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Optimum Anti-Seismic Improvement Plan of Water Piping Network

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Abstract

Lying on the Circum-Pacific earthquake zone, the Japanese Archipelago not only is the site of considerable volcanic activity, but also is one of the world's most seismologically active areas. Particularly, recent disastrous tremor was the Great Hansin-Awaji Earthquake of 1995, which at a magnitude of 7.2(JMA) caused extensive damages throughout Kobe City. The water supply was interrupted in many areas for long periods. The importance of anti-earthquake planning is being reconsidered in water supply engineering.

Many kinds of pipes are used according to local conditions in Japan. Since the latter half of the 1950's, the resistance to earthquakes of the water pipelines has been remarkably improved by the use of ductile cast iron pipe with mechanical joints and the progress of welding technology for steel pipe. But, the water supply system in the old town has many old pipes which are no longer production in Japan and/or pipes which are considered to be insufficient for earthquakes. These systems may receive extensive damages to the piping elements during a big earthquake. For this reason, there is an urgent need to develop an effective anti-seismic improvement plan of the actual water piping system.

In this paper, we deal with a methodology to develop the anti-seismic improvement plan of the water piping system and its application to a local city in Japan.

Introduction

Since the area vulnerability assessment of earthquakes was announced by Tokyo Metropolitan Government at 1978, the estimation of damages during earthquake was conducted by many local governments(Tokyo Metropolitan Council for Disaster Prevention, 1978). The result of this assessment has been utilized for the basic data on the planning of disaster prevention at each local government. These assessments included the estimation of damages to the water supply system. Some advanced local autonomous bodies have proceeded the master plan for the earthquake resistant water system with these estimation data.

In this paper, at first we describe the evaluation procedure of the potential risk of pipe element. Next, considering fire-fighting sources during earthquake as an importance factor, we demonstrate the determination method of the renewal priority of pipe elements.

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Evaluation of the potential risk of pipe element

The estimation equation of damage to water pipes in Japan is advanced by Isoyama and Katayama based on the area vulnerability assessment of earthquake, which was announced by Tokyo Metropolitan Government at 1978(Isoyama, R. and Katayama T., 1982).

$$R_m(\alpha) = C_1 \cdot C_2 \cdot C_3 \cdot \cdot C_n \ R(\alpha) \qquad (1)$$

where, $R(\alpha)$ is the standard damage rate, and $C_i(i=1\text{-}n)$ are corrective coefficients and α is the maximum acceleration of seismic motion. Here, the standard damage rate $R(\alpha)$ is obtained by the regression analysis of the relation between the maximum acceleration and the rate of damage to pipelines during 1971 San Fernando earthquake. But, as this equation has involved a defect too much increasing the damage rate with the increasing acceleration as shown in Fig. 1, this equation is modified by the data of the 1995 Hanshin-Awaji earthquake. New relation is obtained by the following formula, and illustrated in the same figure(Isoyama, R. et al., 1998).

$$R(\alpha) = 2.88\text{x}10^{-6}(\alpha - 100)^{1.97} \qquad (2)$$

And also equation (1) is defined as following formula;

$$R_m(\alpha) = C_p \cdot C_d \cdot C_s \cdot C_l \ R'(\alpha) \qquad (3)$$

where, $R'(\alpha)$ is the modified standard damage rate (eq.(2)), C_p, C_d, C_s and C_l are corrective coefficients concerned with the pipe kind, the pipe diameter, the topographical aspect and the capability of liquefaction of ground, respectively. It can combine many conditions due to various situations of each city. And also its coefficient can reflect the latest data of past earthquakes. As an example, corrective coefficients used in this study are shown in Table 1 .

Here, we express the potential risk of pipe element as the non-damage probabilistic ratio(P) which is obtained as the following equation.

$$P = \text{Exp}(- \ R_m(\alpha) \ \cdot L) \qquad (4)$$

where, L is the length of pipe element on the pipeline network.

Determination of the renewal priority considering the water pipeline as the fire fighting source during earthquakes

Developing the renewal plan of piping system, we need not only the evaluation of potential risk of pipe elements, but also the rational determination method of renewal priority as the water supply system. There are many determination methods to obtain this priority. In this study, as a determination method of the renewal priority, we adopt a method considering the fire fighting sources immediately after the earthquakes. Fire department considers the fire fighting activity with other sources prior to the usage of hydrant during a big earthquake. But according to the development of the water system, an expectation of the fire fighting with public hydrants increases. When a number of simultaneous post-earthquake fires occur, it is important to fire-fight by citizen's voluntary activity using hydrants for the initial stage. The 1995 Great Hanshin-Awaji earthquake teaches us that citizen's voluntary activity is considerably effective for reducing fire damages. Therefore, water supply should have a role of supplying sufficient water for citizen's activity even in the time of earthquake(Ikeda, O. Yasuno, K. and Motosugi, K. 1999).

The objective of this study is to construct more safe social system with the capability of fire fighting by hydrants even if immediately after a big earthquake by considering the effective combination of hydrants and other sources.

Necessity of hydrants for the fire fighting

Many fires occur simultaneously when a big earthquake strikes. Then in case of planning on the fire-fighting, we need the consideration based on the damage evaluation of the whole region. At first, we divide the objective region to suitable meshes(400mx400m). Considering the fire prevention measures already arranged , we estimate the relative "potential risk" on each mesh. In this analysis, we take account of the following items; ①the population in the mesh, ②the number of important facilities(regional disaster prevention center, regional refuge and so on), ③the characteristics of the region based on the urban planning on each mesh, and ④the covering rate of fire fighting sources(fire cisterns, underground tank and other sources) except hydrants.

We introduce a new index "necessity of hydrants" defined by the following formula;

$$\text{Necessity of Hydrants} = \frac{\text{Population factor x Facility factor x Regional usage factor}}{\text{Covering rate of fire-fighting source except hydrant}} \quad (5)$$

The population factor is set up as shown in Table 2 due to the population in the mesh. As important facilities, we count the regional disaster prevention center, refuges, and so on which are necessary for the command offices of search/rescue at the initial stage after earthquakes. Generally, the usage of the region is designated by the city planning. For example, as the factory is under obligation to prevent a fire after 1964 Niigata earthquake, the probability of occurring a fire is very low. On the other hand, the probability of occurring of higher risks of fire spread at the residential area is accounted to become very high. Then, this regional usage factor is a good index of the occurrence of fire. Finally, the covering rate of the fire-fighting sources is expressed by the rate of the covered portion to each mesh considering that a source can cover the square with 400mx400m. Here, the mesh size 400mx400m was determined from the fire-fighting by a fire engine. In case of figure 2, mesh A and B are 6/16, and C and D are 2/16.

These factors used in this study are tabulated in Table 2.

Determination of the renewal priority of the pipe element considering necessity of hydrants for the fire fighting

First, we classify the necessity of hydrant of each mesh into 3-Levels. Next, from the flow analysis of water supply system, we select the path from the reservoir to the objective mesh with the highest necessity of hydrants among Level-3 meshes. On the other hand, the objective non-damage rate on each level of the necessity is established in advance. Comparing the non-damage rate of the pipe element on this path with the objective value mentioned above, elements which does not reach to the objective value are chosen to be renewed.

In this manner, we improve the paths with level-3 at first, after that we proceed to the path with level-2, and so on.

Application to the actual water piping system

The water supply pipeline network of Himi city was adopted in this paper as a case study. At present, the information on the ground condition and pipeline in Himi city are completed as the GIS data base. As next step, an effective renewal plan of aged pipes is considered. The result of determined pipe elements to be renewed is shown in Fig. 3. And figure 4 shows the importance of pipe element considering by the water flow in the network. This result shows that these elements to be renewed are on the important line of water pipeline network. In this study, for the objective non-damage rate on each level of the necessity, we used values of 0.90, 085 and 080 for Level 3, Level 2 and Level 1, respectively.

Concluding remarks

In this paper, we proposed an anti-seismic improvement plan of water piping network considering the evaluation of potential risk of pipe elements based on the modified damage rate and the importance factor of pipe elements taking account of the fire-fighting activity with public hydrants immediately after the earthquake. The priority order determined in this study almost coincides with the important line obtained from the flow analysis of the network.

As a next actual problem, we remain the work determining the annual renewal plan in a concrete way within the annual budget. In this case, Genetic algorithm is considered to be a useful tool.

References

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Table 1 Corrective Coefficients

Topographical Aspect C_s		Pipe Kind C_p		Pipe Diameter C_d		Liquefaction C_l	
Definition	Value	Definition	Value	Diameter (mm)	Value	Definition	Value
Artificial Hill	1.1	DIP	0.3	-75	1.6		
Terrace	1.5	CIP	1.0	100-150	1.0	Non-Possibility	1.0
Abandoned River Channel, Valley	3.2	VP	1.1	200-400	0.8	Locally	2.0
Alluvial Fan	1.0	SP	0.3	500-	0.5	Entirely	4.0
Others	0.4	ACP	1.2				

DIP: Ductile Iron Pipe CIP: Cast Iron Pipe ACP: Asbestos Cement Pipe
VP: Vinyl Pipe SP: Steel Pipe

Table 2 Factors of Hydrants Necessity

Population		Covering Rate		Facility		Regional Usage	
Number	Value	Definition (/16)	Value	Definition	Value	Definition	Value
-25	1.0	0	1.0	Regional disaster Prevention Center	9.0	Residential	2.5
26-50	1.5	1,2	2.5			Commercial	2.0
51-75	2.0	3,4	4.0	Regional Refuge	2.5	Industrial	1.2
76-100	2.5	5,6	5.0	Local Refuge	2.0	Non-restricsion	1.0
101-125	3.0	7,8	5.6	Nothing	1.0		
126-175	4.0	9,10	6.1				
176-225	5.0	11,12	6.5				
226-325	7.0	13,14	6.9				
236-425	9.0	15,16	7.2				
426-	10.0						

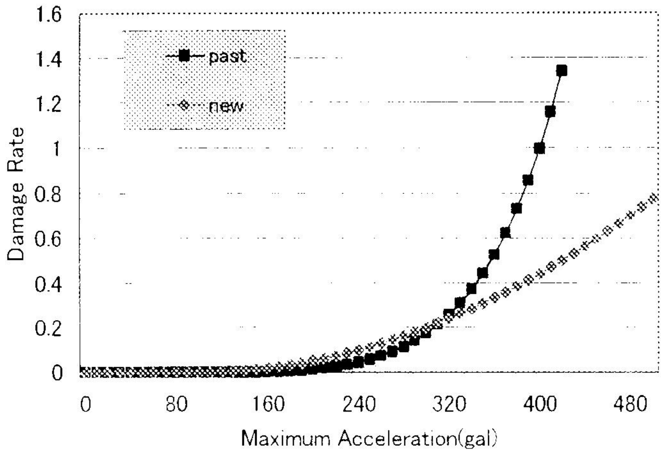
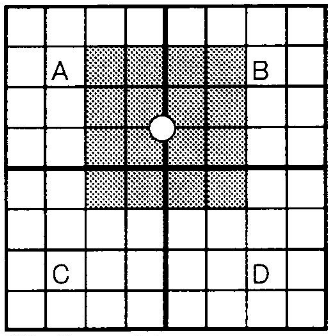


Fig. 1 Relation between Damage Rate and Maximum Acceleration



▨: Covered Area
○: Fire-Fighting Source

Fig. 2 Calculation of Covering Rate of Fire-Fighting Source except Hydrant

Figure 3 Selected pipe element

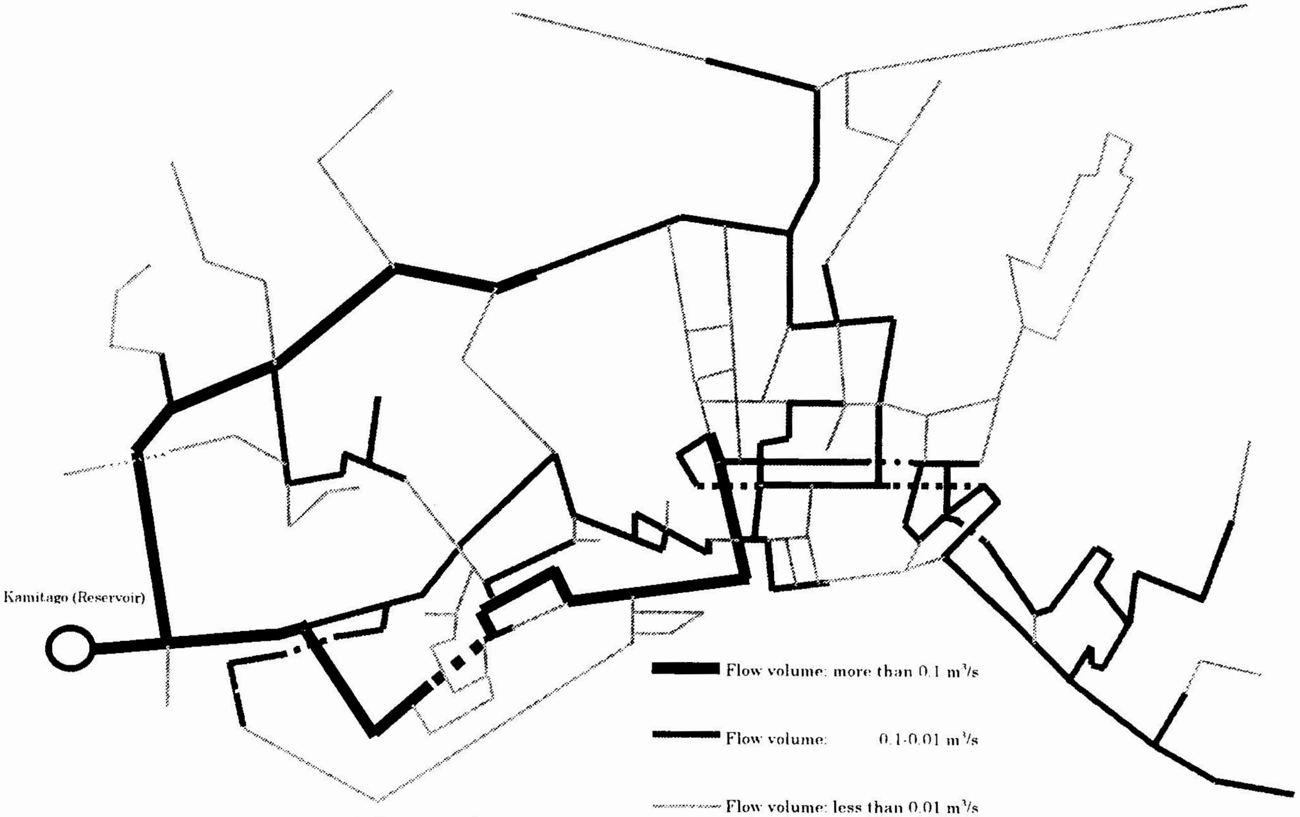


Figure 4 Flow volume of pipe element