24	
	17～18m	4	11.34	0.35	
	18～19m	1	9.24	0.11	
	19～20m	4	8.15	0.49	
	20～21m	2	7.29	0.27	
	21～22m	1	6.27	0.16	
	Over 22m	5	26.87	0.19	
Summary except developed land		92	2624.56	0.04	-
Summary within developed land		317	1790.17	0.18	-
Total		**409**	**4414.72**	**0.09**	-

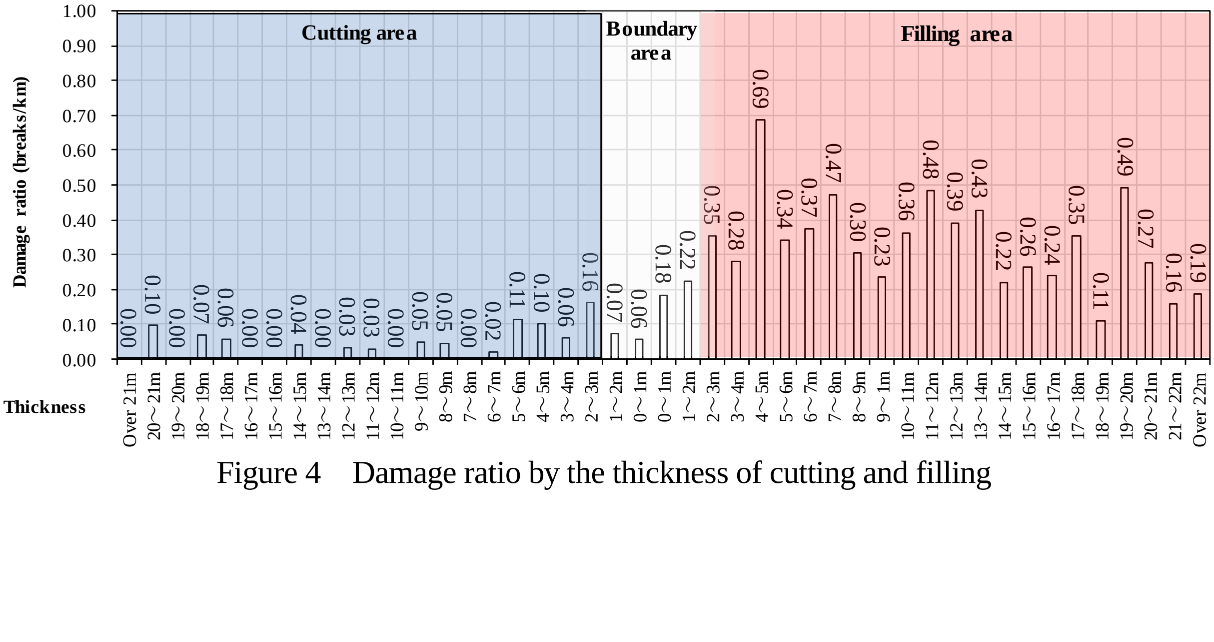


Figure 4 Damage ratio by the thickness of cutting and filling

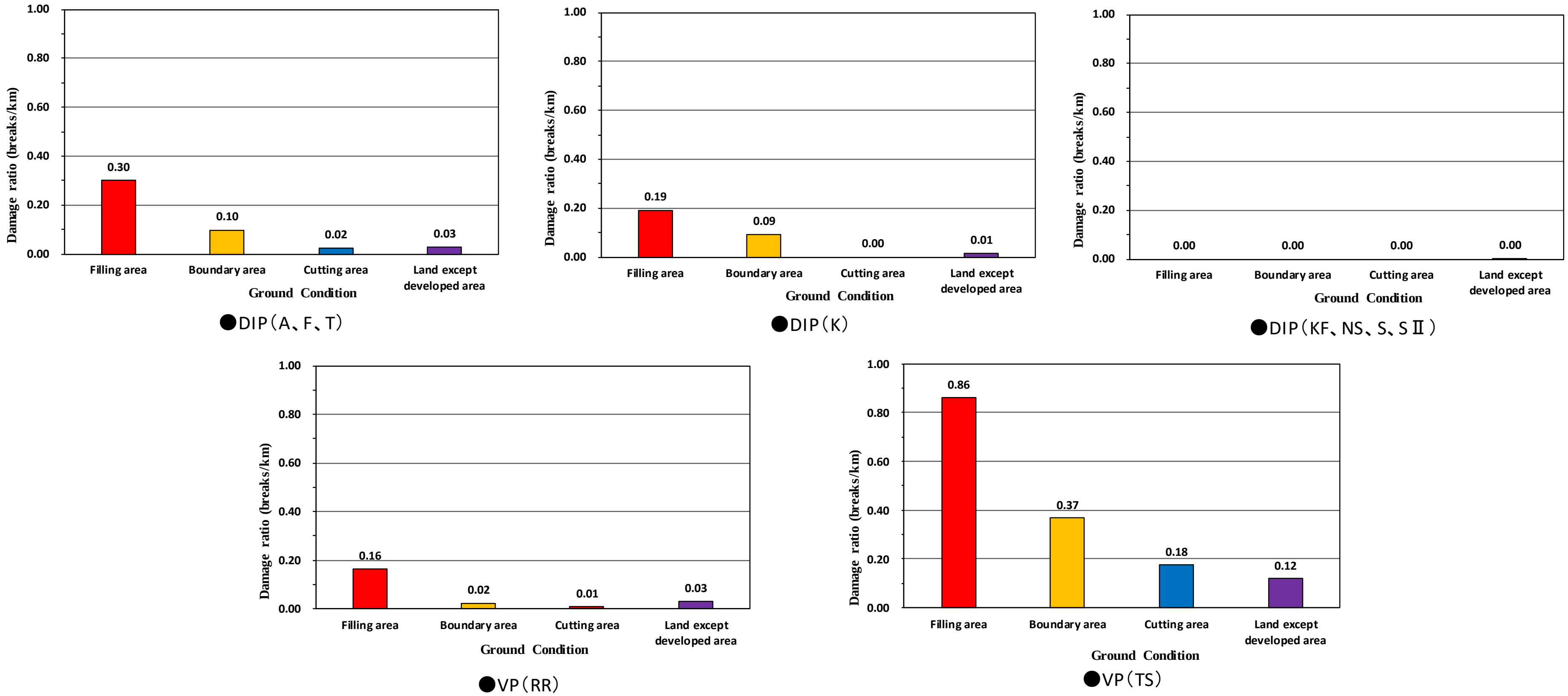
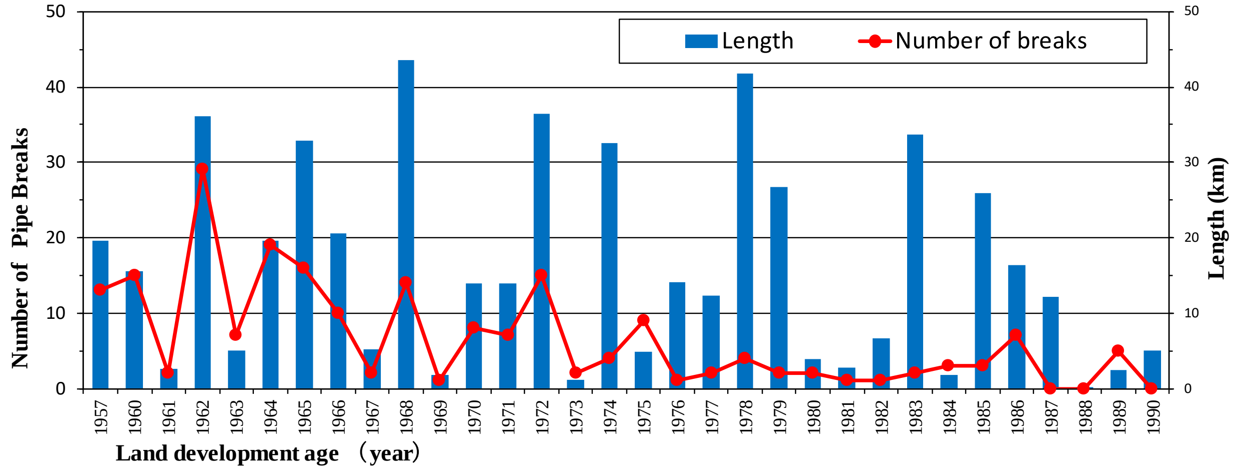
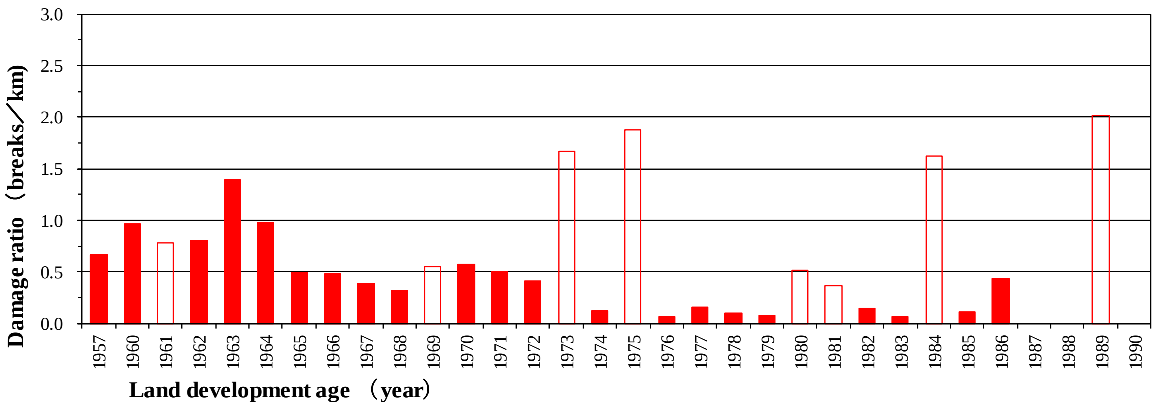


Figure 5 Damage ratio for pipelines per ground condition by pipe materials and joints.



・After 1990, damaged pipeline was not found in filling area.

Figure 6 Number of Pipe Breaks and Length in filling area



・Damage ratio for total length under 5km doesn't deal with effective value, and the graphs of that are showed by erasing the color.

Figure 7 Damage ratio in filling area by land development age

CONCLUSION

We researched for the damaged pipeline by the Great East Japan Earthquake and calculated the damage ratio of pipelines from viewpoints of the specific characteristic of ground conditions, pipe materials and joints. According to the study, we concluded as follows. First, this study shows a tendency that high damage ratio is cutting, boundary, and filling area in that order. Second, especially it implies that DIP (A, F, T) and VP (TS) installed in filling area have high priority to be replaced. Lastly, Sendai City applied an Act on Regulation of Residential Land Development in 1965, so the damage ratio of pipeline that installed in filling area after 1965 is lower than that of others. Therefore, it implies that the pipes installed in filling area before 1965 have high priority to be replaced by earthquake resistant pipe.

Sendai Waterworks Bureau has set the priority for the pipelines to be replaced against the necessity and emergency of historical leakage of water. We would like to promote the earthquake resistant of the pipes effectively by utilizing this result.

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