e. Tokura water source (figure 4)

Located about 500m inland from the coast and which was used as a primary water source for the Tokura Water Treatment Facility, which provided water to about 680 households in the Tokura area which stretches to the east and west (from Rikuzen Tokura station to Kamiwarizaki station on the Kesennuma line). Water pumped from the water source was immediately chlorinated before then being made available to households. The treatment capability was 1,057 m^3/day (614 m^3/day in fiscal 2009), or quite a large volume of water.

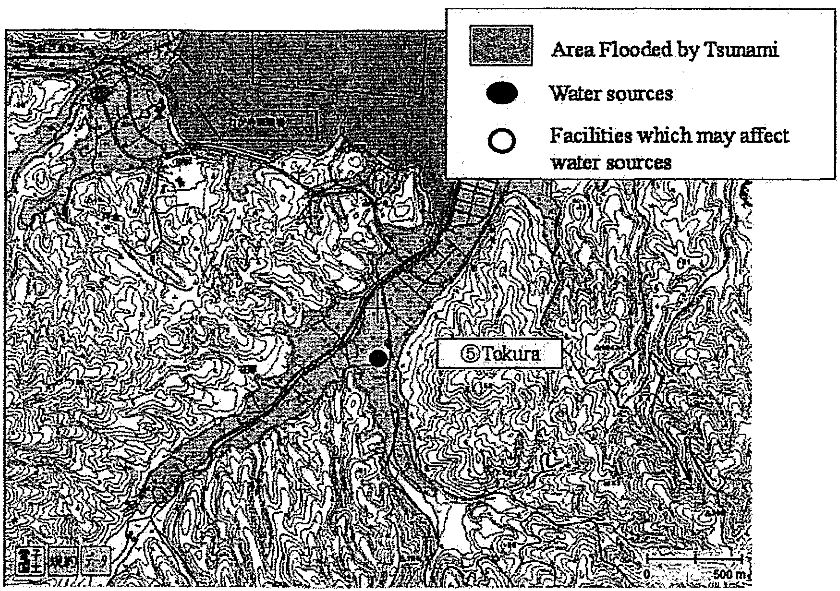


Figure 4. Location of Tokura water source
(Reference: Association of Japanese Geographers HP)

(2) Expected effects of the tsunami on the water sources

The tsunami resulting from the Great East Japan Earthquake, as reported by the Japan Metrological Agency, rose as high as 15m in Minamisanriku-cho. The areas we surveyed are mostly at most about 10m above sea level (as predicted by a digital map provided by the Geospatial Information Authority of Japan). All the wooden buildings in the areas were completely destroyed. Only the frames of reinforced concrete and steel frame buildings remained and we couldn't tell what they actually looked like prior to the disaster. Every existing water source was completely flooded by the tsunami and the total amount of chloride ions had increased, and gasoline, pesticides, and human excreta had also possibly contaminated the water sources from nearby gas stations and houses.

In addition, the ground level near every water source had sunk 0.6 to 0.7m after the Great East Japan Earthquake. This then led to the possibility of the underground water source having been changed, and the effect of a change in the tide level was causing the chloride ion concentration to fluctuate.

For this reason we concentrated on surveying the situation with contamination at each of the water sources via use of water quality tests and monitored the change in chloride ion concentrations.

(3) Period and content of the survey

The period and main content of the survey are shown in table 1. Surveys took place a total of four times during August through to November in 2011 via water quality survey teams being dispatched to the field. The surveys mainly focused on water quality analysis, and during the 1st and 2nd surveys the teams conducted simplified tests in the field (on the chloride ion concentrations, smell, turbidity, pH, etc.) and returned with some samples to the Yokohama Waterworks Bureau for detailed examination of water quality standard items and agricultural chemicals, and to check for the possibility of contamination. During the 3rd and 4th surveys a decreasing tendency with the chloride ion concentration was mainly investigated, and a conductivity meter installed as an alternative indicator at the water sources in thereby enabling the concentration level to be constantly monitored.

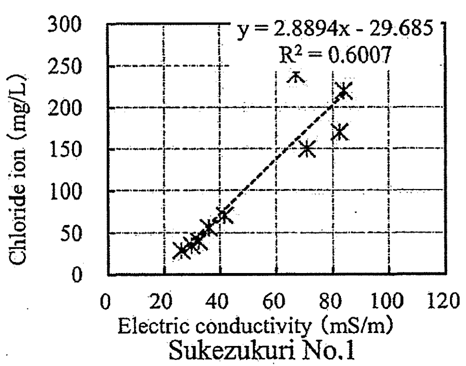
With any of the water sources whose chloride ion concentrations had not decreased enough (Sukezukuri and Isatomae water sources) the decision was made to continue to monitor the transition of the concentration levels after December 2011, with the water and sewage services division of Minamisanriku-cho then being entrusted to install a compact conductivity meter and continue the survey.

TABLE Ⅰ. Period and main content of each survey

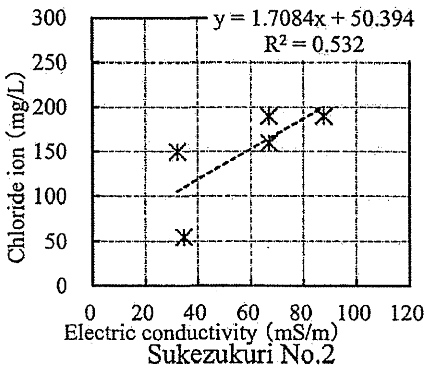
	1st Survey	2nd Survey	3rd Survey	4th Survey	Continuous Survey
Period	2011.8.8~8.12	2011.9.26~9.30	2011.10.17~10.21	2011.11.13~11.16	2011.12~2013.3
Method	Dispatched survey team to the site and examined water quality				Constant monitoring of electric conductivity was conducted by compact conductivity meters
Target water source	Sukezukuri No.1,Sukezukuri No.2, Isatomae				
	Tajiribatake, Tokura				▨
	Komori			▨	▨
Item of water examination	• Water quality standard items(27items) •Salt concentration, etc.(5items) •Anaerobic spore-forming bacteria •Agrichemicals (70items)	• Water quality standard items (23items) •Langelier's index •Salt concentration, etc.(6items) •Radioactive substances (3items)	• Water quality standard items(23items) •Salt concentration, etc.(5items)	• Water quality standard items(13items) • Salt concentration, etc.(4items)	•Chlorine ion, Sodium ion
Other Survey		•Constant monitoring of electric conductivity (Sukezukuri No.1)	•Constant monitoring of electric conductivity (Sukezukuri No.1,No.2, Isatomae)	•Constant monitoring of electric conductivity (Sukezukuri No.2, Isatomae)	• Constant monitoring of electric conductivity (Sukezukuri No.1,No.2,Isatomae)

(4) Electric conductivity measurement as an alternative indicator of chloride ion concentrations

Figure 5 shows the correlation between the chloride ion concentration and electric conductivity. As the figure reveals there is a high correlation between the chloride ion concentration and electric conductivity, with the slope being about 3. This confirms that electric conductivity can be used as an indicator of the chloride ion concentration. The decision was therefore made to install compact electric conductivity meters at the water sources in thereby enabling constant measurement of the transition in the chloride ion concentration, being in addition to periodic manual analysis.



Sukezukuri No.1



Sukezukuri No.2

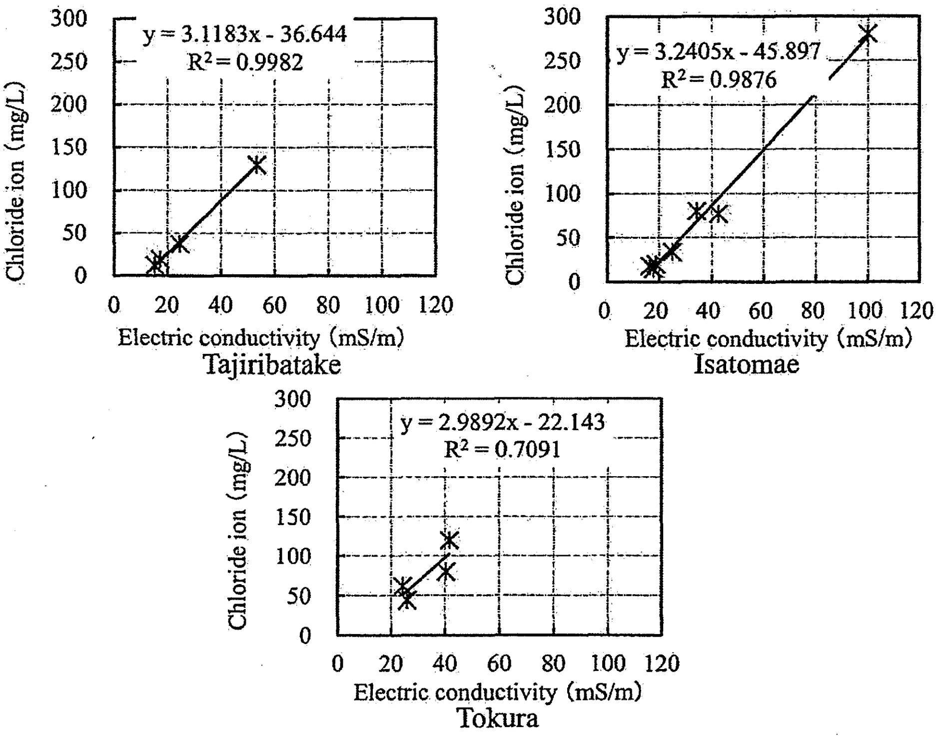


Figure 5. Correlation between chloride ion concentration and electric conductivity

3. RESULTS OF THE SURVEY

(1) Outline of the situation with contamination from nearby facilities.

The results of surveying the situation with contamination from nearby facilities are as follows:

a. Contamination from toxic substances

Surveys made by Minamisanriku-cho revealed the Sukezukuri No.1 and No.2 water sources to contain 0.002mg/L of arsenic immediately after the disaster (11 April, 2011). However, the first survey, which was conducted on August 2011, detected no toxic substances at all the water sources, and hence the increase in concentration was considered temporary and due to diastrophism from the disaster.

In thereby investigating the situation with contamination from radioactive substances released during the accident that occurred at the Tokyo Electric Power Company Fukushima Daiichi Nuclear Power Station the second survey measured the concentrations of 3 radioactive nuclides (namely Cs134, CsI137, and I131). The results revealed no radioactive substances (detection limit 10Bq/kg) and thus confirmed that there was no effect from radioactive substance contamination.

b. Contamination from pesticides or human excreta

The first survey that took place in August 2011 revealed no pesticides in any of the water sources. No anaerobic spore-forming bacteria, which indicate contamination from human excreta, etc. to have occurred, were detected either and the ammonium nitrogen level was less than 0.1mg/L. For this reason the possibility of the raw water having been contaminated by pesticides or human excreta was considered to be very low.

c. Contamination from gasoline

No petroleum components were identified in any of the water sources, thus confirming contamination from gasoline to be negligible.

d. Effects of water hardness on the piping

All the water sources were of higher hardness levels due to the effect of the seawater, thus making separation of the hardness components within the piping system a matter of concern. The Langelier Saturation Index was therefore calculated as part of the second survey. The results, however, were between -1.3 and -1.4, thereby indicating no separation would occur.

We concluded that none of the water sources had been contaminated by the nearby facilities. The results indicate that the water sources can be reused again once their chloride ion concentrations have decreased.

(2) Situation with the chloride ion concentration

Table 2 and Figure 6 reveal the trends of the chloride ion concentrations of the 6 water sources surveyed. After the disaster all the water sources had higher chloride ion concentrations than water quality standards allow for (200mg/L) due to the effect of the tsunami, but later on they gradually decreased, and 8 months after the disaster (November 2011) they were below the water quality standards at all the water sources.

The trend of a decrease, however, was not uniform. At the Sukezukuri No.1 and No.2 water sources the concentrations decreased exponentially, whereas concentration level at the other water sources significantly fluctuated for a while after the disaster. In addition, tests that took place after the heavy rain resulting from the typhoon of 27 September, 2011, revealed increased chloride ion concentrations at all the water sources. This then indicated the possibility of residual salt content in the soil having flowed into the underground water sources after the rainfall, thereby causing the chloride ion concentrations to repeatedly fluctuate.

At the Komori, Tajiribatake and Tokura water sources the chloride ion concentrations were below the water quality standard one month after the disaster (April 2011). At the Sukezukuri and Isatomae water sources, however, the concentrations had remained at relatively high levels. At the Sukezukuri water source, in particular, the concentration was about three times higher than before the disaster even 2 years after the earthquake (February 2013). This was considered likely to have resulted from the earthquake induced subsidence having caused the underground water source to have changed, thus leading to the water source being affected by the tide. If that were true then the chloride ion concentration may change in accordance with the change in tide level. Tidal changes include short-term changes in which the tide changes twice daily according to the Earth's rotation (daily change), mid-term changes which occur twice a month according to the revolutions of the moon (monthly change), and long-term changes of the period of one year according to the revolution of the earth (yearly change). The concentrations were likely to be affected by these tidal changes.

For this reason the assumption was made that the chloride ion concentration would fluctuate after rainfall or from tidal changes, and thus the decision was made to monitor the long term trend of the chloride ion concentration, and particularly at the Sukezukuri and Isatomae water sources where the chloride ion concentrations were high. The results of that are revealed on the following pages.

TABLE Ⅱ. Trends of chloride ion concentrations

Date	Chloride ion concentration(mg/L)					
	Shizugawa aria				Utatsu aria	Tokura aria
	Sukezukuri No.1	Sukezukuri No.2	Komori	Tajiribatake	Isatomae	Tokura
Before disaster (Average in 2010)	9	9	-	-	8	9
2011/3/26	302	-	-	545	248	239
2011/4/11	1330	1310	-	-	152	-
2011/4/18	921	980	22	70	127	-
2011/4/20	-	-	-	-	-	-
2011/4/25	826	990	164	144	-	-
2011/5/2	828	898	52	128	559	-
2011/5/11	815	776	23	55	238	-
2011/5/18	760	747	82	131	484	-
2011/5/25	707	726	29	-	225	-
2011/6/1	638	541	175	104	668	182
2011/6/8	611	503	99	160	325	211
2011/6/15	616	557	40	72	200	228
2011/6/21	531	419	25	49	134	212
2011/6/29	359	423	51	84	295	151
2011/7/6	417	392	53	57	205	-
2011/7/14	385	363	32	35	124	102
2011/7/22	332	314	31	27	87	-
2011/7/29	303	275	31	22	104	79

2011/8/11	240	190	26	19	80	62
2011/9/6	166	127	-	129	225	-
2011/9/27	220	160	160	130	280	120
2011/10/18	170	190	18	37	77	80
2011/11/14	150	150	-	12	34	44
2012/2/16	56	55	-	-	-	-
2012/3/22	71	-	-	-	-	-
2012/8/28	44	-	-	-	14	-
2012/10/16	35	-	-	-	15	-
2012/12/17	40	-	-	-	20	-
2013/2/26	29	-	-	-	18	-

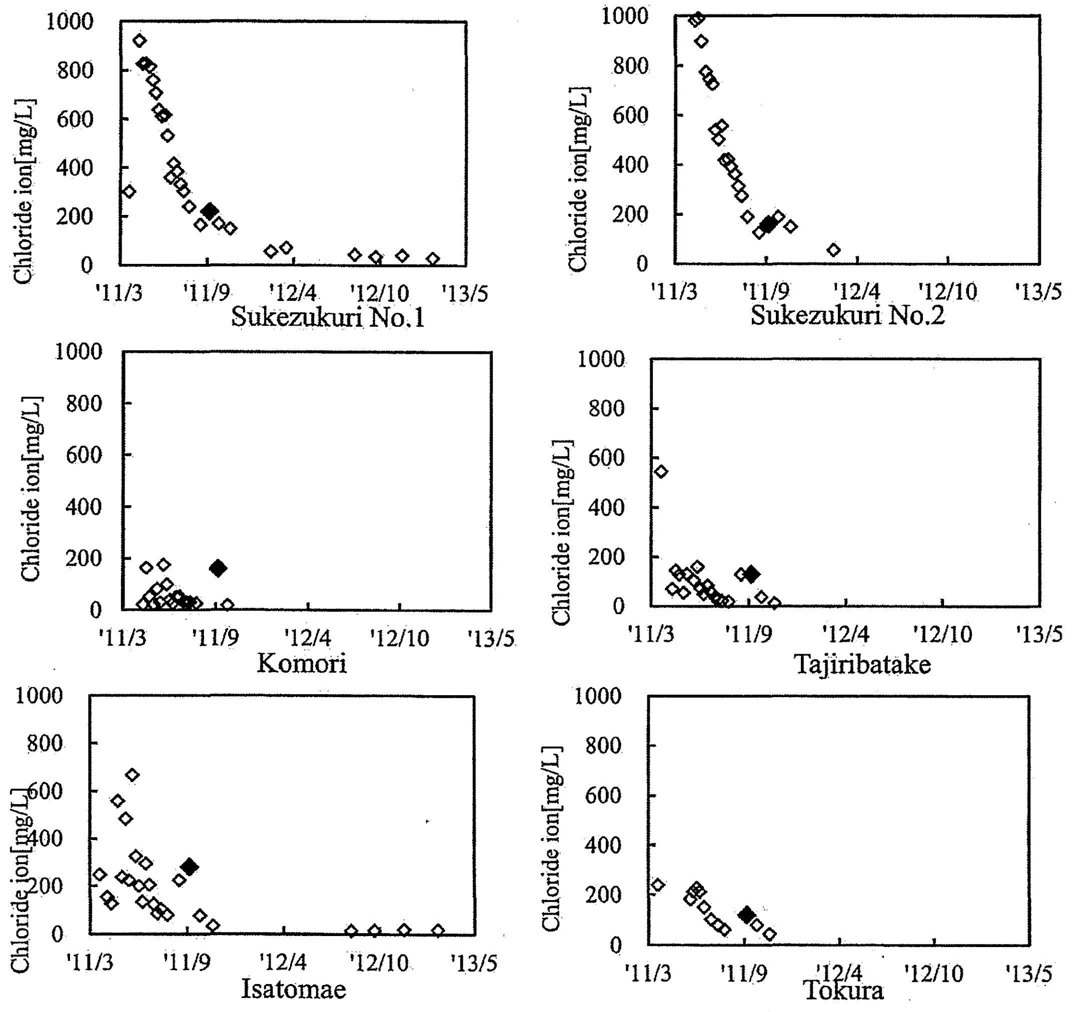


Figure 6. Trends of chloride ion concentrations
(Black mark indicates the data after the heavy rain resulting from the typhoon)

(3) Results of the surveys and future prospects with the water sources

a. Sukezukuri No.1 and No.2 water sources

Although the chloride ion concentration exponentially decreased at the Sukezukuri No.1 and No.2 water sources the level of concentration was still high when compared to other water sources, and still fluctuated around the water quality standards (200mg/L) 6 months after the disaster (November 2011). This was most likely to have been caused by the fact that the height above sea level near the Sukezukuri water source sank to the highest recorded historical tide level (1.6m) (according to a survey conducted by the Ministry of Land, Infrastructure, Transport and Tourism), thus causing the water source to be affected by the tide level. Therefore, and as an alternative indicator of the chloride ion concentration, we measured the electric conductivity of the Yahata River, which is close to the Sukezukuri water source. The result revealed the electric conductivity of the water source to be higher than that of the Yahata River, and thereby indicating the possibility of seawater reaching near the Sukezukuri water source (Figure 7).

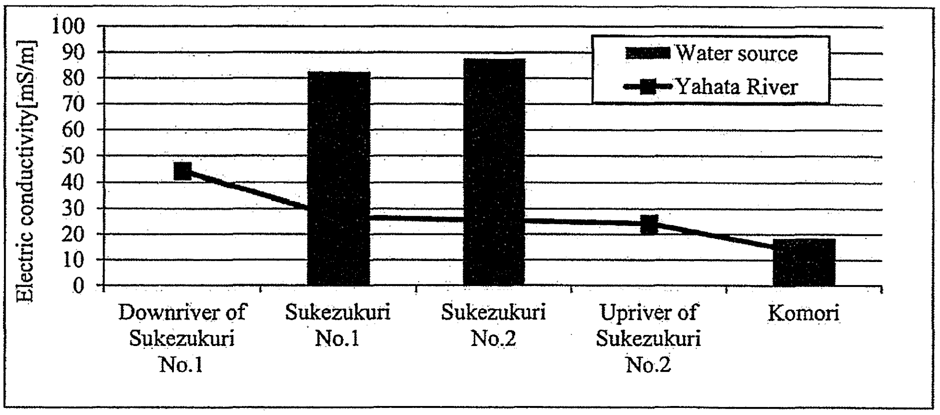


Figure 7. Electric conductivity at the Sukezukuri No.1, No.2, Komori water source and Yahata river(Located nearby these water sources) (measured on 18 October, 2011)

To measure the long term change in chloride ion concentration we installed an electric conductivity meter at the water source as an alternative indicator, and which enabled constant measurement of the concentration. Figure 8 shows the monthly fluctuations in the electric conductivity at the Sukezukuri water source and tide level, rainfall, and electric conductivity before the disaster (calculated from the chloride ion concentration before the disaster and based on the correlation equation provided in Figure 5).

Figure 8 reveals there to be no correlation between the electric conductivity and monthly tidal change, with the electric conductivity decreasing in a uniform manner. In addition, about 50 mm/day of rain fell on 3 December, 2011, but no change was observed in the electric conductivity, which then revealed that rainfall of about 50 mm/day had no effect on the electrical conductivity.

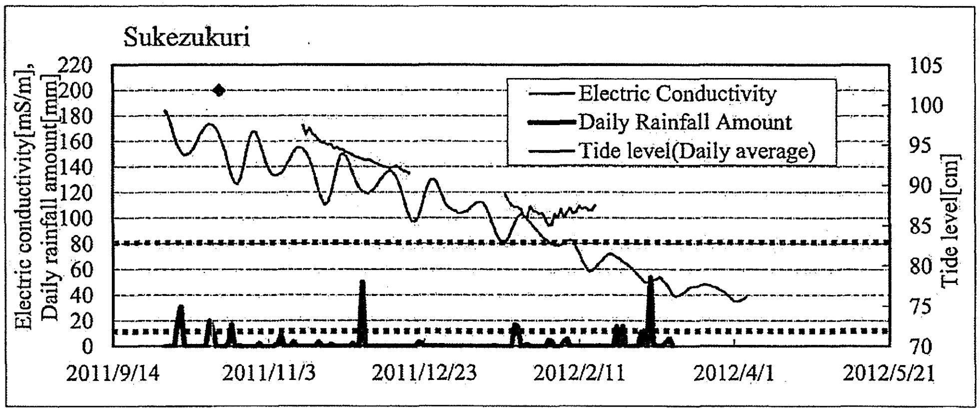


Figure 8. Electric conductivity of Sukezukuri water source, with rain fall amount(in Shidugawa) and tide level(in Ayukawa, daily average)※Black dotted line indicates electric conductivity at the water source before disaster, calculated from chloride ion concentration. Red dotted line indicates electric conductivity corresponding to water quality standard value of chloride ion.

Furthermore, the results of a survey on the correlation between the electric conductivity and annual change in tide level are shown in Figure 9. The results reveal that even in August, when the tide was at its highest level of the year, the electric conductivity didn't increase significantly and instead remained at basically the same level as in winter, or even lower, thus indicating that the tidal change has no major effect on the quality of water sources. Although no major change was recorded in the electrical conductivity during the above measurement period we weren't able to collect data during the heavy rain that fell in May and December 2012, and thus the effect of heavy rain has not been completely identified.

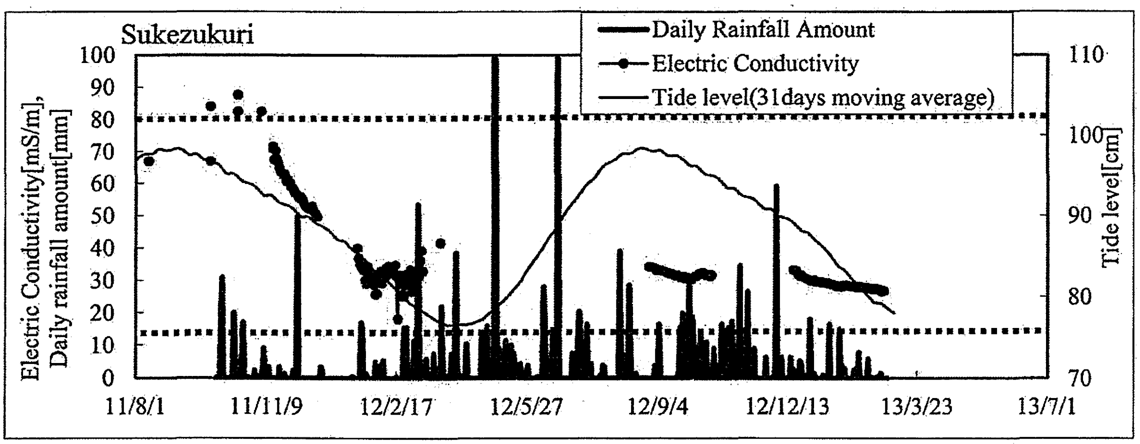


Figure 9. Electric conductivity at the Sukezukuri water source, with rain fall amount(at Shizugawa) and tide level(at Ayukawa, 31days moving average) ※Black dotted line indicates electric conductivity at the water source before disaster, calculated from chloride ion concentration. Red dotted line indicates electric conductivity corresponding to water quality standard value of chloride ion.

As revealed above, although the chloride ion concentration of the Sukezukuri water source was about three times higher than before the disaster the concentration level doesn't get significantly changed by a small amount of rainfall (about 50 mm/day) or via the tide level and it has been confirmed to be useable as a drinking water source as long as the chloride ion concentration doesn't significantly increase after heavy rain (100 mm/day).

b. Isatomae water source

After the disaster the chloride ion concentration level was way over water quality standards and continuously fluctuated. It then, however, started to decrease, although the fluctuation range of the chloride ion concentration was rather large, and the concentration level was near the water quality standard level (200 mg/L) 6 months after the disaster (September 2011). As with the Sukezukuri water resource, and to monitor the long-term fluctuations in the chloride ion concentration, we therefore installed an electric conductivity meter as an alternative indicator and constantly measured the concentration level.

Figure 10 shows the monthly fluctuations in the electric conductivity at the Isatomae water source and tide level, rainfall, and electric conductivity before the disaster (calculated from the chloride ion concentration before the disaster and based on the correlation equation provided in Figure 5). Figure 10 reveals there to be no correlation between the electrical conductivity and monthly tidal change, and the electric conductivity to have decreased in a uniform manner. However, a significant increase in the electric conductivity did occur during the rain that fell on 3 December, 2011 (about 50 mm/day). This therefore then confirmed that unlike the Sukezukuri water source the Isatomae water source is easily affected by rainfall.

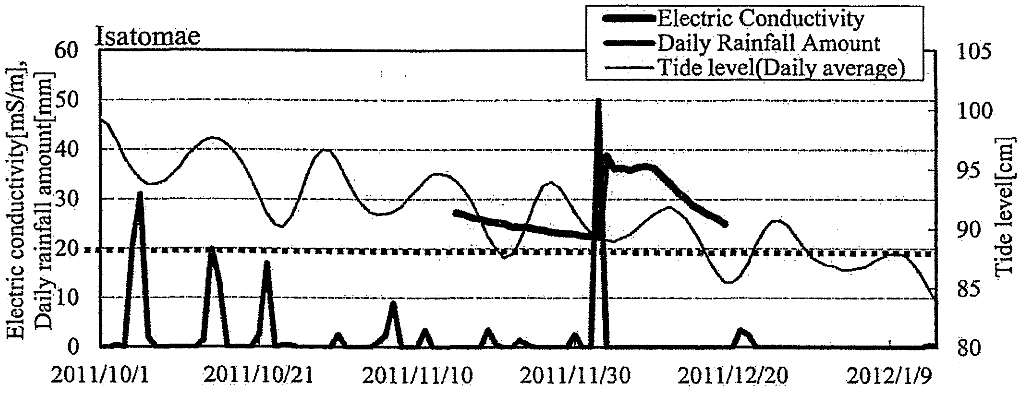


Figure 10. Electric conductivity at the Isatomae water source, with rain fall amount(at Shidugawa) and tide level(at Ayukawa, daily average)※Black dotted line indicates electric conductivity at the water source before disaster, calculated from chloride ion concentration. Red dotted line indicates electric conductivity corresponding to water quality standard value of chloride ion.

The results of a survey on the correlation between the annual fluctuations in electric conductivity and tide level and rainfall are shown in figure 11. The results reveal that even in August, when the tide was its highest level of the year, the electric conductivity didn't significantly increase and basically remained at the same value as in winter or even lower, thus indicating that the tidal change has no major effect on the quality of the water sources. As with the Sukezukuri water source we were unable to collect any data during the heavy rain that fell in May and December 2012, and hence the effect of heavy rain has not been completely identified.

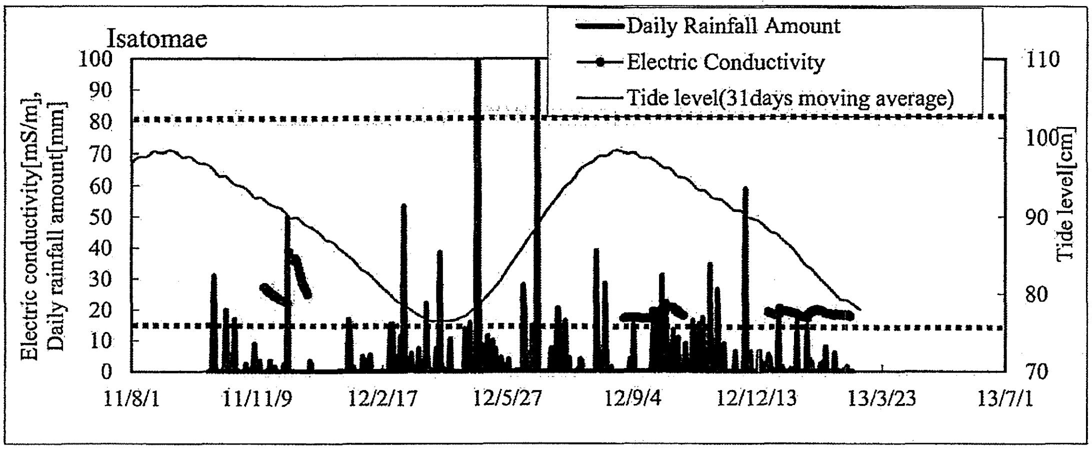


Figure 11. Electric conductivity at the Isatomae water source, with rain fall amount(at Shidugawa) and tide level(at Ayukawa, 31days moving average)※Black dotted line indicates electric conductivity at the water source before disaster, calculated from chloride ion concentration. Red dotted line indicates electric conductivity corresponding to water quality standard value of chloride ion.

As revealed above no significant change was observed to have resulted from the tide level at the Isatomae water source, and the chloride ion concentration has decreased to near the level it was before the disaster. The concentration is unlikely to be affected by small amounts of rainfall (50 mm/day), but the fluctuation in chloride ion concentration does need to be constantly monitored after heavy rainfall as it is easily affected by rainfall.

c. Komori, Tajiribatake, and Tokura water sources

The chloride ion concentrations at the Komori, Tajiribatake, and Tokura water sources repeatedly fluctuated but were less than 200mg/L at an early stage, and remained within the water quality standards level after heavy rain resulting from a typhoon. We therefore considered that no issue of concern exists about using them as drinking water sources and thus stopped surveying them in November 2011 (fourth survey).

4. CONCLUSION

The results revealed no contamination from nearby facilities apart from chloride ion concentrations at all the water sources. The reason for this, we believe, is that there are no factories close enough which deal with chemicals and oil. The chloride ion concentration had gradually decreased and reached below the water quality standard level at all the water sources by 8 months after the disaster. The trend of the decrease in chloride ion concentration, however, was not uniform, and some of the water sources (Sukezukuri and Isatomae water sources) were possibly being affected by salt entering them from nearby soil or because of the tidal level due to land subsidence. Further surveys revealed no significant changes to have been caused by the tide level, although they did indicate the possibility of the chloride ion concentration increasing again after heavy rainfall.

For this reason we consider all the water sources to be useable as drinking water sources under normal conditions. However, with the Sukezukuri and Isatomae water sources, whose chloride ion concentrations remain high, it will be necessary to constantly monitor the levels of concentration via measuring the electrical conductivity, and to ensure to identify the fluctuation range of the chloride ion concentration after any heavy rainfall.

Verification of a Prediction Method of Earthquake Damage to Water Supply Pipeline by Using Damage Data of the 2011 Great East Japan Earthquake

Masakatsu Miyajima, Masahiro Fujiwara

ABSTRACT

This paper deals with a prediction method of earthquake damage to water supply pipeline. The 2011 Great East Japan Earthquake caused extensive damage to water supply pipeline at not only Tohoku region but also Kanto region. The authors collect damage data of water supply pipeline and make a database of not only the damage but also the ground condition and peak ground velocity at the damage site. The authors already have made a database of damage to the pipelines in the 2004 Niigata-ken Chuetsu Earthquake, the 2007 Niigata-ken Chuetsu-oki Earthquakes with additional data from the 1995 Hyogok-ken Nambu Earthquake, and proposed an equation to predict earthquake damage to the pipelines. The present study verifies the equation proposed by authors by using the database of the damage of the 2011 Great East Japan Earthquake.

Since comparison between the damage predicted by using the present equation and the actual damage occurred at strong ground motion areas in the 2011 Great East Japan Earthquake shows good agreement, the present method is verified. The damage to pipeline in liquefied areas is, however, not explained precisely by using the present prediction method because liquefaction occurred extensively at the area of relatively low peak ground velocity such as Urayasu City in Chiba Prefecture. Modified prediction method of damage to pipeline in liquefied area is, therefore, proposed based on the database of the damage in the 2011 Great East Japan Earthquake in this paper.

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INTRODUCTION

The 2011 Great East Japan Earthquake caused extensive damage to water supply pipeline at not only Tohoku region but also Kanto region. The authors collect damage data of pipelines and make a database of not only the damage but also the ground condition and peak ground velocity at the damage site. The authors already have developed a database of damage to water supply pipeline in the 2004 Niigata-ken Chuetsu Earthquake, the 2007 Niigata-ken Chuetsu-oki Earthquakes with additional data from the 1995 Hyogok-ken Nambu Earthquake, and proposed a prediction method of earthquake damage to pipeline. The present study verifies the prediction method proposed by authors by using the database of the damage of the 2011 Great East Japan Earthquake.

Since comparison between damage predicted by using the present equation proposed by authors and actual damage occurred at strong ground motion areas in the 2011 Great East Japan Earthquake shows good agreement, the present method proposed by authors is verified. The damage to pipeline in liquefied areas is, however, not explained precisely by using the present equation because liquefaction occurred extensively at the area of relatively low peak ground velocity such as Urayasu City in Chiba Prefecture. Modified prediction method of damage to pipeline in liquefied area is, therefore, proposed based on the database of the damage in the 2011 Great East Japan Earthquake in this paper.

EQUATION TO PREDICT EARTHQUAKE DAMAGE TO WATER SUPPLY PIPELINE

Attributes of Damaged Pipelines

We collected data on damaged pipelines in Kobe, Ashiya, and Nishinomiya (the 1995 Hyogo-ken Nambu Earthquake; n = 2170, n is number of data); Nagaoka and Ojiya (the 2004 Niigata-ken Chuetsu Earthquake; n = 277); and Kashiwazaki and Kariwa (the 2007 Niigata-ken Chuetsu-oki Earthquake; n = 491). We developed a database of damage locations in a geographical information system (GIS) and sorted the data by pipe attributes (pipe type, joint type, pipe diameter). The GIS database exported 250 m × 250 m cell data for analysis. We also developed a database of the peak ground velocity and microtopography types (drawn from the Japan Seismic Hazard Information Station: J-SHIS).

Reference Damage Rate

The reference damage rate was calculated from the approximate curve obtained by the least-squares regression equation relating the damage rate and the peak ground velocity. Equation 1 shows the reference damage rate obtained here. The calculation conditions reflected the fact that almost no pipelines were damaged by recent earthquakes at a peak ground velocity of <15 cm/s, and were based on measured maximum velocities. The rate of earthquake damage was estimated by multiplying the equation for the reference damage rate by the correction factors described below:

$$R(v) = 9.92 \times 10^{-3} \times (v - 15)^{1.14} \tag{1}$$

where $R(v)$ = reference damage rate (locations/km)
v = maximum surface velocity of ground vibration (cm/s) ($15 \leq v < 120$).

Determining the Correction Factors in the Damage Prediction Equation

The values of the correction factors were determined using cross-tabulation and multivariate analysis based on mathematical quantification theory class I. The valuables of the multivariate analysis were the damage rate (locations/km) obtained from pipe type, joint type, pipe diameter and microtopography respectively. To calculate the damage rates, cross-tabulation was used. Damage locations were plotted on the pipeline map in the GIS, and the damage rate (locations/km) was obtained from the plot by pipe type, joint type, and pipe diameter. The damage rate by microtopography type was also obtained by superimposing the microtopography map on the plot. Then we analyzed the relationship of pipe type, joint type, pipe diameter and microtopography class with the damage rate. The damage rate is the target variable. Since it is affected in a complex manner by pipe type, joint type, pipe diameter and microtopography type, a multivariate analysis was performed to analyze how much each attribute affects the damage rate. The correction factor for an attribute with insufficient samples was determined by taking into account cross-tabulation analysis, engineering knowledge, and a conventional correction factor.

The effect of liquefaction on pipeline damage was assumed to be nearly constant, once it had occurred, and independent of microtopography type. Taking into account the relationship of the correction factor for liquefaction in the conventional damage prediction equation and the correction factor for each microtopography type proposed in this study, if there is a risk of liquefaction, the correction factor for liquefaction is set to 6.0 for all microtopography types.

Table 1 shows the correction factors and the pipeline damage prediction equation based on the reference damage equation.

EVALUATION OF DAMAGE PREDICTION EQUATION

Database of Damaged Pipeline in the 2011 Great Japan Earthquake

We collected data on damaged pipelines in Sendai ($n = 365$; n is number of data), Ishinomaki ($n = 278$) and Tome ($n = 164$) in Miyagi Prefecture, Urayasu ($n = 321$) and Asahi ($n = 60$) in Chiba Prefecture in the 2011 Great East Japan Earthquake, developed a database of damage locations in GIS and stored the data by pipe attributes (pipe type, joint type, pipe diameter). Miyagi prefecture is close to the epicenter and Chiba Prefecture is far from the epicenter but extensive liquefaction occurred in Urayasu and Asahi Cities. We also developed a database of the peak ground velocity and microtopography types (drawn from the Japan Seismic Hazard Information Station: J-SHIS).

Comparison between Predicted Number of Damage and Actual One

The accuracy of the damage prediction equation was evaluated against data from the database mentioned above. Figure 1 shows the relation between a predicted number of damage and actual one in each 250m x 250m cell in Ishinomaki. A solid line in this figure indicates the ratio of the actual number of damage to the predicted one is 1.0. The ratios of 0.5 and 2.0 are also indicated as dotted lines in this figure. 57.7% of all data are plotted between two dotted lines. So, comparison of the predicted number of damage with the actual one shows relatively good agreement. However, some plots locate at area above 2.0 of the ratio and below 0.5. 35.1% of all data are plotted at the area above

2.0 of the ration. Since the correction factor is different in microtopograpy type in the prediction method, the relation between the actual number of damage and predicted one in each microtopograpy type is drawn in Figures 2 and 3. The actual number of damage is relatively lager than the predict one in case of law correction factors for microtopograpy type according to Figure 2. This discrepancy is probably due to land use change for housing development. Thus, the microtopograpy map of 250m x 250m cell is not sufficient for locally change of landform.

Figure 4 is illustrated the relation between an actual number of damage and predicted one in liquefaction area in Urayasu. The correction factor is 6.0 in spite of microtopograpy type in the cell in this case. Most of data are plotted at the area above 2.0 of the ration of the actual number of damage to the predicted one. This means that the predicted number of damage is underestimated very much.

The total piping length in Urayasu was 200.93 km and the number of damage was 321, so the damage rate is 1.60 locations/km. The damage rate of pipeline buried in the reclaimed land of Kobe, Ashiya and Nishinomiya in the 1995 Kobe Earthquake was 1.77 locations/km. Peak ground velocity was about 30 cm/s in Urayasu and that in Kobe area in the 1995 Kobe Earthquake was around 100 cm/s. So, peak ground velocity of Urayasu was much smaller than that at Kobe area in the 1995 Kobe Earthquake, but degree of damage was seems to be similar. This means that the effect of liquefaction on pipeline damage may be nearly constant, once it had occurred, and independent of peak ground velocity. Therefore, some modification is necessary in the prediction method in case of liquefaction.

Table 1 Pipeline damage prediction equation

$$Rm(\mathrm{v}) = C_p \times C_d \times C_g \times R(v)$$

$Rm(v)$: Predicted damage rate [locations/km]

$R(\mathrm{v})$: Reference damage rate [locations/km]

$= 9.92 \times 10^{-3} \times (v - 15)^{1.14}$

v: Peak ground velocity (cm/s)

$(15 \leq v < 120)$

Pipe type, joint	C_p	Diamater(mm)	C_d
DIP (A)	1.0	ø50–80	2.0
DIP (K)	0.5	ø100–150	1.0
DIP (T)	0.8	ø200–250	0.4
DIP (disengagement prevention)	0	ø300–450	0.2
CIP	2.5	ø500–900	0.1
PVC (TS)	2.5		
PVC (RR)	0.8		
SP (welding)	0.5/0		
SP (non-welding)	2.5		
ACP	7.5		
PE (electrofusion)	N/A※		

Microtopography with pipelines installed	C_g
If there is no information available on liquefaction or if there is no possibility of liquefaction	
Mountain, mountain foot, hill, volcanic area, volcanic mountain foot, volcanic hill	0.4
Gravel upland, loam upland	0.8
Valley floor, alluvial fan, backswamp, delta, coastal lowland	1.0
Natural levee, former river channel, sandbar, gravel bar, dune	2.5
Reclaimed land, drained land, lakes and marshes	5.0
If there is information available on liquefaction and if there is the possibility of liquefaction	
All topography types	6.0

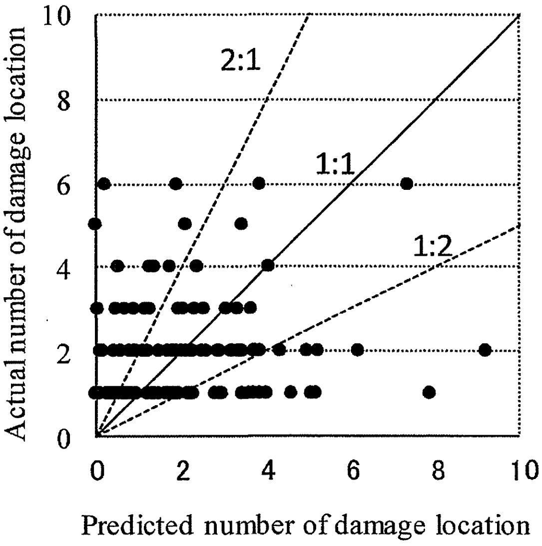

Figure 1 Comparison of actual number of damage with predicted one in Ishinomaki.

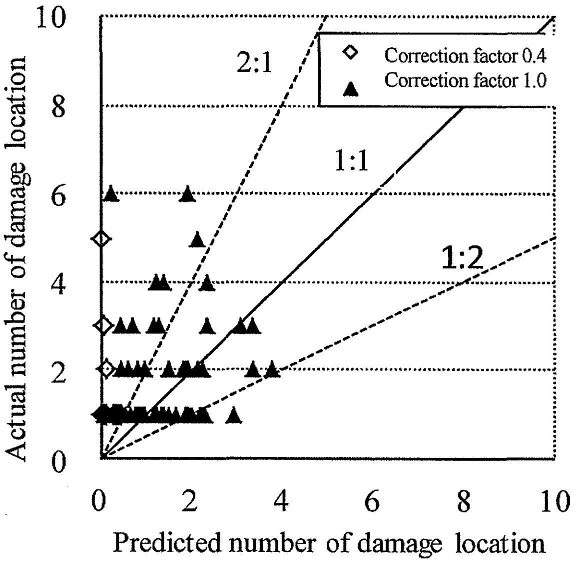

Figure 2 Comparison of actual number of damage with predicted one of correction factors 0.4 and 1.0.

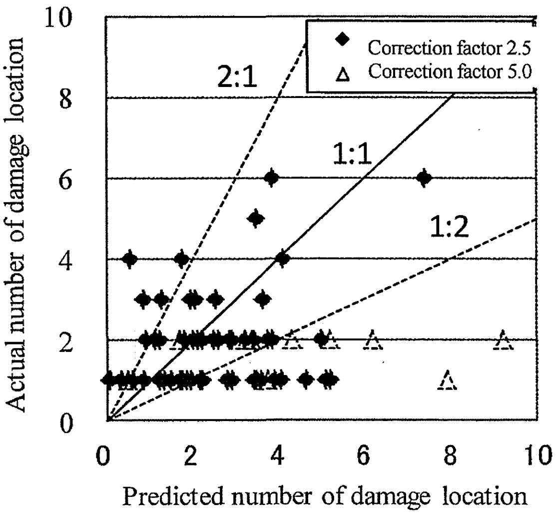

Figure 3 Comparison of actual number of damage with predicted one of correction factors 2.5 and 5.0.

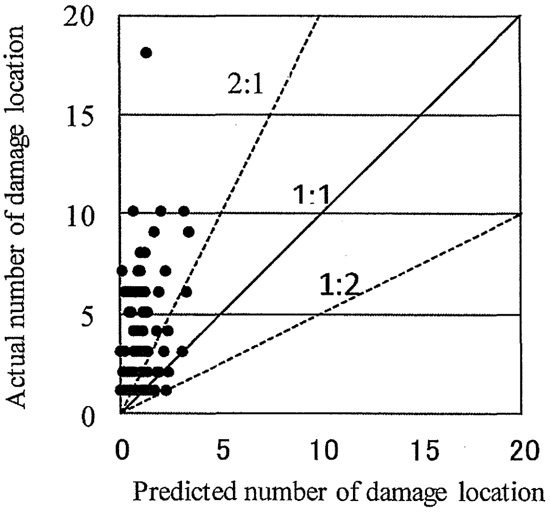

Figure 4 Comparison of actual number of damage with predicted one in Urayasu.

Estimation of Correction Factor in Liquefaction Area

If liquefaction occurred, the effect of liquefaction on pipeline damage seems to be constant and independent of peak ground velocity. An average damage rate in liquefaction area must be estimated independently of peak ground velocity. The average damage rate of liquefaction area is estimated by reference damage rate divided by correction factors on pipe type and pipe diameter by using database of Urayasu and Asahi in the 2011 Great East Japan Earthquake. The average damage rate of liquefaction area is finally set to 5.5.

Figure 5 shows the relation between an actual number of damage and predicted one in liquefaction area by using the average damage rate of liquefaction area, in comparison with that using the damage prediction equation in Urayasu. 60.4 % of all data are plotted between two dotted lines and only 14.3% are plotted above 2.0 of the ratio. So, comparison of the predicted number of damage with the actual one shows good agreement.

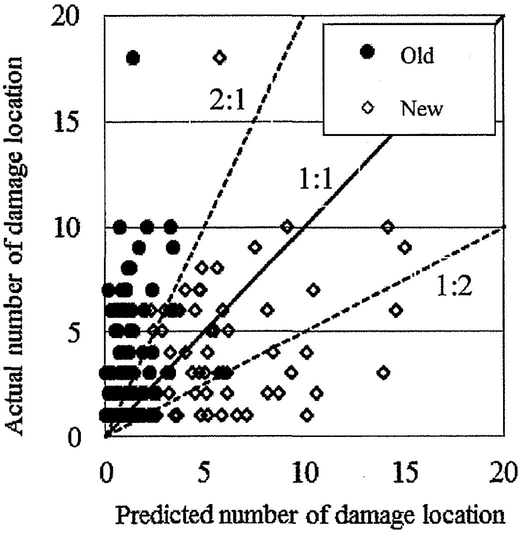

Figure 5 Comparison of actual number of damage with predicted one by using the average damage rate of liquefaction area in Urayasu.

Finally the method of damage prediction of water supply pipeline is newly proposed as shown in Table 2.

Table 2 Newly proposed pipeline damage prediction equations

Pipeline damage prediction equations	
If there is no information available on liquefaction or if there is no possibility of liquefaction	If there is information available on liquefaction and if ther is the possibility of liquefaction
$R_m = C_p \times C_d \times C_g \times R(v)$ R_m : Predicted damage rate (locations/km) C_p : Correction factor for pipe and joint type Cd : Correction factor for pipe diameter C_g : Correction factor for microtopograpy $R(v)$: Reference damage rate (locations/km) $R(v)=9.92\times10^{-3}\times(v-15)^{1.14}$ v : Peak ground velocity(cm/s) $(15 \leqq v < 120)$	$R_m = C_p \times C_d \times R_L$ R_m : Predicted damage rate (locations/km) C_p : Correction factor for pipe and joint type Cd : Correction factor for pipe diameter R_L : Average damage rate of liquefaction area (locations/km), $R_L = 5.5$

C_p, C_d, C_g are refered to Table 1.

CONCLUSION

The equation for prediction of earthquake damage to water supply pipelineproposed by authors is verified by using damage data in the 2011 Great East japan Earthquake. Since comparison between the damage predicted by using the present equation and the actual damage occurred at strong ground motion areas in the 2011 Great East Japan Earthquake shows good agreement, the present method is verified. It is, however, clarified that the microtopograpy map of 250m x 250m cell is not sufficient for locally change of landform. The damage to pipeline in liquefied areas is, however, not explained precisely by using the present prediction method because liquefaction occurred extensively at the area of relatively low peak ground velocity such as Urayasu. If liquefaction occurred, the effect of liquefaction on pipeline damage seems to be constant and independent of peak ground velocity. Modified prediction method of damage to pipeline in liquefied area is, therefore, proposed based on the database of the damage in the 2011 Great East Japan Earthquake in this paper.

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Application of Two-stage Coagulation for High Turbidity Raw water

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As a result of frequent occurrence of heavy rain, widely applicable water treatment processes for high turbidity raw water was required. In the presence of high turbidity, traditional coagulation processes can be inadequate to water quality standards such as *Cryptosporidiidae*. Two-stage coagulant addition easily applies many existing water purification plant and expects to treat high turbidity raw water effectively. In this study, high turbidity raw water was used to compare one- and two-stage coagulant addition on conventional water treatment process. Jar test were conducted with various water quality conditions and verified at the pilot scale experiment. The settled-water turbidity and particle counts were approximately 20% and 50% lower than for the single-stage process less using the two-stage process respectively. Though, the steady-state filter effluent turbidity for the two-stage process was approximately 20% lower than for the single-stage process, the one-stage process did not exhibit particle breakthrough during a typical filter run, whereas the two-stage process broke through approximately 4hr before the hydraulic completion of the run. Additional experiments allowed a mechanism for the improved process performance to be proposed. As a simple and efficient approach, two-stage coagulation could have great practical significance in conventional water treatment process.

Simplified Evaluation Method of Seismic Resistance for Water Treatment Facilities

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ABSTRACT

As the Seismic Design Code (SDC) has revised its requirement following major earthquakes in the past decades, old water infrastructure in Japan must be seismically upgraded to keep up with the latest SDC.

As a first step, such upgrade usually requires an assessment whether a specific civil structure is seismically resistant. The Detailed Evaluation Method (DEM) is well-known as a full evaluation method, but due to its complexity and required high technical knowledge, the Simplified Evaluation Method (SEM) is normally applied to prioritize the structures for DEM testing. This simple assessment method, however, falls behind the current civil engineering technology in some respects, being thirty years old.

Therefore, we propose a new SEM with a revised procedure, which adopts a three-step approach where the target structure is evaluated according to "threat of liquefaction," "year of construction" and then "structural resistibility."

INTRODUCTION

Japan is located in one of the most active seismic zones in the world, and undertaking adequate seismic countermeasures is crucially important to protect the public water supply from seismic hazards or restore it promptly after such an event. This is why Japan's drinking water infrastructure is designed in compliance with the Seismic Design Code (SDC). The first edition of the SDC was defined in the *Guidelines for Earthquake-Resistant Design Methods for Waterworks Facilities*, which was published in 1953 in the wake of the 1948 Fukui Earthquake. Since then the SDC has undergone several revisions to adopt more rigid criteria, e.g., after the 1964 Niigata Earthquake and most recently after the 1995 Kobe Earthquake. Installed before or in the 1960s-1970s, a considerable proportion of the water infrastructure remains to be seismically upgraded and meet the latest SDC.

As a first step to an upgrade, a drinking water utility usually makes an assessment whether a specific civil engineering structure at a water treatment plant (WTP) is seismically vulnerable and must be reinforced. The Detailed Evaluation Method (DEM) is available as a common, full evaluation method, in which the target structure is evaluated through the simulated calculations of the stress imposed on each structural member under specific seismic intensities and motions as well as other design conditions. However, as the DEM requires high technical knowledge as well as time and effort, the Simplified Evaluation Method (SEM) is normally applied as a preliminary step to identify and prioritize which structures need a thorough evaluation by the DEM. As a qualitative assessment method, the SEM adopts a scorecard (Diagnostic Sheet) approach where the user grades the target structure for various indices to know the level of its seismic resistance. Established in 1981 by the Ministry of Health and Welfare, however, the SEM is partially outdated, not necessarily reflecting the current civil engineering technology.

With the aim of revising the SEM and its Diagnostic Sheet to make them more practical and convenient to use, the Japan Water Research Center (JWRC) started a three-year research project in 2011 in collaboration with utilities and academics under Health Labour Sciences Research Grant.

This paper discusses the current progress and findings of the ongoing project.

METHOD

We collect the DEM results from utilities and apply the SEM to the same structures tested by the DEM in order to compare the DEM and SEM results and identify weaknesses of the Diagnostic Sheet. We also investigate the damage to the facilities by the Great East Japan Earthquake in March 2011 to reflect the actual damage observations in revising the SEM.

Survey of damage caused by the Great East Japan Earthquake. To find out the damage to the facilities by the Great East Japan Earthquake, we sent out a questionnaire to the five government agencies in five affected prefectures (Iwate, Miyagi, Fukushima, Ibaraki, and Chiba). These agencies regulate the utilities in respective prefectures and receive the damage reports following earthquake events. The questionnaire did not address the damage related to the inundation due to tsunami. Upon receiving responses, we conducted on-site investigations of the facilities reported to have sustained particularly severe damage.

Proposals to improve the SEM. As a case study we applied the Diagnostic Sheet approach to two groups of structures: the one that was designed according to older SDCs and the other conforming to the latest SDC. We examined improvement measures for the SEM based on the case study results as well as the reports on the damage in the Great East Japan Earthquake and other earthquakes.

RESULTS AND DISCUSSION

Damage by the Great East Japan Earthquake. Of the five government agencies, four responded to the questionnaire. The result showed there were breakage or fall of plate settlers at some WTPs but there were none but three plants that were forced to suspend water supply for extended periods due to critical damage. Subsequently we made on-site investigations of the three plants (Hebita in Miyagi, Wanigawa in Ibaraki, and Shinjuku in Chiba). The follow-up investigations revealed that the primary cause of the damage was not the ground shaking itself but the ground failure due to liquefaction. Afterwards we examined and found this was also the case in the 1995 Kobe Earthquake as well as subsequent earthquakes: the critical impact on the WTPs was brought about largely by the liquefaction effect, and the other effects played a minor role.

Photo 1. Land subsidence due to liquefaction (Shinjuku WTP)

Photo 2. Concrete expansion joint forced widened due to ground deformation (Hebita WTP)

Weakness of the current SEM. The “total score” approach through the Diagnostic Sheet (Table 1) is one of the most common among various SEMs currently available. In this approach, the user grades the target structure in numeric values (scores) for a series of indices from “Ground Condition” to “Seismic Intensity” in Table 1 and multiplication of all the indices leads to Seismic Resistibility. This is a common seismic vulnerability assessment but is not without some weaknesses: for example, the user must fill in every index and to grade every index is not always easy to smaller utilities due to limited personnel and financial resources. Furthermore, developed in 1981, this approach is not designed based on the latest seismic intensity scale defined by the Japan Meteorological Agency in 1996. Addressing these weaknesses in a proper fashion is a motivation behind our research project.

Table 1. SEM Diagnostic Sheet

Type of Structure	Roofed Basin (Distribution reservoir, Clear water tank)			
Name of Facility	A Distribution Reservoir			
Item	Category	Weight	Score	Remarks
Ground Stiffness	Type I	0.5		
	Type II	1.5		
	Type III	1.8		
Liquefaction	No	1.0		
	Possible	2.0		
	Yes	3.0		
Ground Formation	Natural ground	1.0		
	Slope	1.2		
	Hilltop	1.3		
	Embankment/landfill	1.5		
Basement Level	Onground	1.2		
	Semi inground	1.1		
	Inground	1.0		
Material	RC	1.0		
	Bricks/others	3.0		
Wall Area/ Water Area*	0.05＜	1.0		
	0.05＞	1.5		
Depth of Reservoir	5m≧	1.0		
	5m＜	1.3		
Modeling Type for Structural Analysis	Wall	1.0		
	Pillar & baem	1.2		
	Flat slab	1.4		
Upper Load	0.4m≧	1.0		
	0.4m＜	1.2		
Construction Year**	Befor 1953	1.8		
	1953～1966	1.6		
	1967～1980	1.5		
	After 1980	1.0		
Flexible Joint (connected pipe)	Mounted	1.0		
	Nil	2.0		
Expansion Joint (wall, slab, etc.)	Good condition	1.0		
	Nil or no good	2.0		
Aging	Relatively new	1.0		
	Medium	1.5		
	Aged	2.0		
Seismic Intensity	5	1.0		
	6	2.2		
	7	3.6		
Seismic Resistibility (score)	High	10＞		
	Middle	10～17		
	Low	17＜		

* Wall Area/Water Area = [horizontal cross-sectional area of wall] / [water surface area]

**Category in "Construction Year" was amended in 2000 by JWRC