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ESTIMATION OF THE DISTRIBUTION OF SEWER PIPELINE'S LENGTH BASED ON ROAD NETWORK DATA

Ryota NAKAZAWA[1] and Fumio YAMAZAKI[2]

ABSTRACT

Damage estimation for scenario earthquakes is extensively conducted by local governments in Japan for emergency response planning. However, local governments usually do not possess detailed grid data of lifeline systems with pipe material, diameter and length's information in the grid cell of GIS. The accuracy of lifeline's mesh data is considered to be highly related to the accuracy of damage assessment results. Therefore, to improve the accuracy of earthquake damage assessment, a correlation analysis is carried out to estimate the sewer pipeline length within a grid cell of 250 m from the corresponding road network's GIS data for Urayasu city, Chiba prefecture, Japan. The equation to estimate the sewer pipeline length is examined by using the actual pipelines' GIS data, and the efficiency of estimation from the road data. Using the data from Kashiwazaki city, Niigata prefecture, the accuracy of the method developed for Urayasu city was examined and its accuracy was demonstrated.

Keywords: earthquake damage estimation, sewer pipeline, 250 m grid data, road data, GIS

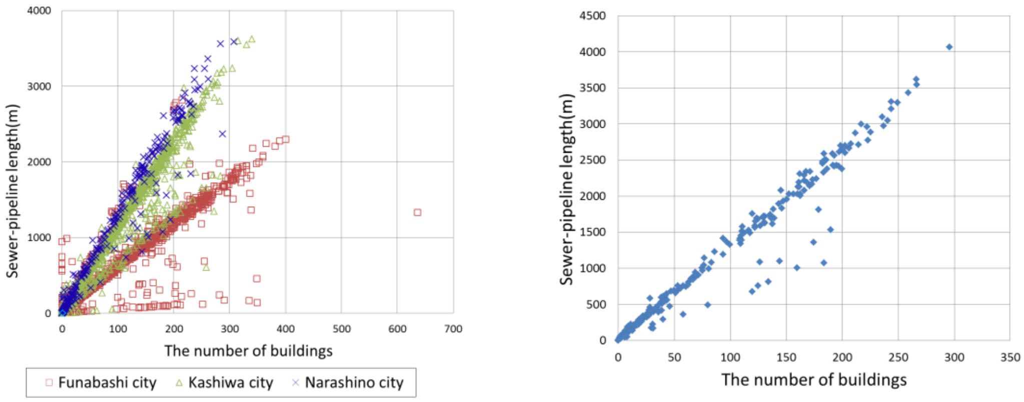
INTRODUCTION

In order to reduce effects from natural disasters, disaster mitigation strategy and recovery planning of urban functions are important. As a part of such efforts, national and local governments in Japan conduct damage assessment for scenario earthquakes. Damage assessments are usually carried out using various fragility curves developed empirically based on past earthquake data, such as from the 1995 Hyogoken-Nanbu (Kobe) earthquake. For example, the method of Ministry of Land, Infrastructure, Transport and Tourism (2005) has been often used for damage assessment of sewer pipelines, and the methods by Isoyama et al. (2000) and Maruyama and Yamazaki (2010) for that of water pipelines in Japan.

In damage assessment, inventory data, such as the pipeline length for a specific material and a diameter, are necessary. But acquisition of such lifeline network data is by no means easy. Earthquake damage assessments in Japan are often carried out using a raster (grid) GIS because seismic motion and soil data are usually estimated using a raster GIS. A 250 m grid is often used for buildings and utility lifelines, but the development of such grid data for underground pipelines is not easy for local governments because the network data are not always stored in a GIS format. Hence, they generally estimate the pipeline lengths within a grid cell of 250 m from that of buildings. If the inventory data are obtained by estimation, the accuracy of damage assessment is obviously not so high.

In order to overcome such problems, this study tries to estimate sewer pipeline grid data using road network data because sewer pipelines are buried under public roads and roads data are much more easily available. A case study is carried out using road and sewer pipeline data in Urayasu city, Chiba prefecture, Japan, where the detailed GIS data are available. Then the accuracy of the method developed for Urayasu city is examined using the data from Kashiwazaki city, Niigata prefecture, Japan.

[1] Graduate Student, Department of Urban Environment Systems, Chiba University, Japan, r.nakazawa@chiba-u.jp
[2] Professor, Department of Urban Environment Systems, Chiba University, Japan, fumio.yamazaki@faculty.chiba-u.jp



(a) Several cities in Chiba prefecture (b) Urayasu city

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

PROBLEM OF THE PRESENT UNDERGROUND-PIPELINE LENGTH DATA

Many local governments in Japan now possess GIS databases of sewerage and water pipeline networks. Therefore, they can produce pipeline data with material and diameter in the grid cell of 250m, and use them for earthquake damage assessment. For example, most of the cities and towns in Chiba prefecture have GIS network data of sewer pipelines, but some do not. In order to produce the same level of sewer pipeline data for all the municipalities in the prefecture, the sewer pipeline lengths within grid cells were estimated from the number of buildings in the 250m grid, based on the total length data for each municipality.

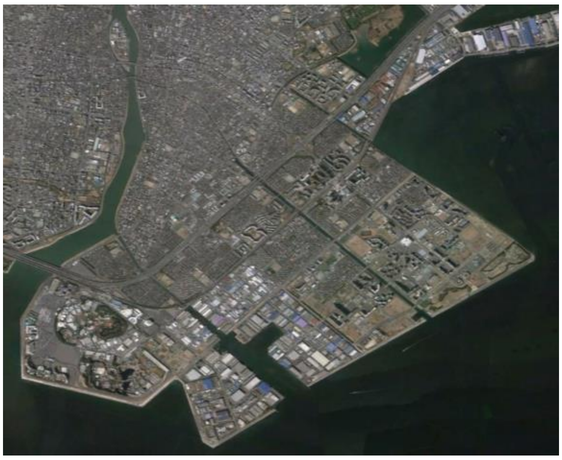
Figure 1 shows the relationship between the number of buildings and the sewer pipeline length in 250m grid cells, used in a damage assessment study of Chiba prefecture (2008). There exists almost linear relationship between the two although no direct relationship in general. The building data were produced by local governments from taxation data, and thus they are reliable and were used as the basic data for in the damage assessment study. On the other hand, sewer and water pipeline length data were made from the building data so that they were in proportion to the building density.

In the case of this estimation method, only the number of buildings within the grid cell affects the estimated pipeline length. Therefore the urban land-use such as a business district or a densely built-up residential area is not considered. In other words, the estimated pipeline length is overestimated in densely built-up areas, and underestimated in low density areas. This is an important issue affecting the accuracy of damage assessment, but often not be recognized. For this reason, we propose a method to estimate the sewer pipeline lengths within grid cells from road network data.

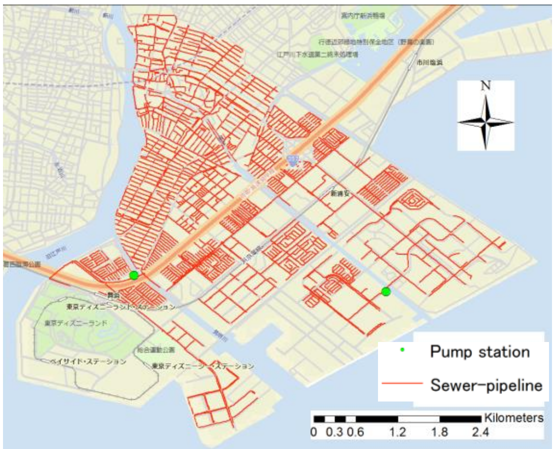
METHOD TO ESTIMATE SEWER PIPELINE LENGTH WITHIN A GRID CELL

Kobayashi et al. (2013) indicated that water pipelines are generally buried under public roads and thus they are collocated. Using water pipeline data in Sendai city, Miyagi prefecture, they proposed the method to estimate water pipeline lengths within 250 m grid cells based on the road data. They assumed that in densely inhabited districts (DIDs), one or two water pipelines are buried under a road, but outside of DIDs, water pipelines are buried under roads along which buildings stand. The similar situation is expected for sewer pipeline systems.

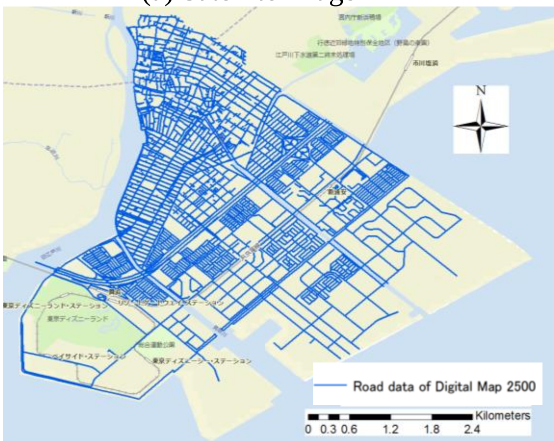
Based on the method, this study examines the correlation between the water pipeline and road lengths within grid cells using the detailed GIS data of Urayasu city, Chiba prefecture, Japan. Since Urayasu has separate waste-water and drainage-water systems, only the lengths of waste-water pipelines were estimated in this study. The sewer pipeline network of Urayasu city on GIS is shown in Figure 2 (b). Road networks in the Digital Map 2500 (2006) and IPC road data (2009) were employed for comparison as shown in Figure 2 (c) & (d). Then the detailed position relations between the roads and sewer pipelines are analyzed on a GIS and the method to estimate the sewer pipeline length within 250m grid cells is proposed based on the road network data.



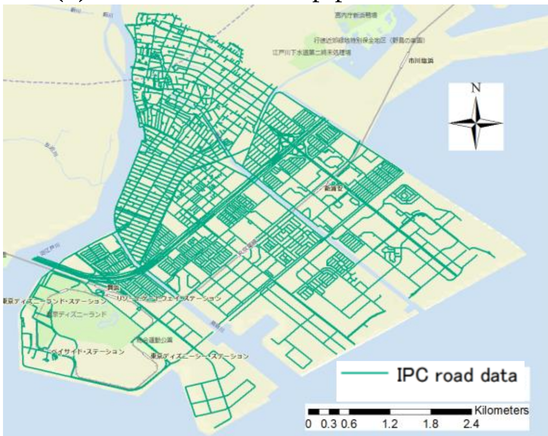
(a) Satellite image



(b) The data of sewer pipeline



(c) The road data of Digital Map 2500



(d) IPC road data

Figure 2. Sewer pipeline and road network data in Urayasu city on GIS

ESTIMATION OF SEWER PIPELINE LENGTH FROM ROAD LENGTH

In Japan, the service rate of sewerage was 76.3% in 2013 while that of potable water was 97.7% in 2012. This means in rural areas, waste water is treated by a septic tank on site and then released to a river system. In addition, there are fewer data on sewerage systems than those of water in the National Land Numerical Information download service. Therefore, following the method by Kobayashi et al. (2013), the service area of sewerage treatment was estimated using the DID as an indicator.

The DID is one of the statistical district sets in the national census of Japan. The DID is considered as an urban area where buildings stand consecutively or is occupied by other urban land uses. Hence, it is thought that there is a high demand for a sewer system. The boundary data of a DID area can be downloaded from the Digital National Land Information (DNLI) download service, and thus anyone can use it easily.

Relationship between the lengths of roads and sewer-pipelines within grid cells

In Urayasu city, the almost entire areas are designated as DIDs, and the coverage rate of sewerage is 99.6% in 2014. Thus it is assumed that sewer pipelines are buried in almost all the roads in Urayasu city. Figure 3 plots the relationship between the sewer pipeline lengths and the road lengths within 250m grid cells in Urayasu city using the road data in Digital Map 2500. The correlation coefficient

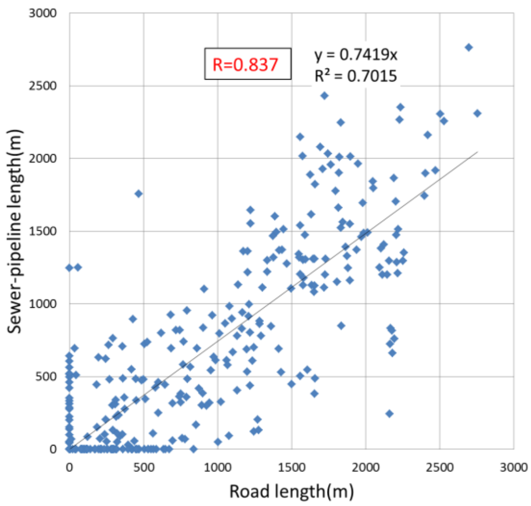


Figure 3. Comparison of the road length of Digital Map 2500 and the sewer pipeline length in 250m grid cells (in Urayasu)

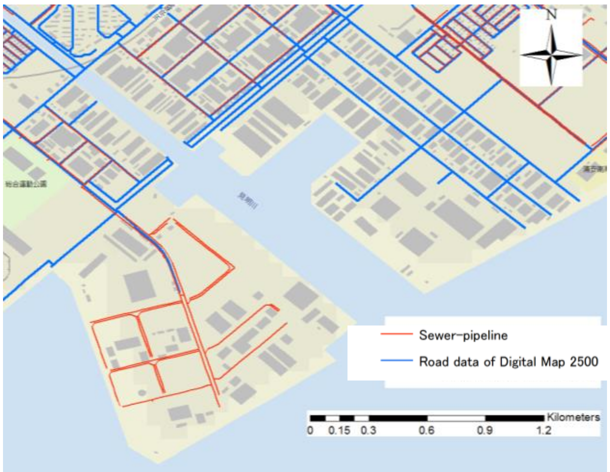


Figure 4. Comparison of the sewer lines and the road data of Digital Map 2500 in the southern part of Urayasu city.

is rather high as *r*=0.837, but some differences are seen between the length of roads and that of sewer pipelines in the 250 m grid. There exist grid cells in which a difference between them is large, and thus the details of differences were examined in GIS.

The grid cells where sewer pipeline lengths are zero in Figure 3 indicate areas without a sewer service, which is seen as those only blue lines in Figure 4. On the contrary, the cells where the road length is much shorter than that of sewer are seen in the southern coastal zone in Figure 4. Furthermore, two or more sewer pipelines are sometimes buried under one road. These differences may be partially related to the time difference between these line data were prepared.

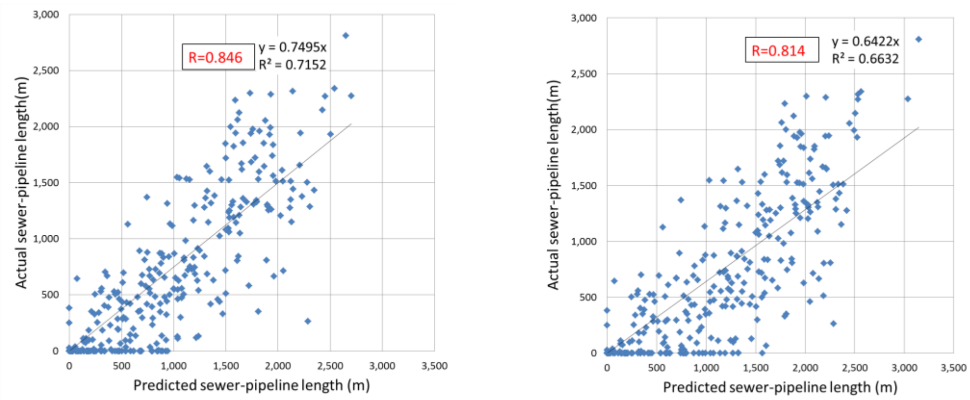
Estimation of sewer-pipeline lengths in consideration of road width

To improve the accuracy in estimation of sewer pipeline lengths, the IPC road data for car navigation systems was introduced because more detailed information of roads are included. It is considered that roads under which two or more sewer pipelines are buried have large widths with multiple lanes and center dividers. In fact, such estimation was confirmed on GIS, and hence this observation was introduced when counting sewer line lengths underneath broad roads.

The IPC road data includes attribute information such as owner, category, the number of traffic lanes, width etc. for each road. The both the number of traffic lanes and road width are given as the attributes related to the road width, the road width (m) was used in this study because the traffic lanes data was not always available. The road width data consists of 5 classes as: less than 3.0m, 3.0m-5.5m, 5.5m-13.0m, 13.0m or more, and no data.

Figure 5 (a) shows the case that the road lengths equal to the estimated sewer pipeline lengths using the IPC road data, and Figure 5 (b) shows the case that the estimated sewer length was estimated by doubling the length of a road with a width of 13.0 m or more. As a result of considering the road width in this way, the correlation coefficient has fallen down. The estimation accuracy of water pipeline lengths in Sendai city was improved by this method in Kobayashi et al. (2013), but in the case of sewer pipeline in Urayasu city, this correction did not work well.

The reason for this discrepancy may be explained by the difference in the urban circumstance and road data between Sendai and Urayasu. In general, water distribution systems have redundant networks (plural lines) so that the service can be continued in emergency situations. This is thought to be one of the differences between water and sewer systems. In addition, the two road data sets used in this study sometimes express the same road in a different manner. As shown in Figure 6, the road with a large dividing green is represented as two roads in the IPC road data while one road in the Digital Map 2500. It is necessary to consider such issues in estimating lifeline lengths from road data in the future.



(a) Road length equal to sewer pipeline length (b) Road length times two for wide roads

Figure 5. Estimation of sewer pipeline lengths within 250m grid cells using the IPC road data

Figure 6. Example of different expressions of large width roads in the two road data

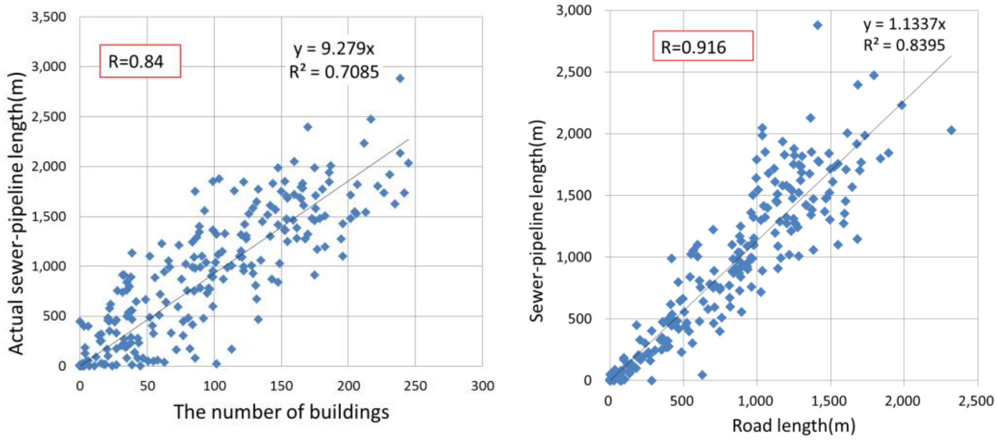
Examination on the removal of dead-end roads in residential areas

The total length of the IPC road data is 311 km, that of the Digital Map 282 km, and that of sewer pipeline 213 km in Urayasu city, all showing quite different values. Therefore, to improve the accuracy of estimation of sewer pipeline lengths, it is necessary to consider the buried status of sewer pipelines under each road in detail. Especially when using the IPC road data, it is much longer than sewer pipeline length, which indicates the IPC road data includes private roads where public sewer pipelines are not buried. Hence, the method to exclude such private roads from IPC data was sought.

Figure 7 shows roads and sewer pipelines around the Urayasu subway station on GIS. Many cases that sewer pipelines are not buried under dead-end roads in residential areas could be confirmed. These dead-end roads are considered to be private ones, and thus sewer pipelines were not listed in sewer line inventory of the city although their extensions are actually buried. Thus we tried to exclude such dead-end roads in residential areas.

In order to extract residential areas, the land-use regulation data in the DNLI was used. In this study, dead-end roads were excluded for Category 1 residential districts. The number of 250m grid cells in Urayasu city was 346, and the number of grid cells where dead-end roads were excluded was 112 with excluded road lengths of 13,101m. There were 82 grid cells that the road length got closer to the sewer pipeline length by this manipulation. On the other hand, the differences between their lengths got bigger in 29 grid cells. From this result, the estimation of sewer pipeline length was improved in most cases by excluding dead-end roads in residential areas of Urayasu city.

Figure 7. Roads and sewer pipelines around the Urayasu subway station



(a) The number of buildings and road length (b) The method using road data

Figure 8. Estimation of sewer pipeline lengtha within 250m grid cells in Kashiwazaki city by the current practice from the building density (a) and from the road data (b)

VERIFICATION OF THE ACCURACY OF THE PROPOSED METHOD

The accuracy of the proposed method was verified using the data sets in other regions, comparing with the current practice. The DID areas in Kashiwazaki city, Niigata prefecture, were employed because sewer pipeline vector data and building footprint data were available (Maruyama et al., 2011). At first, sewer pipeline lengths were compared with the number of buildings within 250 m grid cells, that is used in the current practice, in Figure 8(a). The relationship between the road length, which is used as the estimated sewer pipeline length, and the actual sewer pipeline length is shown in Figure 8(b), without considering the road width. On the estimation of sewer pipeline lengths in Kashiwazaki city, the method without considering the road width had higher estimation accuracy also. The correlation coefficient was very high as 0.916 while that of the current practice was 0.840. Thus the effectiveness of the estimation method of sewer pipeline lengths using the road data was demonstrated.

CONCLUSION

In order to improve the accuracy of earthquake damage assessment for scenario events, a method to estimate sewer pipeline inventory data from road network data was investigated. Since the method to estimate pipeline length data from building density data was found to be not so accurate, a correlation analysis was carried out to estimate the sewer pipeline length within a grid cell of 250 m from the corresponding road network's GIS data. Two different road data were available for Urayasu city, Japan as well as sewer pipeline vector data. From the two road datasets, the IPC road data was used for sewer inventory data estimation since it includes road width information. But some private roads were also included in the IPC data, and hence dead-end roads in residential areas were excluded since sewer lines underneath private roads were not in the municipality’s database. After these manipulations, the estimation result got higher accuracy. Finally, the accuracy of the proposed method was verified using the data in densely inhabitant districts (DIDs) of Kashiwazaki city. Compared with the result from the current practice, estimation from building density, the proposed method showed much better estimates. Hence, if buried pipeline data must be estimated from some other data source in earthquake damage assessment, it is better to use road network data than to use building density data.

ACKNOWLEDGMENTS

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