ESTIMATION OF THE DISTRIBUTION OF WATER-PIPELINE LENGTH BASED ON OTHER INFRASTRUCTURE DATA

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ABSTRACT: Damage estimation for scenario earthquakes has been conducted by local governments in Japan for emergency response planning. However, local governments usually do not possess detailed grid data of lifeline systems with pipeline material, diameter and length's information in the grid cell of GIS. To improve the accuracy of earthquake damage assessment, a correlation analysis is carried out to estimate the water-pipeline length within a grid cell of 250 m from the corresponding road length and other lifeline lengths using the detailed GIS data of Kashiwazaki city, Niigata prefecture, Japan, where buried-pipelines were disrupted due to the 2007 Niigata-ken -Chuetsu-Oki earthquake. The equation to estimate the water-pipeline length is examined using the actual-pipelines' GIS data, and the efficiency of estimation from the road data is demonstrated by limiting the target area only for densely inhabited districts (DIDs). But outside of DID, the relationship between the road length and water-pipeline length is scarce because no water-pipeline is buried under some rural roads. Hence some other environmental parameters must be introduced to estimate the water-pipeline length outside DID. In addition, strong correlations between the water-pipeline length, the gas-pipeline length and the wastewater line length are observed in Kashiwazaki and other cities near Tokyo. The detail correlation analysis is carried out for each lifeline on GIS to provide the fundamental data to estimate the other lifeline data, basically from road network data, which is, in general, most easily available.

1. INTRODUCTION

According to the Headquarters for Earthquake Research Promotion in Japan (2009), a concern is increasing for large earthquake occurrence in Tokyo Metropolitan area, where many infrastructures including water and gas pipelines are extended, creating complicated networks. Various public organizations have tried to estimate the damages of underground pipelines against scenario earthquakes in Tokyo Metropolitan area to develop disaster mitigation plan. Several studies have developed prediction methods to estimate the damage of water pipelines. In recent years, earthquake damage estimation in Tokyo Metropolis has been calculated based on the studies by Isoyama et al. (2000) and Maruyama and Yamazaki (2010). To use these methods, detailed grid data of lifeline systems with pipeline material, diameter and length's information within a grid cell of GIS are required. However, most local governments do not possess these detailed data, and generally estimate the water pipeline length within a grid cell of 250 m prorated from the number of buildings or night population. A problem of this approach is that it is generally difficult to obtain the number of buildings within a grid cell. Even if such data is available, the accuracy of the water pipeline length estimated from the data is not so high.

This study tries to perform the estimation of lifeline data for earthquake damage assessment more accurately. The method to estimate the water pipeline length is proposed within the grid cell of 250 m from the corresponding other infrastructure data in Kashiwazaki city, Niigata prefecture, Japan, where the detailed GIS data is available. Then the estimation method is evaluated by comparing the estimated data with the actual pipeline data.

Since the lifeline systems are usually closely located each other, it is also expected that the length of the pipelines are strongly correlated. Therefore, the correlation analyses are extended to other lifeline data to provide predictive equations of those lengths for the purpose of damage estimations against scenario earthquakes.

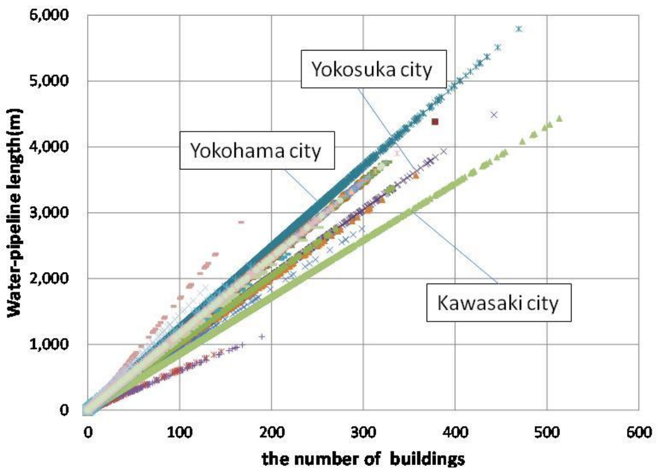


Figure.1. Comparison of the number of buildings and water pipeline lengths in 250m grid cells for cities in Kanagawa prefecture.

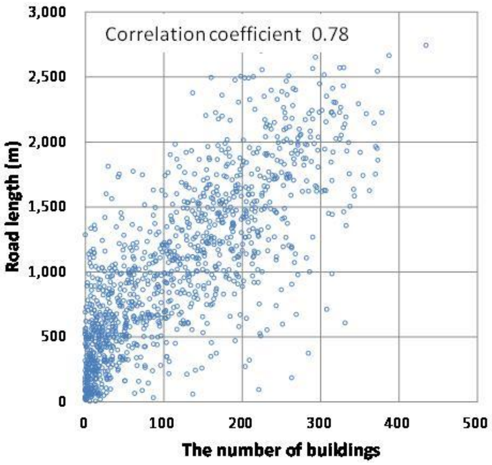


Figure.2. Relationship between the number of buildings and road lengths in 250m grid cells for cities in Kanagawa prefecture.

2. THE ESTIMATION OF WATER-PIPELINE LENGTH

Water pipeline network is one of the objects of damage estimation for scenario earthquakes. To improve the accuracy of the estimation of water pipeline length, the correlations between the water pipeline length and infrastructure data including buildings and road data within a grid cell are studied. Then, the method to estimate water pipeline length is proposed.

2.1 The Estimation of Water Pipeline Lengths from Building Inventory

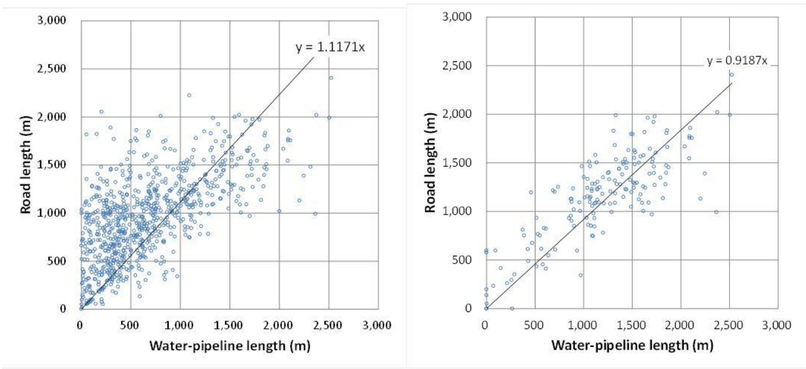
Local governments in Kanagawa prefecture estimated the water pipeline length within a grid cell from the number of buildings based on the data published by the Japan Water Works Association (2008). However, this relationship does not reflect the difference between low-rise buildings such as residential houses and high-rise buildings such as office towers in estimating water pipeline lengths (Figure 1). Therefore, the length of water pipeline is overestimated than the actual length in the area where many low-rise buildings exist, and underestimated in the business district where many high-rise buildings exist. For example, the prediction errors were calculated in the city near Tokyo between the estimated length and the actual length within the grid cell of 250 m. More than 30% of the grid cells underestimated the water pipeline lengths by 500 m with the maximum error of 2,678.6 m. Therefore, these errors will propagate to the accuracy of damage estimations against scenario earthquakes.

It is general to use building data to estimate the water pipeline length in the recent earthquake damage assessments. However, these estimates have a potential problem that they cannot reflect the local district conditions which are very important for damage estimations against scenario earthquakes. Generally, there is no direct relationship between the water pipeline length and the number of buildings. For this reason, to improve the accuracy of earthquake damage assessment, the method to estimate pipeline data based on environmental parameters which can reflect the local site condition is needed.

2.2 Estimation of Water Pipeline Length from Road Length

In this study, the method to estimate the water pipeline length from the road length is proposed and investigated. This is because that underground pipelines including water and gas supply are generally buried under a road and thus they are expected to be highly correlated each other. It is also practical to use road data for earthquake damage assessment since it is obtained easily compared with the number of buildings data. In this study the distribution pipelines are only considered from a few classes of water pipelines since those have been mainly used in the previous earthquake damage assessments based on the case histories of major damages observed in the past earthquakes, including the case of the 1995 Kobe earthquake.

It is assumed that the estimated water pipeline length from the number of buildings is little different from that from the road length if the buildings data and the road data are strongly correlated. Figure 2 shows the relationship between the number of buildings, which have been used as a parameter for estimating water pipeline data, and the road length, which is proposed in this study, for the city near Tokyo, where data plots were constructed for each



(a) All area (b) DID

Figure.3. Comparison of actual and predicted water pipeline length in 250m grid (in Kashiwazaki)

Figure.4. A part of road and water pipeline data on GIS in Kashiwazaki.

grid cell of 250 m. It is observed that they have little correlation, and thus the estimation of water pipeline length from the road length is different from that from the number of buildings.

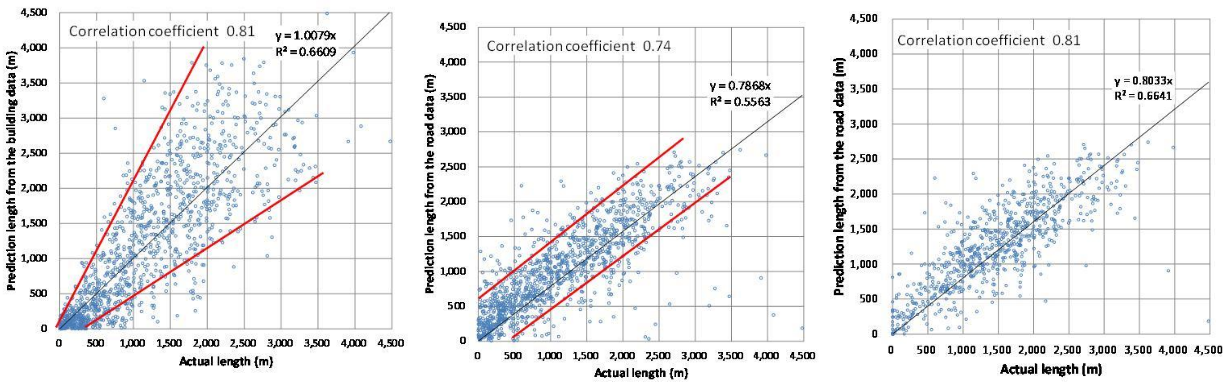
Geographic Information System (GIS) is often used to analyze the damages to lifeline systems during earthquakes (Jeon and O'Rourke, 2005; Kuwata et al., 2008). This study uses GIS to analyze correlation to estimate water pipeline length within the grid cell in Kashiwazaki city, Niigata prefecture, and evaluates that predictive equation against the actual pipelines' GIS data in the city near Tokyo. The lengths of pipelines were calculated within the grid cell of 250m in GIS based on the original pipeline dataset, which includes other information such as pipe material, diameter and length.

2.3 The Correlation between Water Pipeline Length and Road Length

The correlation analysis within the grid cell of 250 m in Kashiwazaki city was carried out. The grid cells which have both data of the water pipeline and the road were considered to investigate the correlation. The relationship between the water pipeline lengths and the road length is shown in Figure 3(a). There are significant differences between the water pipeline length and the road length within grid cells. This is because that some water pipelines are buried under driveways which were not included in the road data as shown in Figure 4. Additionally, there are several roads where water pipelines are not buried, as seen in Figure 4. This can attribute to the variation of the road data and the environment of the city with many agricultural fields. Therefore, it will be difficult to predict the water pipeline lengths in Kashiwazaki city and those in the Tokyo metropolitan area using the same expression without considering local site conditions. Therefore, the method developed in Kashiwazaki city needs to be modified when it is used for the Tokyo metropolitan area. It is expected that this method does work for densely inhabited districts (DIDs), which were published by Ministry of Land, Infrastructure and Transport (MLIT), and the analysis was carried out only for the selected area. As it is expected, a higher correlation is observed between the water pipeline length and the road length in the DID within Kashiwazaki city than all over Kashiwazaki city, as shown in Figure 3(a) and 3(b). The gradient of the regression line obtained by the least-square method is close to 1:1 relationship. The efficiency of estimation from road data was confirmed by limiting the target area only for DIDs. Hence, for outside of DID, the estimation of water pipeline length within grid cells should employ water pipeline modeling (Nagata et al., 2008), which uses night and daytime population from Population Census and the number of customers. For outside of DID, the correlation between the road length and water pipeline length decreases because no water pipeline is buried under some rural roads. It is expected that the estimation from population and the number of customers is effective for outside of DID.

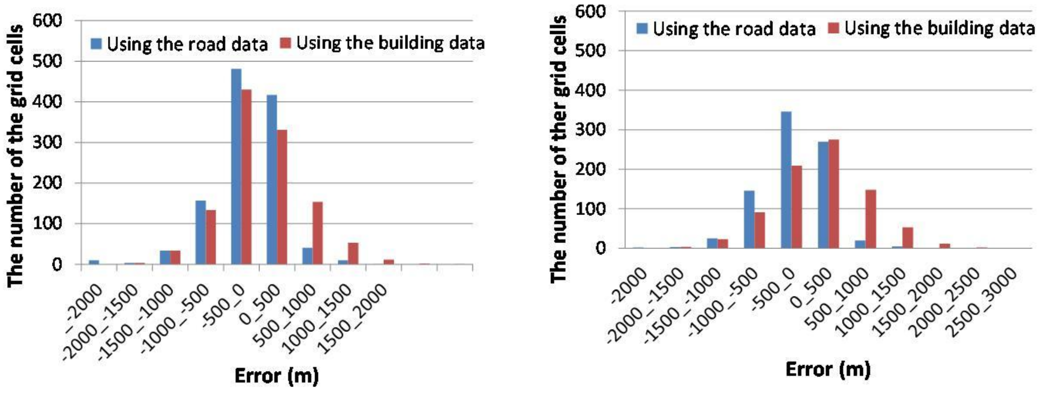
2.4 Verification in The City in Kanagawa Prefecture

The accuracy of the water pipeline length estimation from road data was examined for the city in Kanagawa prefecture. The relationship between the estimated water pipeline lengths from the road data and the actual length is shown in Figure 5. To evaluate the accuracy of the estimation, the relationship between the estimated water pipeline lengths from the number of buildings, which is usually used for the earthquake damage assessment, and the actual length is investigated. The correlation coefficients have little difference between the estimation from the road data and that from the number of buildings. However, it is noted that the data variation increases with the increase of number of buildings in Figure 5(a). In contrast, the variation of data is consistent along the predicted values in the estimation from the road data in Figure 5(b). There are some cells which show a longer pipeline length for water than road. This may be caused by the driveways which are not included in the road data and the water pipelines



(a) Estimation from the buildings data (All area) (b) Estimation from the road data (All area) (c) Estimation from the road data (DID)

Figure.5. Comparison of actual and predicted water pipeline lengths in 250m grid cells (in Kanagawa).



(a) All area (b) DID

Figure.6. Comparison of errors between the actual and predicted water pipeline lengths in the city in Kanagawa prefecture from the road data and the building data.

buried under the both sides of the wide road. Similar to the case of Kashiwazaki city, the more accurate estimation of the water pipeline length was obtained if the target area is limited to DID than all the areas in the city. Difference between those in Kanagawa is not as large as in Kashiwazaki city. There is a difference between the two cities; the DID ratio of the city in Kanagawa is larger than that of Kashiwazaki city. Figure 6 shows the histogram of the residuals of actual water pipeline lengths from the predicted values by the road data for the grid cell of 250 m. Figure 6(a) and 6(b) shows the residuals for all over the city and DID, respectively, in the city in Kanagawa. Figure 6 shows the smaller variation of residuals by the road data than that by building data, indicating the efficiency of estimating water pipeline length from the road data in the city in Kanagawa.

3. CORRELATION ANALYSIS OF OTHER LIFELINE DATA

In general, damage estimations of wastewater line and gas pipeline are also performed for earthquake damage assessments. This study analyzes the correlation between lifeline data, focusing on a combination of water pipeline and wastewater line or water pipeline and gas pipeline. The service areas in Kashiwazaki city was limited to those where both pipeline data exist, to evaluate the correlation between them. Thus, the limited area is based on the existence of wastewater line, which is buried in the smallest area of the three. The gas pipeline data, which were provided from Kashiwazaki city in a digital format, include pipe material, diameter and joint-type information. On the contrary, the wastewater line data were digitized from paper maps on GIS, including material and diameter information. Figure 7 shows the pipelines' GIS data produced for Kashiwazaki city.

3.1 Relationship between Lengths of Water Pipeline and Wastewater Line

Wastewater line damage is usually estimated using a predictive formula. Wastewater line length data is often prorated from the water pipeline length within grid cells, which is often estimated from the number of buildings. If the wastewater line lengths are estimated from the estimated water pipeline lengths, the errors in the estimated wastewater line length may become large because of double fold estimation.

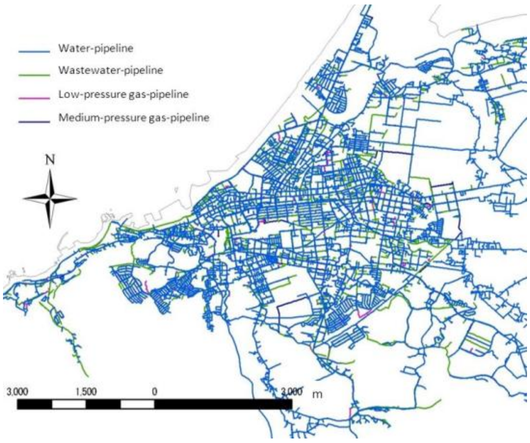


Figure.7. Various pipeline data on GIS in Kashiwazaki.

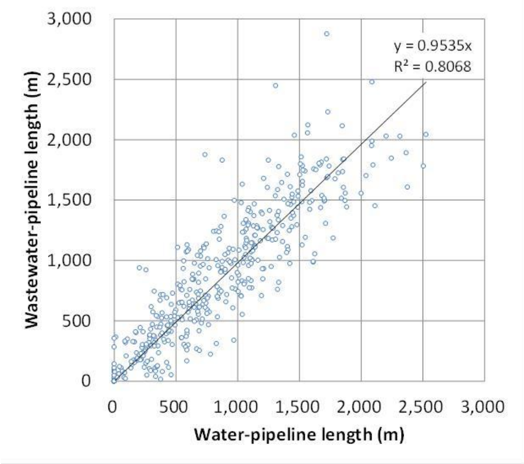


Figure.8. Relationship between water pipeline and wastewater line length in 250m grid in Kashiwazaki.

Figure 8 shows the relationship between the water pipeline length and the wastewater line length within the grid cell of 250 m. Little difference exists between their total lengths for the target area. There are differences between their lengths in a lot of cells even though the gradient of a regression line is approximately 45°, as noted in Figure 8. The errors when digitalizing the paper drawings of the wastewater lines may be responsible for the some discrepantly. When analyzing the water-pipeline and wastewater line data on GIS, some cells where two wastewater lines are buried were found. These areas may have different levels of wastewater lines, such as local-serving and transmission. Around some large customers, such as industries and schools, only water pipelines are observed. The differences between the lengths of the two systems within grid cells might be caused by several reasons.

3.2 The Relationship between the Lengths of Water and Gas Pipelines

Earthquake damage assessment is more difficult to perform for gas pipelines since it is difficult to obtain the data. Hence, it is often the case that the damage estimation calculation is carried out by gas companies, and that the result is provided to local governments. The gas pipeline damages were estimated using the damage function proposed by Kousaka et al. (1998) in Kanagawa prefecture's earthquake damage estimation. Even the case when local governments carry out the estimation by themselves, they usually do not possess detailed grid data of gas pipeline material, diameter and length's information. Therefore, if the gas pipeline length is estimated with higher accuracy than the current practice, it will improve the accuracy of the estimated damage.

The relationship between the water pipeline length and the gas pipeline length was studied on GIS in order to provide a dataset to estimate other lifeline length data from (known) water pipeline data. In Kashiwazaki city, it is expected that the relationship between the water-pipeline length and the gas-pipeline length is strongly correlated because the both pipelines are owned by the local government and they are buried in close locations each other. Figure.9 shows the relationship between the water-pipeline length and the gas-pipeline length. The gas data includes both low-pressure and medium-pressure pipeline data. This study evaluates the applicability of the water-pipeline's relationship to only low-pressure pipelines or to both low and medium-pressure pipelines. In the case for the low-pressure pipeline, the number of cells which show a longer pipeline length for gas than water is much smaller. However, in some areas, the water pipeline length is longer than the gas-pipeline length. The detail analysis of the pipeline data was carried out on GIS, and showed that only water-pipeline or gas-pipeline is buried in many areas, which may be the cause of the difference between the both lengths. As a result, the gas-pipeline length has high correlation with the water-pipeline length if only low-pressure pipelines are

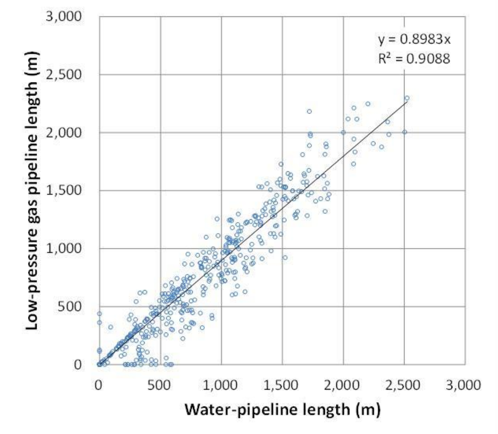


Figure.9. Relationship between water and gas pipeline lengths in 250m grid cells in Kashiwazaki.

considered. A further detailed verification is necessary to estimate the gas-pipeline length from the water-pipeline length because they have some different characteristics.

4. CONCLUSION

In this study, the estimation of the water-pipeline length within the grid cell from the road data is proposed in Kashiwazaki city, and examined in the city in Kanagawa prefecture by using the actual-pipelines' GIS data. As a result, it is concluded that the grid cells which have a large difference between the estimated water-pipeline length and the actual length were reduced using the estimation from road data. The efficiency of estimation from the road data was demonstrated by limiting the target area only for DIDs. This methodology also has an advantage that road data is easier to obtain than building data.

In addition, correlations between the lengths of water pipeline, gas pipeline and wastewater line in grid cells were studied in DIDs of Kashiwazaki city. There are correlations, especially between the water-pipeline length and the low-pressure pipeline length. However, a lot of differences between both of lengths are observed whereas they have the high correlation coefficient.

A further research is necessary to improve the accuracy of the estimation method and to verify its applicability to various sites.

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