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DAMAGE ANALYSIS OF WATER SUPPLY PIPES DUE TO THE 2004 NIIGATA-KEN CHUETSU, JAPAN EARTHQUAKE

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ABSTRACT

The present paper describes a Geographic Information System (GIS)-based analysis of water supply pipe damage due to the 2004 Niigata-ken Chuetsu Earthquake in Cities of Nagaoka and Ojiya, Niigata Prefecture. GIS was used to not only visualize, but also analyze the damage distribution overlaying geomorphologic classification, liquefaction and landslide maps. The results of the analysis show that damage to the pipes was concentrated within alluvial fans and gravelly terraces along the boundaries of geomorphologic map units, such as between alluvial low lands and terraces or hills in the western zone along the earthquake source fault. The average damage rate in the liquefaction zones is 1.5 times higher than that in other regions in Ojiya city.

Introduction

Extensive damage to lifeline systems occurred in cities due to the 2004 Niigata-ken Chuetsu earthquake. It is important to clarify the relationship between pipeline damage and factors showing ground condition such as geomorphologic classifications and ground failure such as liquefaction or landslide. A Geographic Information System (GIS) provides a useful tool to relate damage distribution to other factors by location. Analyses of lifeline damage using overlaying layers in GIS have been conducted in the decade following the 1995 Hyogo-ken Nanbu earthquake (Japan Water Works Association 1996, Isoyama et al 1998). However, for improved damage assessment which can apply to all over Japan, further analysis of lifeline damage using a unified ground condition map is needed.

After the Chuetsu earthquake, data sharing using web-based GIS was attempted to support the disaster area (Sawada et al. 2005). Information on damage, recovery or evacuation was accumulated and entered on this site. However, data on lifeline damage was insufficient. A similar trial, which was conducted using another web-based GIS, provided landslide data and was open to the public (Geographical Survey Institute 2004). If such open data were available not only as web-based information but also in desktop PC database format, it could be used in

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many applications, such as earthquake damage analysis.

The current study analyzes water supply pipeline damage due to the 2004 Niigata-ken Chuetsu earthquake using GIS and the GIS databases that were open or available. The target cities in this study are Nagaoka and Ojiya in Niigata prefecture, where large-scale damage of lifeline systems was reported.

One of layers in the GIS database is a geomorphologic classification map which is based on the new engineering-based geomorphologic classification scheme and covers large area including large cities in Japan. Using this map, we conduct basic damage analysis and aim to build a new damage estimation method for water supply pipes applicable to all over Japan.

Data for Analysis

The damage and water pipeline data that was provided by local governments had not yet been entered into GIS, thus we were required to enter the offered printed data into GIS. Some vector data, including a geomorphologic classification map (Wakamatsu et al. 2005a), and distribution of liquefaction (Wakamatsu et al. 2005b) and landslide (Geological survey institute 2005) data were available for GIS analysis. The digital databases were built by each researcher in the early stage of the study, after the damage survey.

Table 1 shows the water supply pipeline damage data, and the pipeline network and other maps that we used for the analysis. The damage locations were plotted as points and the pipeline network was digitized as polylines using image maps. Since the liquefaction and landslide distribution map was expressed by point or line, these data needed to be converted into regions for overlay analysis with damage location points. Buffer regions were created using these data within 200 meters radius for liquefaction and 50 meters radius for landslide.

The location of the target area of this study is shown in Fig. 1. In this figure, the hypocenter and the estimated earthquake fault are overlaid. Figures 2 to 4 show the thematic maps used to analyze the damage: a geomorphologic classification map, and distribution maps of liquefaction and landslide.

Table 1. Water supply pipe damage and other factors data for GIS analysis.

Data name	District	Explanation
Water supply pipeline damage map	Nagaoka city	Printed map where pipeline damage locations are plotted.
Water supply pipeline damage map	Odiya city	Printed map where pipeline damage locations are plotted.
Attributes of water supply pipeline damage	Odiya city	Digital sheet including pipeline information, state of damage, date of repair, etc.
Water supply pipeline network map	Odiya city	Printed maps of pipeline network.
Geomorphologic classification map	Niigata prefecture	250 m grid cell map for GIS, including 21 classifications. (Wakamatsu 2005a)
Liquefaction distribution map	Disaster area	Point data for GIS, based on field surveys and aerial photograph analyses (Wakamatsu 2005b)
Landslide distribution map	Disaster area	Polyline data for GIS, interpreted from aero photographs (Geological Survey Institute 2004)

Analysis Procedures

The analysis was executed using the following procedures.

(1) Collecting data and maps with water supply pipe damage and water supply network information.

(2) Collecting maps that provided data on crucial factors contributing to the damage.

(3) Entering the damage maps and data into GIS.

(4) Overlaying damage and water pipe network layers on the factor layers in GIS.

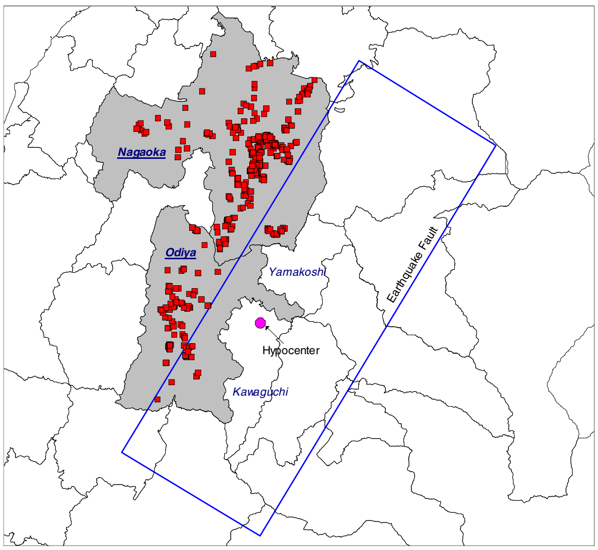

Figure 1. Distribution of water supply pipeline damage. (gray area: research target)

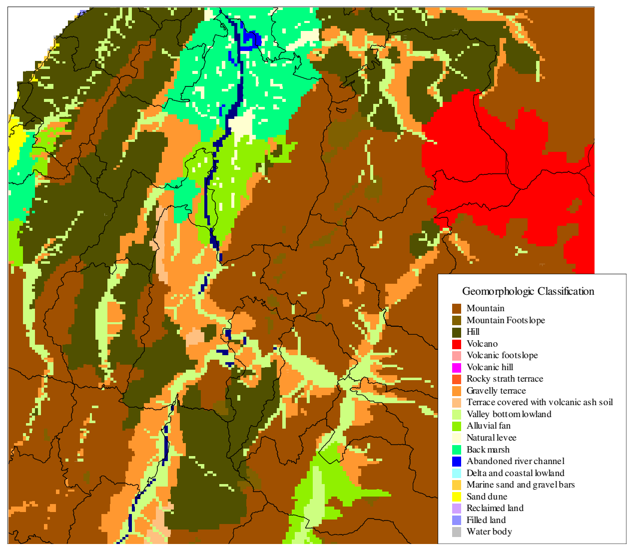

Figure 2. Geomorphologic classification map.

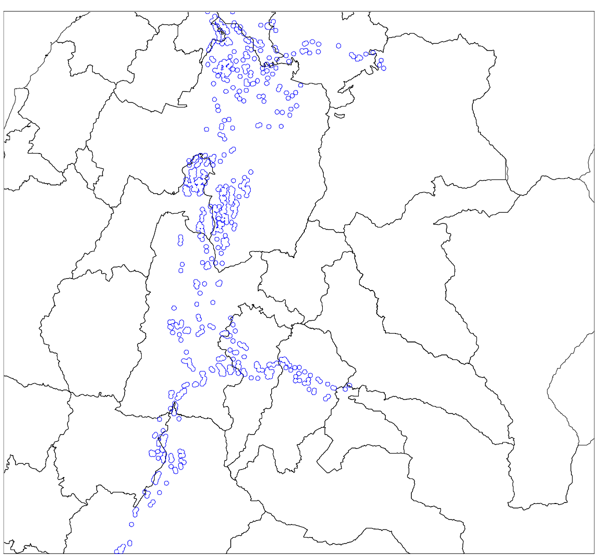

Figure 3. Distribution of liquefaction.

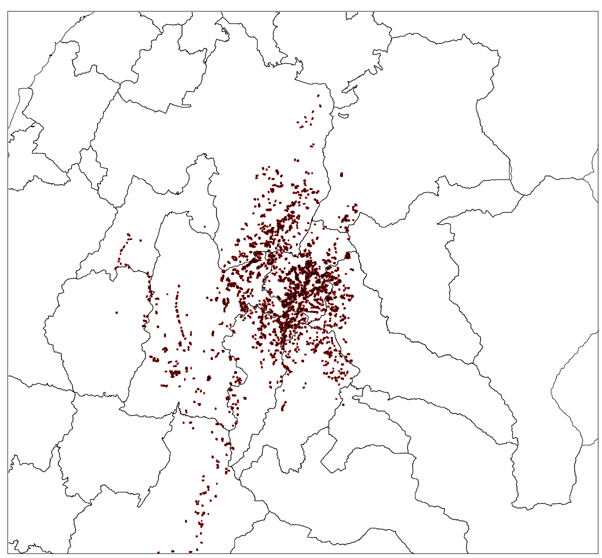

Figure 4. Distribution of landslides.

Analysis Results

Distribution Characteristics of Damage, Geomorphologic Classification and Earthquake Fault

Overlaying Figs. 1 and 2 in GIS reveals the distribution characteristics of water supply pipeline damage based on the geomorphologic classification map and earthquake fault locations. Namely, the severely damaged zone is distributed in the buffer zone along the earthquake fault to the west. Within the zone, the damage locations are focused at the boundaries between geomorphologic classifications, such as between alluvial fans and gravelly terraces, or gravelly terraces and hills.

The extensive ground motion is assumed to have caused significant soil strain in artificially altered land within the geomorphologic boundary zones, as is evident in the damage distribution. In general, the boundary zones of geomorphologic classifications correspond to slope zones, which are developed into residential areas.

Distribution Characteristics between Damage, Liquefaction and Landslide

Liquefaction zones are spread widely, not only along the alluvial plains but also on terraces. The overlay analysis of damage and liquefaction indicates that 16 percent of Ojiya city is within the liquefaction zone, and 8 percent of Nagaoka city is within the liquefaction zone.

In contrast, landsides had little effect on water supply pipes. Overlaying the landslide map on the damage distribution reveals only 2 damaged sites in Ojiya city and 10 damaged sites in Nagaoka city located within the hazard zone because most landslides occurred in the mountains or on hills. However, lifelines were severely damaged due to landslides in areas such as the new town of “Takamachi,” located on a hill in Nagaoka city.

Extent of Damage and Geomorphologic Classification

In Nagaoka city, water supply pipeline network information was not collected. Thus the total number of damaged areas in the two cities is summarized according to geomorphologic classification. Table 2 shows the results of this analysis. Most of the damage is in the alluvial fan, followed by the gravelly terrace. On the whole, the number of damage sites in the alluvial plain (below “valley bottom lowland” in table 2) is nearly the same as those in mountainous, hilly and terrace areas. For reference, average damage rate per area (km^2) for each geomorphologic classification is also shown in Table 2.

Next, restricting the data to Ojiya city, the average damage rate per pipeline length (km) in each geomorphologic classification was computed. Table 3 shows the results. The damage rate on terraces with volcanic ash, alluvial fans and hills is higher than in other classifications. The classifications with higher damage rates were found to have shorter segments of pipeline. More damage information should be added for these classifications to obtain higher reliability.

The average damage rate due to the 1995 Hyogo-ken Nanbu earthquake was about 0.93 (number of damage sites/km) in the cities of Kobe, Nishinomiya and Ashiya (Japan Water Works Association 1996), whereas the total average damage rate in Ojiya city is 0.31 (Table 3). Thus the damage rate due to the Niigata-ken Chuetsu earthquake is less than that from the Hyogo-ken Nanbu earthquake. To compare damage rates due to these two earthquakes according to the geomorphologic classifications, the same geomorphologic classification map should be used.

Damage Rate within Liquefaction zones

In Ojiya city, the number of water supply pipeline damage sites and the length of pipelines were summed up separately, in and out of the liquefaction zone. The average damage rate (number of damage sites/length of pipeline) of each zone was computed. Table 4 shows the results. The damage rate in the liquefaction zones is 1.5 times higher than in other zones. To confirm this tendency using the 250 meter grid cells, we computed the damage rate for each grid cell. Table 5 shows the results. The average of the damage rates within liquefaction zones is 3 times higher than that of the other zones, and the standard deviation of damage rates in liquefaction zones is much larger than that of the other zones.

Relationship between Damage Rates and Pipeline Age

It was reported that older pipelines should be changed to improve earthquake resistance (Ministry of Health, Labor and Welfare 2005), however few studies have analyzed the relationship between pipeline age and the damage rate. Figure 6 compares the damage rate to the age of pipelines in Ojiya city. The damage rates of pipelines laid before 1974 were confirmed to be higher than those installed after 1975.

Table 6 shows the average damage rates classified by pipeline age and the three geomorphologic classifications, including pipelines laid before and including 1974 (referred to as “before 1974”) and beginning with 1975 (referred to as “after 1975”). The damage rates in gravelly terraces and valley bottom lowlands before 1974 are higher than those after 1975. The total damage rate before 1974 is more than 3 times higher than that after 1975. This shows the importance of both, the pipeline installation age and the geomorphologic classification.

Table 2. Water supply pipeline damage rate per area for each geomorphologic classification in Nagaoka and Ojiya cities.

Geomorphologic classification	Number of damage sites	Area (km^2)	Damage rate (number/km^2)
Mountain	56	120.4	0.46
Mountain foot slope	5	2.6	1.95
Hill	50	70.5	0.71
Gravelly terrace	94	69.2	1.36
Terrace with volcanic ash soil	5	7.0	0.71
Valley bottom lowland	26	21.0	1.24
Alluvial fan	121	34.8	3.48
Natural levee	21	13.0	1.62
Back marsh	45	68.5	0.66
Total	423	407.0	1.04

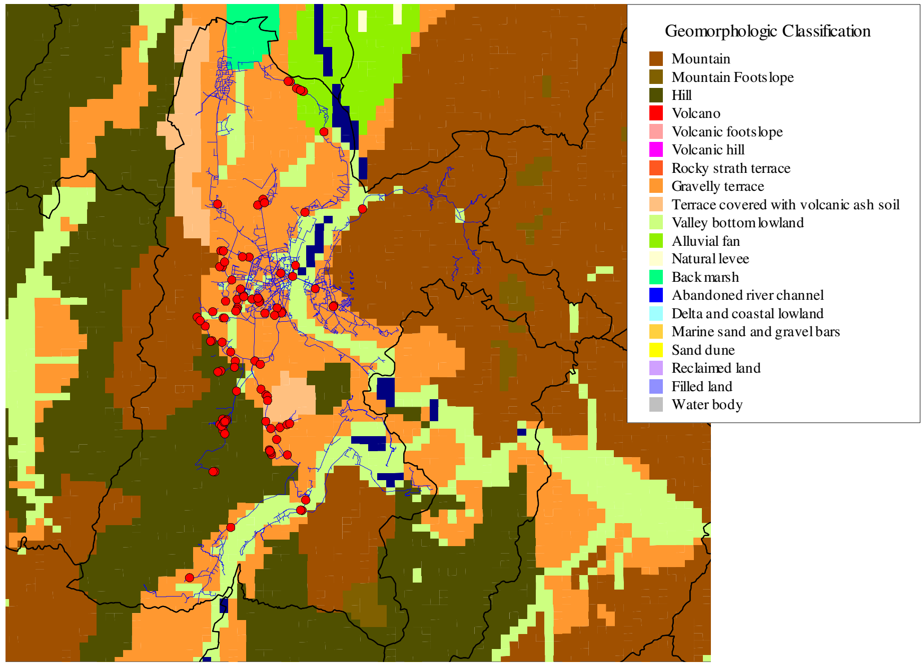

Figure 5. Distribution of damage and pipelines in Ojiya city.

Table 3. Water supply pipeline damage rate by geomorphologic classification in Ojiya city.

Geomorphologic classification	Pipeline length (km)	Number of damage sites	Damage rate (number/km)
Mountain	24.6	3	0.12
Hill	15.4	18	1.17
Gravelly terrace	194.4	51	0.26
Terrace covered with volcanic ash soil	3.0	5	1.68
Valley bottom lowland	63.7	13	0.20
Alluvial fan	4.2	5	1.20
Back marsh	2.0	0	0.00
Total	307.2	95	0.31

Table 4. Water supply pipeline damage rate for liquefaction zone in Ojiya city.

Division	Length of pipelines (km)	Number of damage sites	Damage rate (number / km)
In the liquefaction zone	31.8	15	0.47
Out of the liquefaction zone	273.1	80	0.29

Table 5. Grid-based damage rate for liquefaction zone in Ojiya city.

Division	**Average of damage rates (num. / km)**	**Standard deviation**	**Number of damage sites**
In the liquefaction zone	1.01	10.2	230
Out of the liquefaction zone	0.33	1.8	492

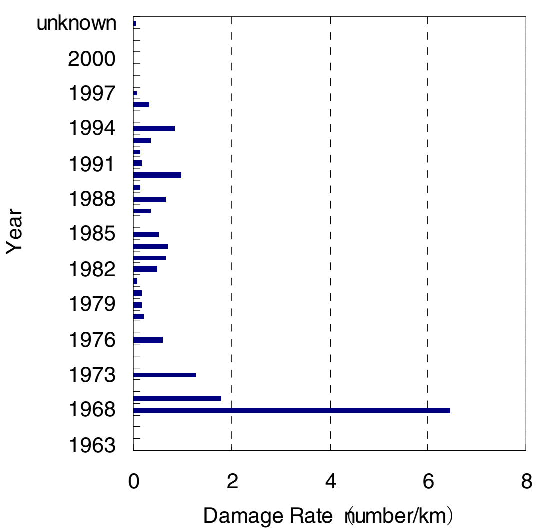

Figure 6. Damage Rate per Year in Ojiya

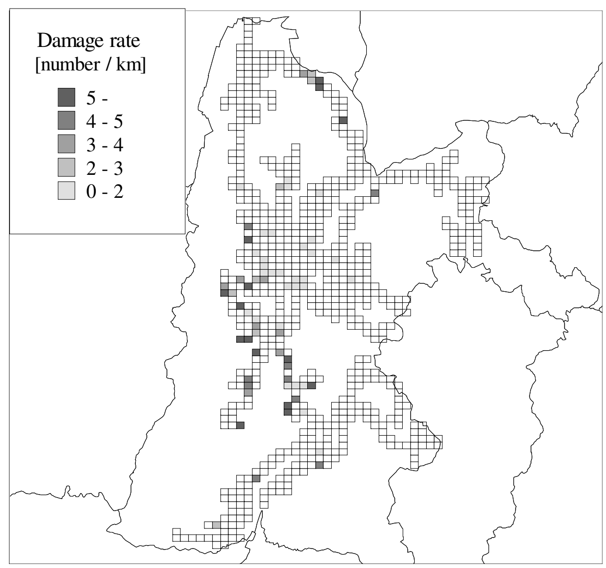

Figure 7. Damage Rate to each Grid in Ojiya

Table 6. Water supply pipe damage rate by year of pipeline installation and geomorphologic classification in Ojiya city.

Year of pipeline installation		**Geomorphologic classification**			**Total**
		Gravelly terrace	**Terrace with volcanic ash soil**	**Valley bottom lowland**	
Before 1974	Number	3	0	1	4
	Length	3.4	0.5	0.4	4.4
	Damage rate	0.89	0.00	2.29	0.92
After 1975	Number	48	5	12	65
	Length	191.0	2.4	63.2	256.7
	Damage rate	0.25	2.05	0.19	0.25
Total	Number	51	5	13	69
	Length	194.4	3.0	63.7	261.0
	Damage rate	0.26	1.68	0.20	0.26

Relationship between Grid-based Damage Rates and Density of Pipeline Distribution

Grid based damage rates in Ojiya city are shown in Fig.7. Grid based spatial densities of water supply pipelines are shown in Fig.8. Fig. 7 confirms that grids with higher damage rates are distributed outside of the central zone in Ojiya city. On the other hand Fig. 8 indicates that the grid based densities of pipeline distributing outside of the central zone are lower than those in the central zone. Table 7 shows the average damage rate to classes of pipeline density. Two kinds of damage rate are computed, one is total average damage rate and the other is average of grid-based damage rate. Both of them show the same tendency that as the density of pipelines decreases, the higher damage rates become.

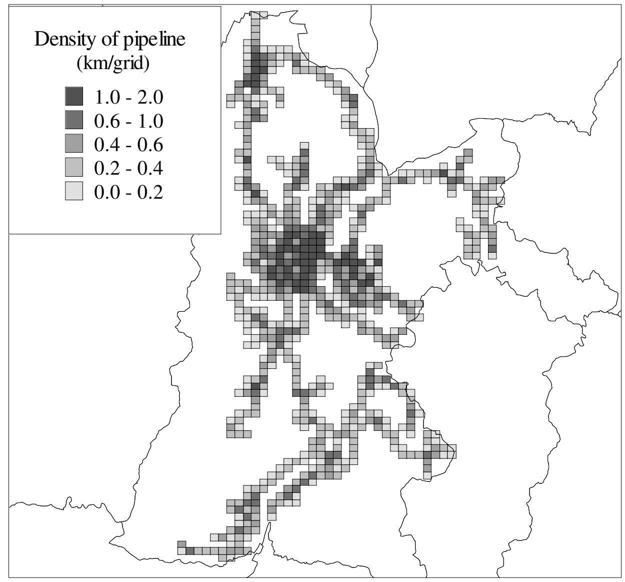

Figure 8. Distribution of spatial density of water supply pipes in Ojiya city.

Table 7. Water supply pipe damage rate by density of pipeline distribution in Ojiya city.

Density of pipeline (km / grid)	**Total damage rate (number / km)**	**Grid-based damage rate (number / km)**
0.00～0.25	0.95	18.2
0.25～0.50	0.33	3.9
0.50～0.75	0.35	2.2
0.75～2.00	0.20	1.3

Conclusions

Using GIS, the damage to water supply pipelines during the 2004 Niigata-ken Chuetsu earthquake was compared with available maps of factors contributing to damage. The damage rate in the liquefaction zone is higher than in the other zone. The damage rate of pipelines laid before 1974 is higher than that of newer ones. Landslides, identified by the interpretation of aero photographs, had less impact on pipeline damage because most landslides occurred in mountainous areas.

Grid-based damage rates per pipeline length were computed in Ojiya city, and the relationship between the damage rates and density of pipeline distribution was confirmed. This tendency should be accounted for in pipeline damage estimation methods.

In the future, we plan to analyze more damage data for water supply pipelines, including those from the 1995 Hyogoken-nanbu earthquake, to develop a universal method of estimating pipeline damage applicable to all of Japan.

Acknowledgments

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