Lessons Learned from Damage to Water Supply Pipelines Due to the 1995 Hyogoken Nambu Earthquake in Japan

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ABSTRACT

Earthquake damage to water supply pipelines during the 1995 Hyogoken Nambu earthquake (Kobe earthquake) was investigated. An overview of the damage to water supply pipelines in Kobe city was presented and the relationship between the damage to water supply pipelines, pipe diameter, geological features and so on was studied. The lessons learned from the damage in the 1995 Hyogoken Nambu earthquake was discussed.

INTRODUCTION

At 5:46 on January 17, 1995, a magnitude 7.2 earthquake occurred around Kobe city. The earthquake was named as the 1995 Hyogoken-Nambu earthquake by the Japan Meteorological Agency. This earthquake has produced significantly great ground motion and extensive liquefaction in the wide areas of reclaimed land. More than 6,000 persons were killed and more than 35,000 persons were injured. About one hundred thousands houses were completely destroyed and more than 7,000 houses were burned by the fire following the earthquake. The water supply system in Kobe city was completely disrupted and its principal functions were lost.

The present paper is concerned with the damage to the water supply system during the 1995 Hyogoken-Nambu earthquake. An outline of the water supply system and the damage to it in Kobe city was presented. The relationship between the damage to water supply pipelines, pipe diameter, geological features and so on was investigated. The characteristics of damage to water supply pipelines during the earthquake are summarizes as follows; (1) Damage to distribution pipelines was markedly hard. (2) Joint separations for cast iron pipe occurred in the older mechanical joints. (3) Liquefaction strongly affected the damage to pipeline. Since the ductile cast iron pipelines with earthquake-proof joint did not suffer damage even in the liquefied area, the effect of earthquake proof joint was confirmed. (4) Damage to the pipe fittings such as valves, hydrants, etc., was remarkable. The present paper describes the details of the damage characteristics of the water supply system and discusses the lessons learned from the damage.

OUTLINE OF DAMAGE IN KOBE CITY

The water supply system of the Kobe Municipal Waterworks Bureau has approximately 4,000 km of distribution pipelines and serves about 1.5 million customers. Since there is no big river in Kobe city, about 75% of the amount of water that is supplied from the Kobe Municipal Waterworks Bureau is obtained from the Hanshin Water Supply Authority. The percentage of pipe length to pipe type is shown in Fig. 1. About 86% of the total length is made up of ductile cast iron pipe (DCIP), 8% cast iron pipe (CIP), 3% steel pipe (SP), 3% vinyl pipe (VP). It is remarkable that about 86% of the total length is made up of ductile cast iron pipe. The ductile cast iron pipelines with earthquake-proof joint were used for the main pipeline with a diameter of more than 400 mm and for pipeline buried in soft subsoil such as reclaimed land, high embankment, etc.

Fig. 2 shows the pipeline network and sites where the pipe failure occurred (Japan Water Works Association 1996). The total number of failures for distribution pipelines was 1,757. The damage rate, defined as the amount of failures per length of pipeline, was about 0.44/km. Fig. 3 indicates the percentage of damage occurrences related to the type of failure. About 55% of the total failures occurred at a joint and the separation of the pipes at joint was remarkable. Fig. 4 shows the relationship for damage rate, pipe diameter and type of failure. It is evident from this figure that the damage to pipe fittings such as valves, hydrants, etc. occurred mostly in the large diameter pipelines. Fig. 5 indicates the relationship for number of cases of damage, pipe diameter and type of failure. According to this figure, number of cases of damage to pipe fittings in large diameter pipelines is not so great. The high damage rate of pipe fittings in the large diameter pipelines seems to depend on the short length of the large diameter pipelines. It is conceivable that the strength

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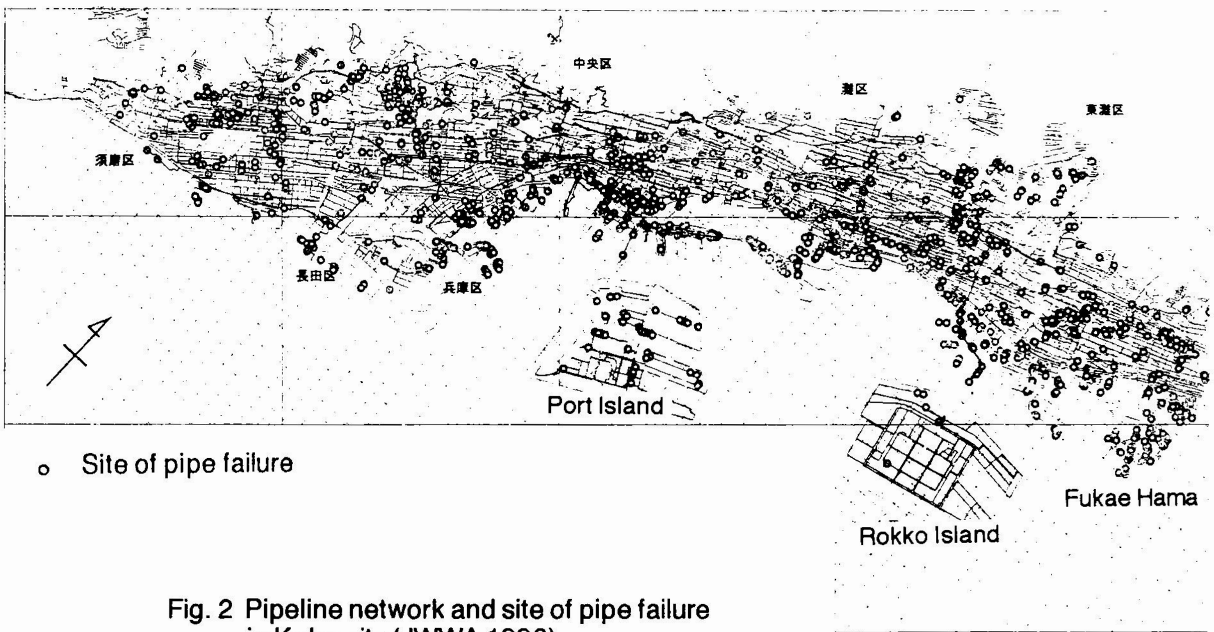


Fig. 2 Pipeline network and site of pipe failure in Kobe city (JWWA 1996).

of pipe fittings would not be sufficient to withstand the earthquake. Ductile cast iron pipelines with earthquake-proof joints, however, did not suffer damage even in liquefied areas.

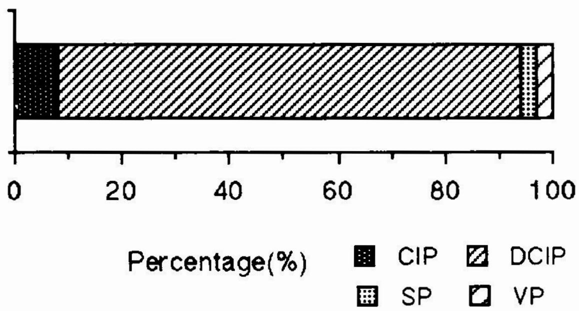


Fig. 1 Percentage of pipe length to pipe type of Kobe city.

The number of service connection repairs reached to 12,827 in public space and 58,408 within private property. The total number of service connections, therefore, was 71,235. Most of them were caused by pipe breaks and joint separations due to building collapses and road deformation (Matsushita, 1995).

The urban area of Kobe city is situated on a narrow and long strip of land in the east-west direction and its height above sea level varies from 0 m to 300 m. The topography and geological features, therefore, change drastically there. There are some artificial islands and the reclaimed land is extensively located in the southern area of the city. The northern part is mountainous with granite bed rock. Fig. 6 shows the number of cases of damage related to the geological features. The number of cases of damage in reclaimed land was the highest and that within alluvium even greater. Pipe failures within soft ground were extensive and liquefaction in reclaimed land affected damage to pipelines strongly. Even the number of cases of damage in basement rock was not as small as expected. The ground deformation induced by the seismic faults seems to be one of the causes of damage to pipe failure. Since the length of piping in each area was not clearly defined unfortunately, the damage rate can not be discussed here (Kitaura and Miyajima 1996).

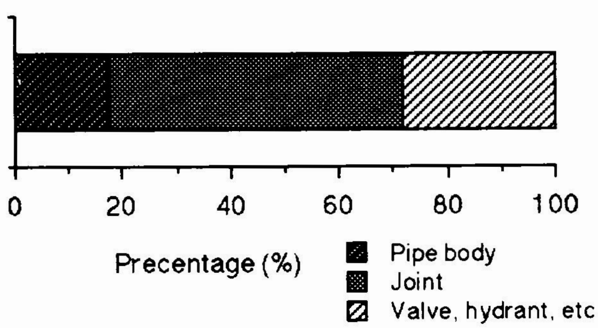


Fig. 3 Percentage of damage occurrences to type of failure in Kobe city.

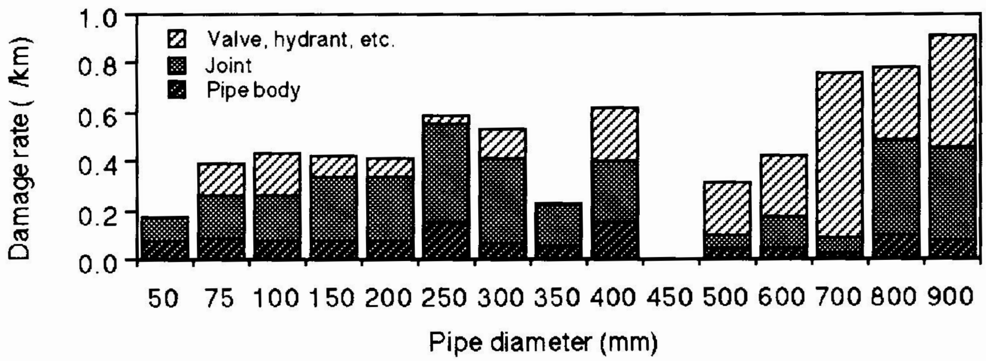


Fig. 4 Relation for damage rate, pipe diameter and type of failure in Kobe city.

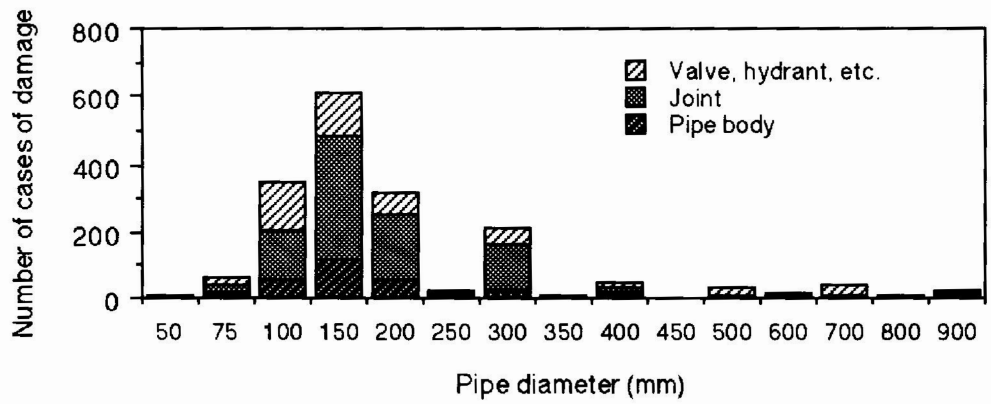


Fig. 5 Relation for number of damage occurrences, pipe diameter and type of failure in Kobe city.

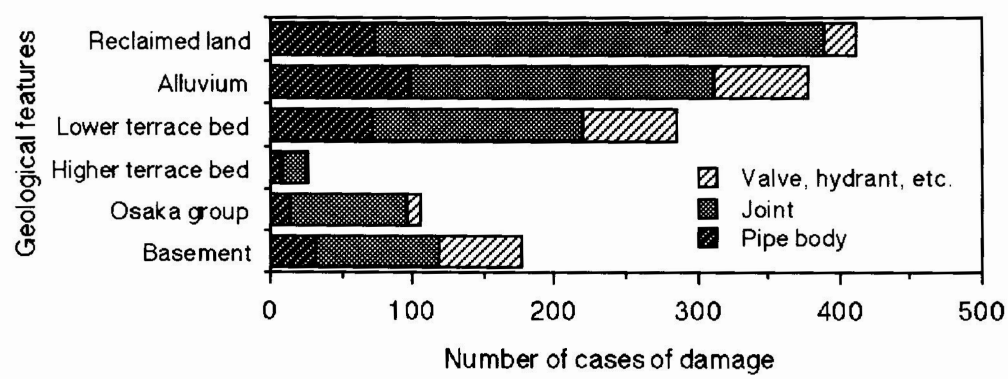


Fig. 6 Relation for number of damage occurrences and geological features for Kobe city.

LIQUEFACTION RELATED DAMAGE

Damage in reclaimed lands

The 1995 Hyogoken Nambu earthquake caused severe liquefaction in extensive area of reclaimed land in Kobe and the adjacent cities. Hamada et al.(1995) measured the surface ground failures in these areas by using aerial photographs taken before and just after the earthquake. The ground failures occurred in the reclaimed area, especially newly reclaimed areas.

The relation between permanent ground displacement and damage to pipeline was investigated in three areas of reclaimed land, that is, Mikage-Sumiyoshi Hama, Uozaki Hama and Fukae Hama in Kobe city. These areas were reclaimed by decomposed granite between 1960 to 1970. Fig. 7 indicates the relationship between horizontal permanent ground displacement and the number of cases of damage. The horizontal permanent ground displacement in this figure indicates the nearest one within 50m from the site of each pipe failure. It is evident from this figure that the pull-out of the pipes at joint was remarkable. This figure also suggests that many pipe failures were caused at sites where the permanent ground displacement was greater than about 70 cm. The permanent ground displacement was divided into the axial direction and the direction of perpendicular to the axis. Figs. 8 and 9 show the relationship between the horizontal permanent ground displacement in each direction and the number of cases of damage. There is no marked difference between two figures (Miyajima et al. 1998). Fig. 10 shows the principal ground strains and sites of pipe failures in northern part of Fukae Hama. According to this figure, pipe failures were occurred at sites where the large ground strains appeared.

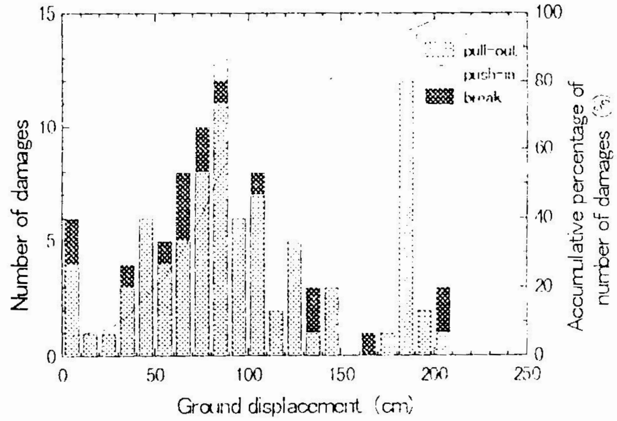


Fig. 7 Relationship between number of damage occurrences and horizontal ground displacement.

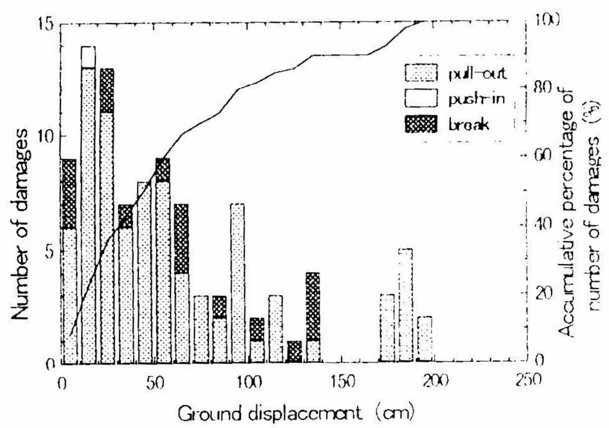


Fig. 8 Relationship between number of damage occurrences and horizontal ground displacement in axial direction.

Relationship among damage rate, degree of liquefaction and joint type

Fig. 11 shows the relationship between damage rate and degree of liquefaction (Japan Water Works Association 1996). The degree of liquefaction was evaluated by the area covered by sand erupted by liquefaction. The damage to pipelines installed in Kobe, Ashiya and Nishinomiya cities was totaled. According to this figure, the damage rate of cast iron pipe constructed in severely liquefied areas was two times greater than that in non-liquefied areas and the damage rate of ductile cast iron pipe with mechanical joint installed in severely liquefied areas was four times greater than that in non-liquefied areas. Ductile cast iron pipelines with earthquake-proof joints, however, did not suffer damage even in severely liquefied areas. Fig. 12 shows the cross section of mechanical (K type) and earthquake-proof (S type) joints. The expansion-contraction value of the earthquake-proof joint is 1.0% of the length of the pipe.

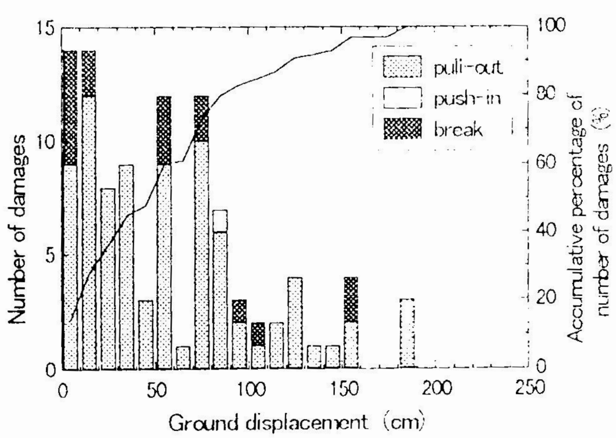


Fig. 9 Relationship between number of damage occurrences and horizontal ground displacement in direction of perpendicular to the axis.

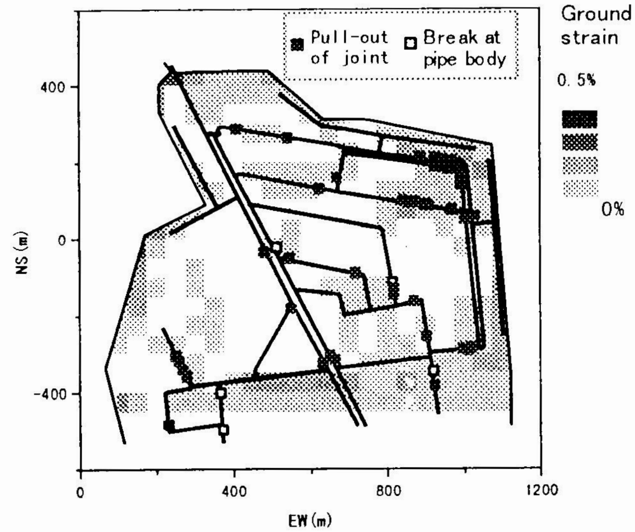


Fig. 10 Distribution of principal ground strain in Fukae Hama.

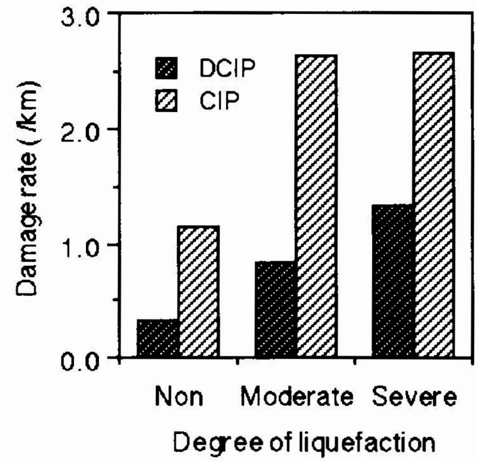
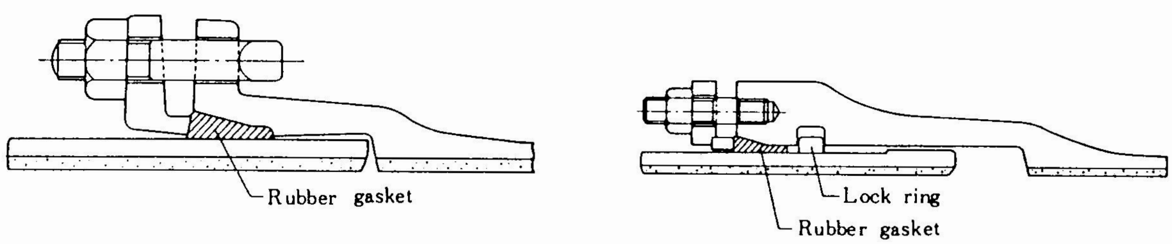


Fig. 11 Relationship between damage rate and degree of liquefaction (JWWA 1996).



(a) Mechanical joint (K type)

(b) Earthquake-proof joint (S type)

Fig. 12 Cross section of mechanical joint (K type) and earthquake-proof joint (S type) for ductile cast iron pipe.

Figs 13 and 14 displayed the relationship between number of lines of pipe, that means the pipeline between a junction and other junction, and average ground strain (Japan Water Works Association 1996). The number of lines of pipe that suffered damage by the earthquake, was indicated by shadow in these figures. The average ground strain means the average value of axial and transversal ground strains at the line of pipe. The pipelines installed in some reclaimed land, that is, Port Island, Rokko Island and Ashiya-Hama was summed up in this figure. Ductile cast iron pipe with mechanical joints suffered damage when the average ground strain was 0.2 to 0.4% and damage occurred at all of lines of pipe when the average ground strain was greater than 0.6%. On the other hand, ductile cast iron pipe with earthquake-proof joints did not suffer damage even at the average ground strain of 1.0%. This coincides with the fact that the expansion-contraction value of the earthquake-proof joint is 1.0% of the pipe length as mentioned above.

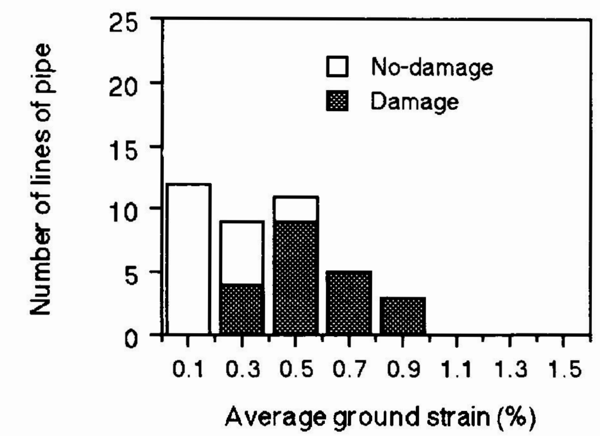


Fig. 13 Relationship between number of lines of pipe and average ground strain (Mechanical joint).

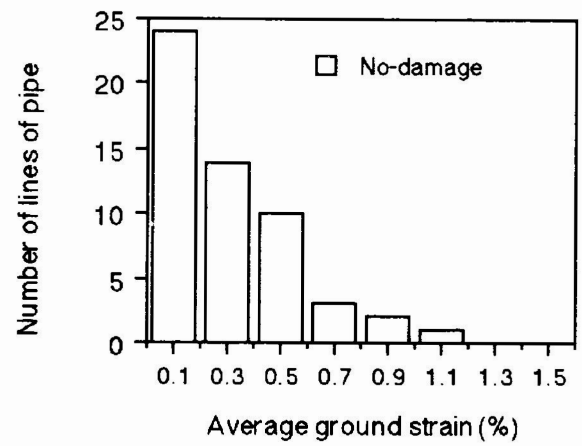


Fig. 14 Relationship between number of lines of pipe and average ground strain (Earthquake-proof joint).

LESSONS LEARNED FROM DAMAGE TO WATER SUPPLY PIPELINES

An outline of the damage to water supply pipelines of Kobe city by the 1995 Hyogoken Nambu earthquake was given and the relationship for the damage to water supply pipelines, pipe diameter, geological features and so on was studied. It is evident from the damage that pipe failures within soft ground were extensive and liquefaction in reclaimed land affected damage to pipe strongly. Therefore, countermeasures for pipeline and surrounding subsoil are required for such ground conditions. On the countermeasure for pipeline, the effect of earthquake-proof joint for ductile cast iron pipe was verified through the earthquake. Since the countermeasures for surrounding subsoil are expensive, it is crucial to predict the extent of liquefaction-related ground deformation precisely.

Although it is not realistic that the earthquake damages were perfectly prevented, strengthening of the system following the priority decided by a seismic diagnosis is indispensable. Moreover, improvement of pipe fittings is also needed. Ishida et al. (1998) clarified the main causes of damages to pipe fittings and proposed measures of their improvement.

ACKNOWLEDGMENTS

The present paper is based on data collected through a detailed investigation. Many individuals and organizations generously helped with this investigation. In particular, we deeply indebted to the staffs of the Kobe Municipal Waterworks Bureau and KUBOTA Ltd. for their help.

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