all the experimental conditions, the finished-water turbidity of both the membrane filtration and the rapid filtration satisfied the 2.0 TU limit of the drinking water quality standard in Japan.

Acknowledgement

This research was supported in part by a Health and Labour Sciences Research Grant of Japan.

REFERENCES

Ebie K., Itoh Y., Hayakawa H. and Nagare H. (2007) Investigation committee report on the technical causes of a stoppage of the water supply in Kitami *(in Japanese)*.

IPCC (2007) Technical Report of Intergovernmental Panel on Climate Change Fourth Assessment Report

Japan Water Research Centre. (2005) A research report on e-Water I project *(in Japanese)*.

Japan Water Works Association, Japan. (2008) Water Statistics *(in Japanese)* .

Kobayashi Y., Itoh M., Yamada T. and Matsui Y. (2011) Performance of high basicity PACl on turbidity removal and residual aluminum concentration control using a pilot scale plant, Journal of Japan Water Works Association, No.918, pp.2-11 *(in Japanese)* .

Ministry of Education, Culture, Sports, Science and Technology, Japan Meteorological Agency, Ministry of the Environment, Japan. (2009) Climate Change and Its Impacts in Japan.

Ministry of the Environment, Japan, 2008, Wise Adaptation to Climate Change - Report by the Committee on Climate Change Impactsand Adaptation Research –.

River Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan. (2008) Flood Disaster Report 2008 (*in Japanese*).

Yan M., Wang D., Qu J., He W. and Chow C. (2007) Relative importance of hydrolyzed Al(III) species (Ala, Alb, and Alc) during coagulation with polyaluminum chloride: A case study with the typical micro-polluted source waters, *Journal of colloid and interface science*, 316(2), pp.482-489.

Yan M., Wang D., Yu J., Ni J., Edwards M. and Qu J. (2008) Enhanced coagulation with polyaluminum chlorides: Role of pH/Alkalinity and speciation, *Chemosphere*, 71(9), pp.1665–1673.

Water Supply Division, Ministry of Health, Labour and Welfare, Japan. (2008) The guidelines for cryptosporidium treatment in waterworks *(in Japanese)* .

Water Supply Division, Ministry of Health, Labour and Welfare, Japan. (2008) Waterworks Vision, revised edition *(in Japanese)* .

Lessons from the 2011 Great East Japan Earthquake and Tsunami Disasters

M. Miyajima*

Abstract

This paper deals with an outline of damage induced by the 2011 great east Japan earthquake and tsunami. An earthquake with a magnitude of 9.0 occurred off the coast of northeast Japan on March 11, 2011 at 14:46 on local time. The earthquake generated a tsunami of unprecedented height and special extent along the coast of the main island of Japan. The earthquake and tsunami caused about 20,000 deaths and missing and injured about 6,000 people. A suspension of water supply was also occurred at about 2,300,000 houses in east Japan just after the earthquake. An outline of damage to water supply facilities is given and lessons learned from the earthquake and tsunami is discussed.

INTRODUCTION

An earthquake with a magnitude of 9.0 occurred off the coast of northeast Japan on March 11, 2011 at 14:46 on local time. Its epicenter was located at 38.1N, 142.9E. A JMA (Japan Meteorological Agency) seismic intensity of 7 was recorded at K-NET Tsukidate observation station in Kurihara City, Miyagi Prefecture. The earthquake generated a tsunami of unprecedented height and special extent along the coast of the main island of Japan. The earthquake and tsunami caused 15,821 deaths and 3,931 missing, and wounded 5,940 people (As of October 4, Japanese Government). The major cause of death was the tsunami. The completely collapsed houses numbered 118,480 (As of October 4, Japanese Government).

The 2011 great east Japan earthquake and tsunami also caused extensive damage to drinking water facilities. Strengthening of the earthquake resistance of drinking water facilities has become a major issue for drinking water utilities, along with the renovation of aging facilities. An outline of damage to water supply facilities is given and lessons learned from the earthquake and tsunami is discussed.

OUTLINE OF THE EARTHQUAKE AND TSUNAMI

Figure 1 illustrates epicenters of main shock and aftershocks[1]. According to the distribution of the epicenters of the aftershocks, the earthquake successively ruptures over an area of approximately 450km x 200km.

Figures 2 and 3 show a distribution of the peak ground acceleration (PGA) and peak ground velocity (PGV)[2]. Maximum PGA was recorded at K-NET Tsukidate observation station in Kurihara City, Miyagi Prefecture. Large PGA and PGV were recorded not only at Tohoku region but also at Kanto region.

---

*Professor, Kanazawa University, Kakuma-machi, Kanazawa, Japan
(E-mail: miyajima@t.kanazawa-u.ac.jp)

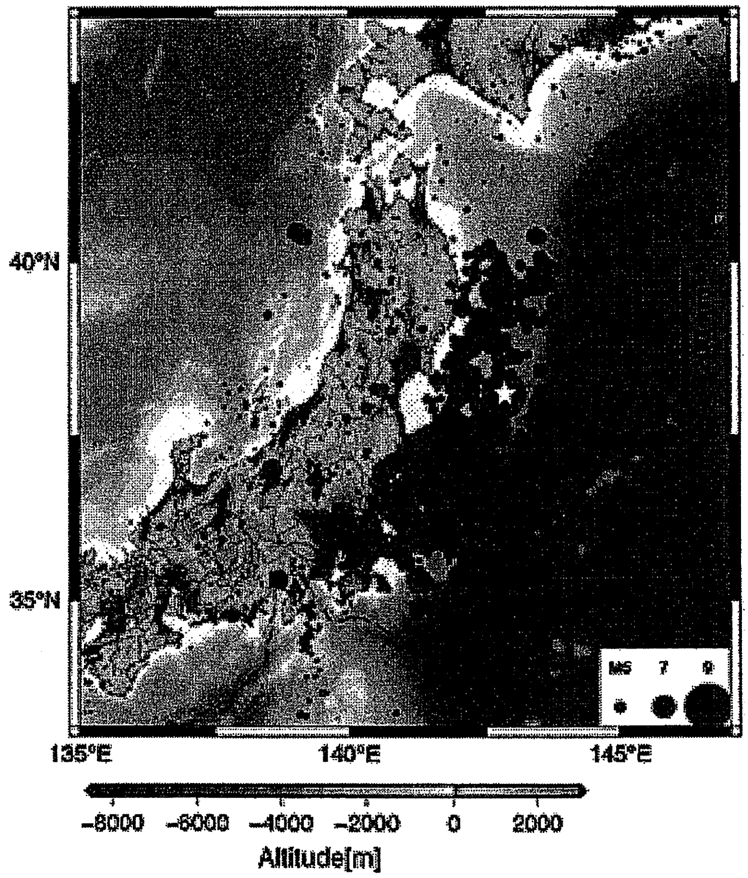


Figure 1 Distribution of epicenters of main shock and aftershocks (2011. 3.11-3.27)[1].

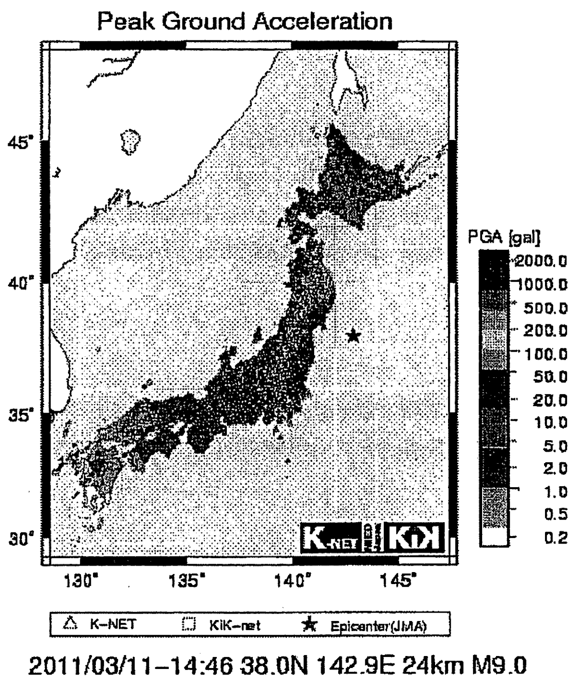


Figure 2 Distribution of peak ground acceleration[2].

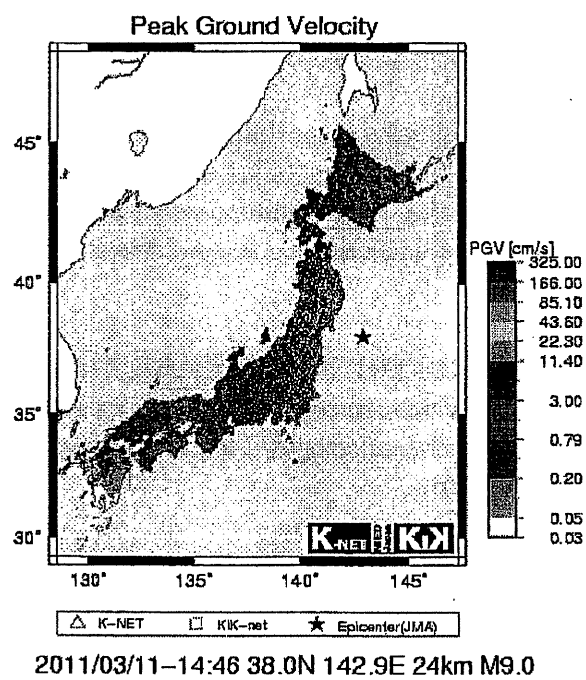


Figure 3 Distribution of peak ground velocity[2].

Table 1 lists observation sites where large PGA recorded. PGA and PGV listed here were vectorial summation of three components. The maximum PGA was 2,933 (cm/s/s) at K-NET Tsukidate station and the maximum PGV also recoded at K-NET Tsukidate station. More than 1G (= 980 cm/s/s) of PGA was observed at the nineteen observation stations of K-NET and KiK-NET observation stations.

Table 1 Large PGA observed sites[2].

	Site Name	Site Code	PGA (cm/s/s)	PGV (cm/s)
1	K-NET Tsukidate	MYG004	2,933	106
2	K-NET Siogama	MYG012	2,019	64
3	K-NET Hitachi	IBR003	1,845	74
4	K-NET Sendai	MYG013	1,808	83
5	K-NET Hokota	IBR013	1,762	71
6	K-NET Imaichi	TCG009	1,444	48
7	K-NET Shirakawa	FKS016	1,425	63
8	KiK-net Nishigou	FKSH10	1,335	41
9	K-NET Oomiya	IBR004	1,312	47
10	KiK-net Haga	TCGH16	1,305	82

PGA and PGV: Vectorial Summation of 3 Components
Bandpass filter to calculate velocity waveform : 0.1-15Hz

Figure 4 shows inundation and run-up heights in Hokkaido, Tohoku and Kanto regions surveyed by Tohoku Earthquake Tsunami Joint Survey Group[3]. Tsunami terminology is given by Figure 5[4]. According to their survey, the maximum run-up height was 39.7m at Miyako City. The maximum inundation height at the Sendai Plain was 19.5m and the mean inundation height near the shoreline was about 10m[4]. It has been estimated from areal and satellite photography that almost 535 km^2 of land were inundated in according to the Ministry of Land, Infrastructure, Transport and Tourism[5]. The tremendous tsunami caused a catastrophic destruction in Tohoku region.

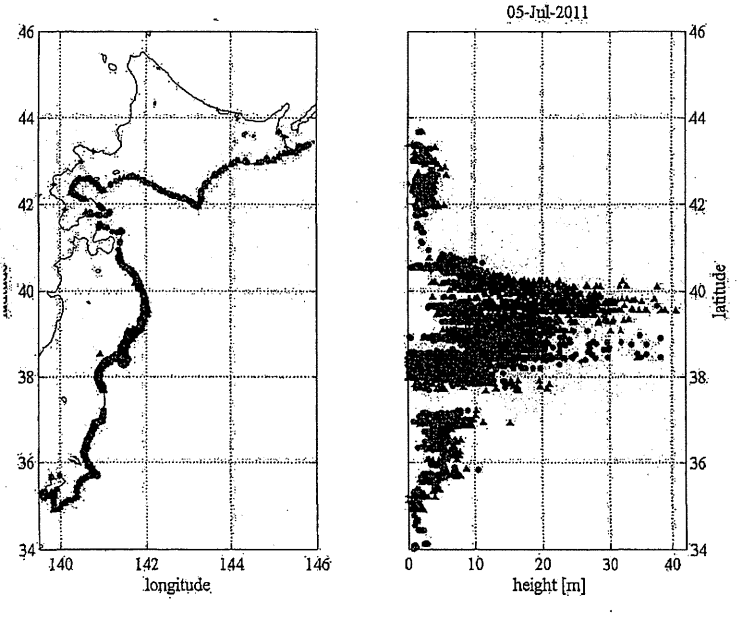


Figure 4 Inundation and run up heights of tsunami[3].
(red circle: inundation height, blue circle; run-up height)

OUTLINE OF DAMAGE TO WATER SUPPLY FACILITIES

Suspension of water supply

A suspension of water supply was occurred at about 2,300,000 houses in the wide area from Tohoku to Kanto regions just after the earthquake. About 90% of water outrage was recovered after one month from the event except flooded areas by the tsunami. Newly damage, however,

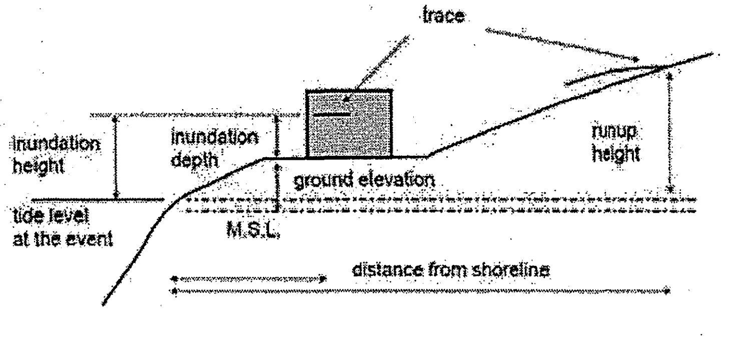


Figure 5 Tsunami terminology[4]

occurred by the strong aftershocks happed in the middle of April.

Causes of damage to facilities

The damage caused by the earthquake and tsunami is classified into five categories. Firstly the causes of damage are divided by earthquake and tsunami. Causes of damage by earthquake are classified into ground shaking, itself and ground failure such as liquefaction, slope failure and etc. Photo 1 shows damage to expansion joint of steel pipe with 2400mm diameter. This damage seems to be caused by ground shaking and/or ground deformation. Photo 2 shows an uplift of underground water tank induced by liquefaction.

Causes of damage by tsunami are classified into three categories; inundation, washing away and scouring of surface ground. Some intake facilities were inundated by tsunami and became malfunction for long time because of high density of calcium chloride in water. Photo 3 shows damage to water pipe bridge by tsunami. The water pipe bridge was completely washed away. Photo 4 shows damage to pipeline. The pipe appeared above ground after tsunami because of scouring caused by tsunami. The mechanism of damage to pipe, that is, how much force acts on a pipe is not sure. The mechanism of this kind of damage must be clarified in future.

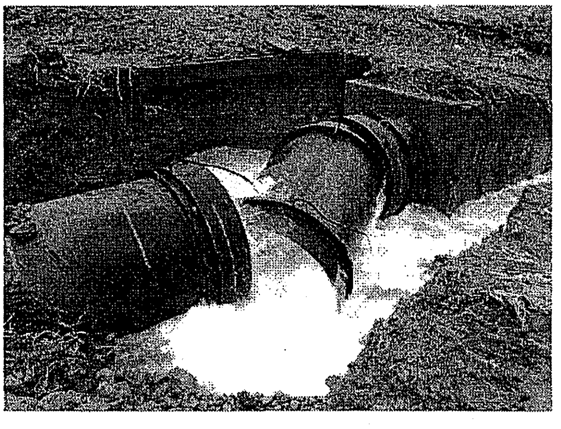


Photo 1 Damage to steel pipe with 2400mm diameter (Miyagi Pref.)[6].

Photo 2 Uplift of underground water tank (Chiba Pref.)[7].

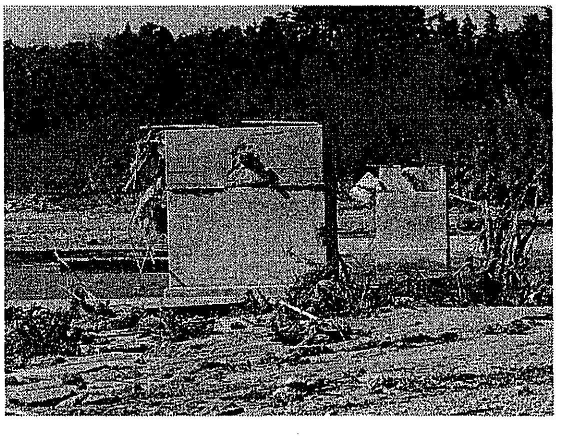


Photo 3 Damage to water pipe bridge (Miyagi Pref.).

Photo 4 Damage to pipe by scouring of tsunami (Miyagi Pref.).

Damage to pipeline

Since residents in the flooded areas by tsunami have not lived there after the event, most of damaged pipelines in the flooded areas are not repair yet. So, we cannot collect the entire data of damage to water supply pipelines yet.

Since the damage to pipeline of Sendai City is obtained except the flooded area, damage rate of pipelines in Sendai City is discussed here. The water supply system of Sendai City has approximately 472,775m of transmission and distribution main pipelines. About 74% of the total piping length is made up of ductile cast iron pipe (DIP), 24% steel pipe (SP). The number of damage to transmission and distribution main pipelines was 10 and that of damage to air valve and hydrant was 43. The damage rate of pipelines, defined as the locations of damage divided by piping length, was 0.02 (locations/km).

The total number of damage to transmission main, distribution main and branch pipelines was 264 except the flooded areas, and the piping length is 3,761km. The damage rate of transmission main, distribution main and branch pipelines was, therefore, 0.07 (locations/km) The damage rate in relation to pipe type and pipe diameter is shown in Figures 6 and 7, respectively. Figure 6 indicates that the damage rate of polyvinyl chloride pipe (VP) is high. Figure 7 reveals that the smaller the pipe diameter is, the higher the damage rate.

Figure 8 illustrates a comparison of damage rate of Sendai City with those of other cities suffered damage to pipeline in the past earthquakes. Kobe, Ashiya and Nishinomiya Cities suffered damage to water supply pipeline in the 1995 Hyogo-ken Nambu Earthquake, Nagaoka City in the 2004 Niigata-ken Chuetsu Earthquake, Monzen Town in the 2007 Noto-hanto Earthquake and Kashiwazaki City n the 2007 Niigata-ken Chuetsu-oki Earthquake, respectively. This figure revels that the damage rate of Sendai City was very low in

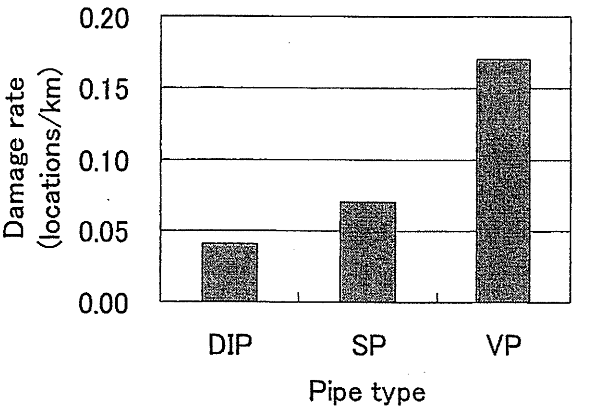


Figure 6 Damage rate related to pipe type.

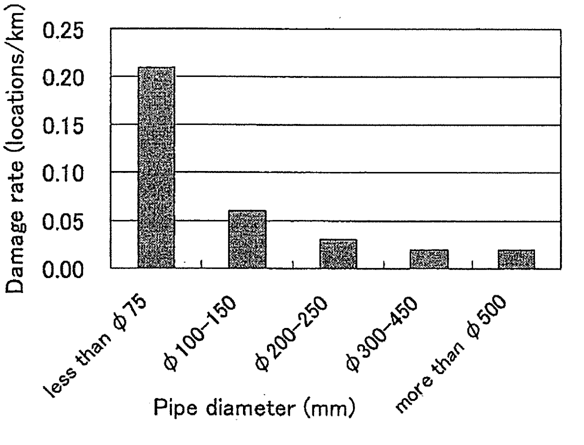


Figure 7 Damage rate related to pipe diameter.

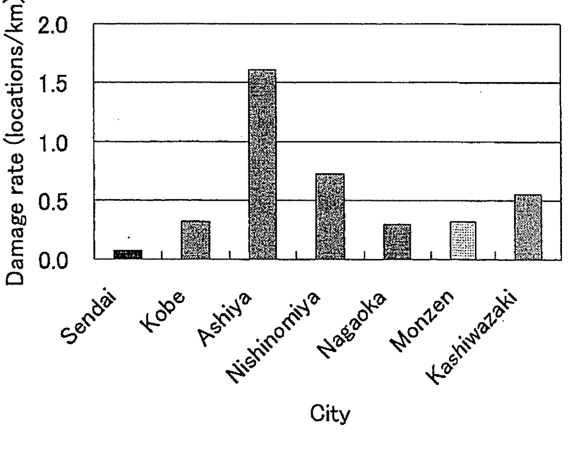


Figure 8 Comparison of damage rate.

comparison with another cities. Magnitude of earthquake and seismic intensity in each city was different. PGA of K-NET Sendai observation station was, however, not small; 1,808 (cm/c/c) according to Table1. This value is higher than most of cities listed in Figure 8. One of reasons of low damage rate in Sendai City seems to be high earthquake-proofing rate. The earthquake-proofing rate is defined as the piping length of ductile cast iron pipe with earthquake resistant joint and welded steel pipe divided by the total piping length. The earthquake-proofing rate of Sendai City is 51.2%.

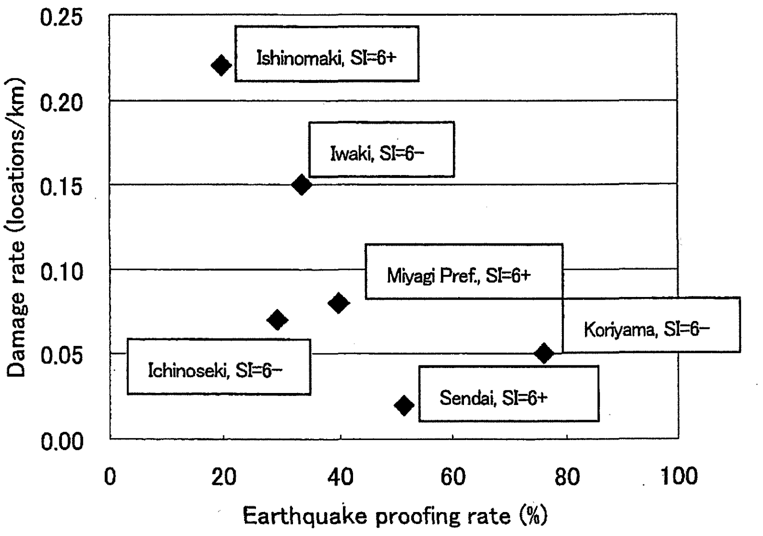


Figure 9 Relation between earthquake proofing rate and damage rate.

Figure 9 illustrates the relation between the earthquake-proofing rate and damage rate suffered damage in the 2011 great east Japan earthquake. The damage rate shown in this figure is calculated by using the damage to transmission and distribution main pipeline, that is, distribution branch pipeline is not included. This figure indicates that the higher the earthquake-proofing rate, the lower the damage rate is. There was no damage to the ductile cast iron pipe with earthquake resistant joint and welded steel pipe. Effect of earthquake-proofing pipe was, therefore, verified by the earthquake.

CONCLUDING REMARKS

An outline of the earthquake and damage to water supply facilities from the 2011 great eat Japan earthquake and tsunami was presented and the damage rate of pipeline was discussed. The following conclusions may be drawn based on the present study.

(1) The affected area was very large because of great earthquake and tsunami. Situation of emergency response and support from other cities must be reviewed.

(2) The entire damage to water supply pipelines is not revealed, especially flooded areas by tsunami. We must collect all damage data and analyze it to learn the lessons from this disaster.

(3) Effect of earthquake-proofing for pipeline was verified. We must accelerate the earthquake proofing, especially for aged facilities.

(4) Force of tsunami acted on a buried pipe is not clear. The effect of tsunami must be studied soon.

ACKNOWLEDGEMENTS

The present paper is based on the collected from an investigation by reconnaissance team of the Ministry of Health, Labor and Welfare, Japan. Many individual and organizations generously helped with this investigation.

REFERENCES

1) http;www.seisvol.kishou.go.jp.

2) http://www.kyoshin.bosai.go.jp/kyoshin.

3) Tohoku Earthquake Tsunami Joint Survey Group; fttp;//www.coastal.jp/ttjt.

4) Earthquake Engineering Research Institute; Learning from Earthquakes The Tohoku, Japan, Tsunami of March 11, 2011; Effects on Structures, EERI Special Earthquake Report, September 2011.

5) Ministry of Land, Infrastructure, Transport and Tourism, 2001 Great East Japan Earthquake -Affected Disaster Status Survey Results, 1st Report Press Release, August 4 (in Japanese).

6) http://www.pref.miyagi.jp/kigyo/

7) http://www.minami-nagareyama.org/20110311/report03a.htm

[The 7th Japan-US-Taiwan Workshop on Water System Seismic Practices, paper]

Technical Assistance Tools for Improving Earthquake Resistance of Drinking Water Infrastructure

M. Kanmatsuse*, W. Adachi*, S. Ando*, M. Fujiwara* and M. Miyajima**

*Japan Water Research Center, 8-1, Toranomon 2-chome, Minato-ku, Tokyo, 105-0001, Japan
(E-mail: kanmatsuse@jwrc-net.or.jp, adachi@jwrc-net.or.jp, ando@jwrc-net.or.jp, fujiwara@jwrc-net.or.jp)
**Kanazawa University, Kakuma-machi, Kanazawa, Ishikawa, 920-1192, Japan
(E-mail: miyajima@t.kanazawa-u.ac.jp)

INTRODUCTION

Located in one of the most seismically active areas in the world, Japan is frequently hit by large-scale earthquakes such as the 2011 off the Pacific coast of Tohoku Earthquake. As such earthquakes cause extensive damage to drinking water infrastructure, strengthening of the earthquake resistance of drinking water infrastructure has become a major issue for drinking water utilities, along with the renovation of aging facilities.

With the aim of constructing drinking water infrastructure that can withstand earthquakes, the Japan Water Research Center (JWRC) has conducted various studies and developed tools to support utilities. Some of the outcomes are explained below.

MANUAL FOR SIMPLE METHODS TO ASSESS EARTHQUAKE RESISTANCE

To assist drinking water utilities, JWRC has developed methods for assessing infrastructure such as pipelines and purification plants. Because conventional assessment methods are comparatively difficult to perform and are only intended to evaluate individual components of infrastructure, we have developed a method for assessing the performance of drinking water infrastructure to allow under-resourced utilities to easily evaluate it. This method is described in the *Manual for Assessing Performance of Drinking Water Infrastructure*. The manual is designed to allow utilities to improve performance through the evaluation of the function of infrastructure from intake facilities to distribution systems. It includes evaluation of the earthquake resistance of infrastructure via a check sheet. The contents of the manual are explained below, with a focus on earthquake resistance.

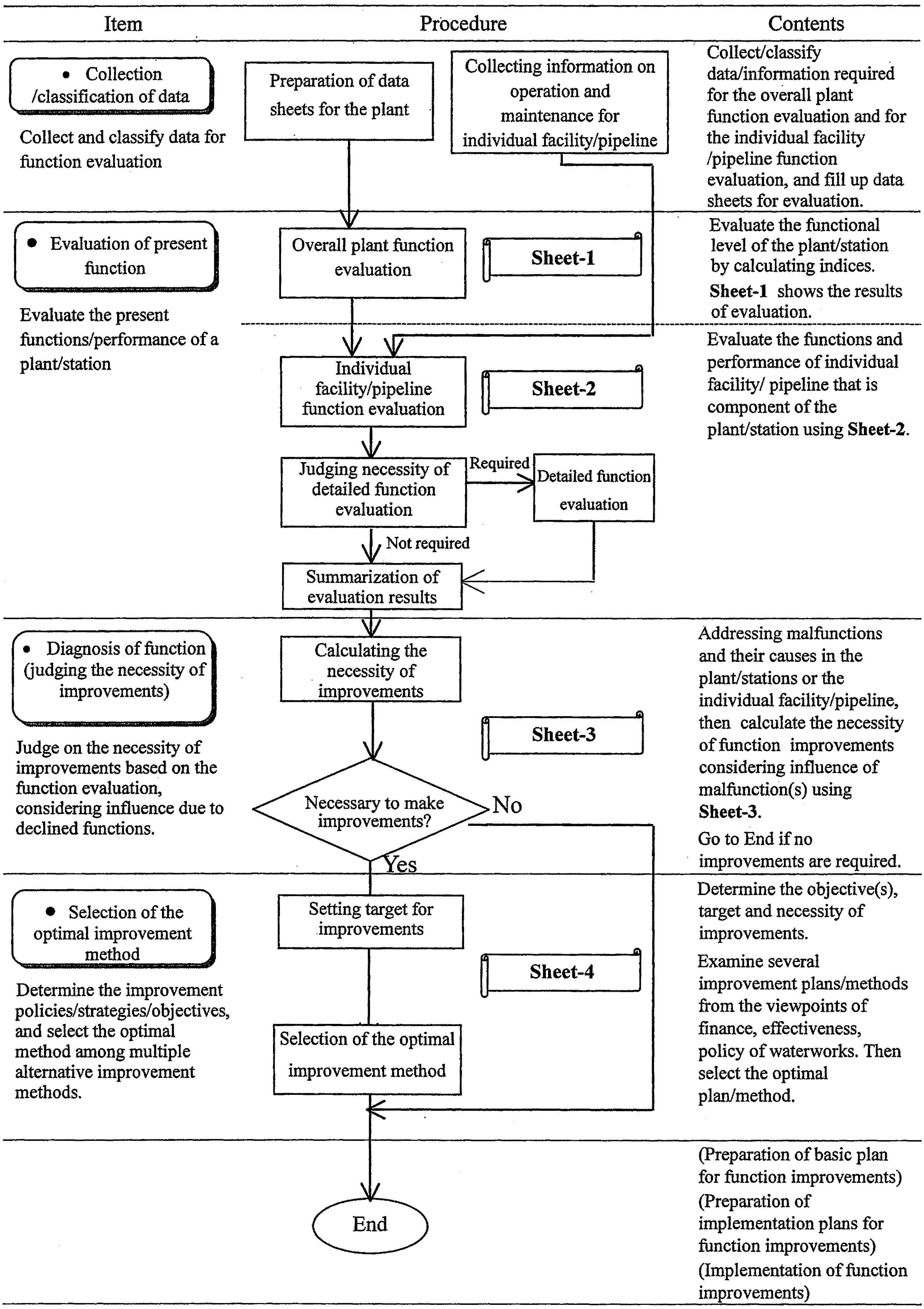


Figure 1: Procedure of performance assessment (P/A)

Function Evaluation of the Whole Plant

The overall function is evaluated by indices defined for each component. Through the comprehensive evaluation of the whole plant, components that have reduced functioning can be identified.

The evaluation indices include ratios of earthquake-resistant distribution reservoirs and pipelines. These indices allow plants with insufficient earthquake resistance to be filtered out. The evaluation indices for a distribution systems and its partial evaluation result are shown as an example in Fig. 2.

Evaluation index		Score
Complaint incidences (red water)	(-)	3 points
Complaint incidences (excluding red water)	(-)	1 points
Ratio of aged pipelines	(%)	2 points
Accidents to water mains	(per 100km)	3 points
Ratio of earthquake-resistant pumping stations	(%)	3 points
Ratio of earthquake-resistant distribution reservoirs	(%)	3 points
Ratio of earthquake-resistant water mains	(%)	3 points
Degree of aging of the distribution reservoirs	(%)	3 points
Ratio of asbestos pipes	(%)	2 points

Fig. 2: Example of evaluating the function of an entire distribution plant.

Function Evaluation per Facility

An individual function evaluation can be used to evaluate the current status of each component. For this purpose, an earthquake resistance check sheet is prepared for each of the following components to enable a simple evaluation:

Intake weir, deep well, intake tower & distribution tower, shallow well, intake gate, open ditch & closed ditch, conveyance tunnel, pumping stations, no-covered basin structure (sedimentation basin, receiving basin, filter basin, etc.), covered basin structure (clear water reservoir, distribution reservoir, etc.), pre-stressed concrete (PC) tank, elevated water tank, water pipe bridge (steel pipe: Table 1), bridge-attached pipe (steel pipe), water pipe bridge (ductile cast iron pipe & grey cast iron pipe), and bridge-attached pipe (ductile cast iron pipe & grey cast iron pipe).

An evaluation is performed by first selecting an applicable category (weighting factor) for each evaluation item. Multiplying all scores together gives a measure of earthquake resistance for an expected seismic intensity. The final score gives an evaluation of high, medium, or low earthquake resistance.

Table 1: Check sheet for evaluating earthquake resistance of infrastructure: water pipe bridge (steel pipe).

Facility types	Water pipe bridge (ductile cast iron pipe & grey cast iron pipe)			
Items	Category	Weighting factor	Points	Remarks
Ground*1	Type I	1.0		
	Type II	1.4		
	Type III	1.2		
Influence of ground deformation	No	1.0		
	Possible	2.0		
	Yes	3.0		
Foundation work	With piles	1.0		
	No piles, pile bend	1.4		
Materials for bridge abutment and pier	Bricks, plain concrete	1.4		
	Other	1.0		
Height of bridge abutment and pier	<5 m	1.0		
	5–10 m	1.4		
	>10 m	1.7		
Beam structure	Both ends fixed beam, arch, rigid frame	1.0		
	Free-fixed beam, continuous beam	2.0		
	Simple beam	3.0		
Number of spans	1	1.0		
	≥2	1.8		
Bridge shoe	With bridge failure prevention	0.6		
	Normal	1.0		
	Movable ends	1.2		
Crest width*2	Wide A/S ≥ 1	0.8		
	Narrow A/S < 1	1.2		
Flexible joint	Closer (eccentric type) Bellows (eccentric type)	0.8		
	Closer, Bellows	1.0		
	Dresser, Sleeve	1.5		
	None	2.0		
Seismic intensity	JMA intensity 5	1.0		
	JMA intensity 6	2.2		
	JMA intensity 7	3.6		
Earthquake resistance	High	<14		
	Medium	14–28		
	Low	>28		

*1 Type of ground

Type I: Hard diluvium ground and bedrock

Type II: Alluvium ground or diluvium ground, excluding Type I and Type III

Type III: Soft alluvium ground

*2 Crest width (see the figure below)

Crest width means the distance between edges of support-base and abutment.

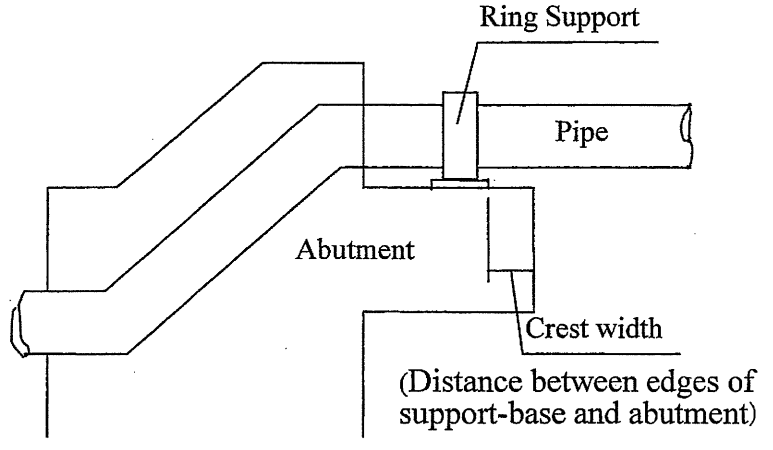
Abutment's strength in case of earthquake can be checked according to A/S.

A is an actual crest width.

S means required crest width to ensure sound abutment against vertical/horizontal force from ring-support in case of earthquake. S can be obtained from the following equation:

$$S=0.2+0.005L \quad (m)$$

Where, L is length of bridge-span. (L should be shorter than 100m.)



An example of evaluation using the check sheet is shown in Table 2.

Table 2: Example of evaluating a water pipe bridge (steel pipe).

Items	Category	Weighting factor	Points (example)
Ground	Type II	1.4	1.4
Influence of ground deformation	No	1.0	1.0
Foundation work	With piles	1.0	1.0
Materials for bridge abutment and pier	Bricks, plain concrete	1.4	1.4
Height of bridge abutment and pier	5–10 m	1.4	1.4
Beam structure	Free-fixed beam, continuous beam	2.0	2.0
Number of spans	1	1.0	1.0
Bridge shoe	Normal	1.0	1.0
Crown width	Wide A/S ≥ 1	0.8	0.8
flexible joint	Closer	1.0	1.0
Seismic intensity	JMA intensity 6	2.2	2.2
Earthquake-resistance	High	<14	9.66

The multiplication result of 9.66 gives an evaluation of high earthquake resistance.

The earthquake resistance check sheet has a few caveats:

・Although the Japan Meteorological Agency's seismic intensity scale was changed in 1996, the evaluation sheet is still based on the old one.

・The evaluation does not yet take into account ground motion (2 levels), the importance of a facility (3 ranks), and the expected earthquake resistance (3 levels), as defined in the *Seismic Design and Construction Guidelines for Water Supply Facilities*.

Because of these inconsistencies, starting in fiscal year 2011, JWRC has begun revising the check sheet with the help of a Health Labour Sciences Research Grants from the Ministry of Health, Labour and Welfare.

HANDBOOK FOR JUDGING GROUND CONDITIONS FOR EARTHQUAKE-RESISTANT K-DCIP (K-joint ductile cast iron pipe)

Types of pipes in Japan

The main types of buried water pipes are ductile cast iron pipes (DCIP), grey cast iron pipes (CIP), steel pipes (SP), polyethylene pipes (PE), polyvinyl chloride pipes (PVC), and asbestos cement pipes (ACP).

In Japan, ductile cast iron pipes account for 60% of the total length of water pipes. Since earthquake damage to these pipes primarily consists of joint disengagement, joint structures have been improved. Joints for ductile cast iron pipes are mainly divided into Types A, T, K, S, S-II, and NS (Table 3). Types S, S-II, and NS are seismic joints with high earthquake resistance.

Table 3. Characteristics of joint types

Joint	Characteristics
Type A	The socket is fitted with a rectangular rubber gasket, and together with a gland, it is connected by tightening the bolt.
Type T	The socket is fitted with a rubber gasket and can simply be connected by inserting the spigot.
Type K	The single use of a rectangular rubber gasket in Type A is modified and a combined rectangular/round rubber gasket is used.
Type S, Type S-II	The socket is fitted with a rubber gasket and a lock ring and can be connected by inserting the spigot. The joint has high elasticity, flexibility, and a disconnection prevention mechanism, and thus has superior earthquake resistance.
Type NS	The earthquake resistance of the joint is the same as Type S, but has better workability.

Table 4. History of the use of joints.

1961	1971	1982	1999 to now
Type A	Type A	Type A	
	Type K, Type T	Type K, Type T	Type K, Type T
		Type S, Type S-II	Type S, Type S-II
			Type NS

Source: Japan Water Works Association (JWWA)

The more recent joints bend and expand substantially to accommodate differential settlement of soft ground and large ground deformation so as to prevent joint disengagement. In the South Hyogo Prefecture Earthquake, no damage was caused to pipes with a joint disengagement prevention mechanism (Fig. 3), demonstrating the high earthquake resistance of Types S and S-II. Subsequently, based on damage data from this earthquake, an easy-to-install NS joint (Fig. 4) was developed to promote the widespread use of seismic pipes.

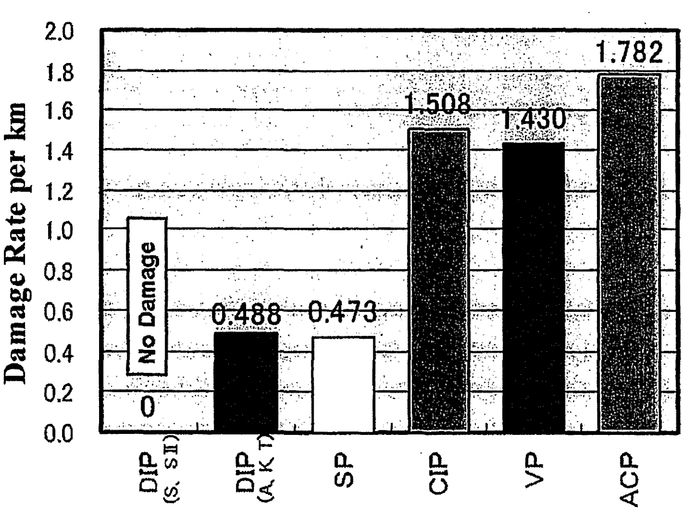


Fig. 3: Pipe damage from 1995 Hyougoken-Nambu earthquake.

On the other hand, research on the

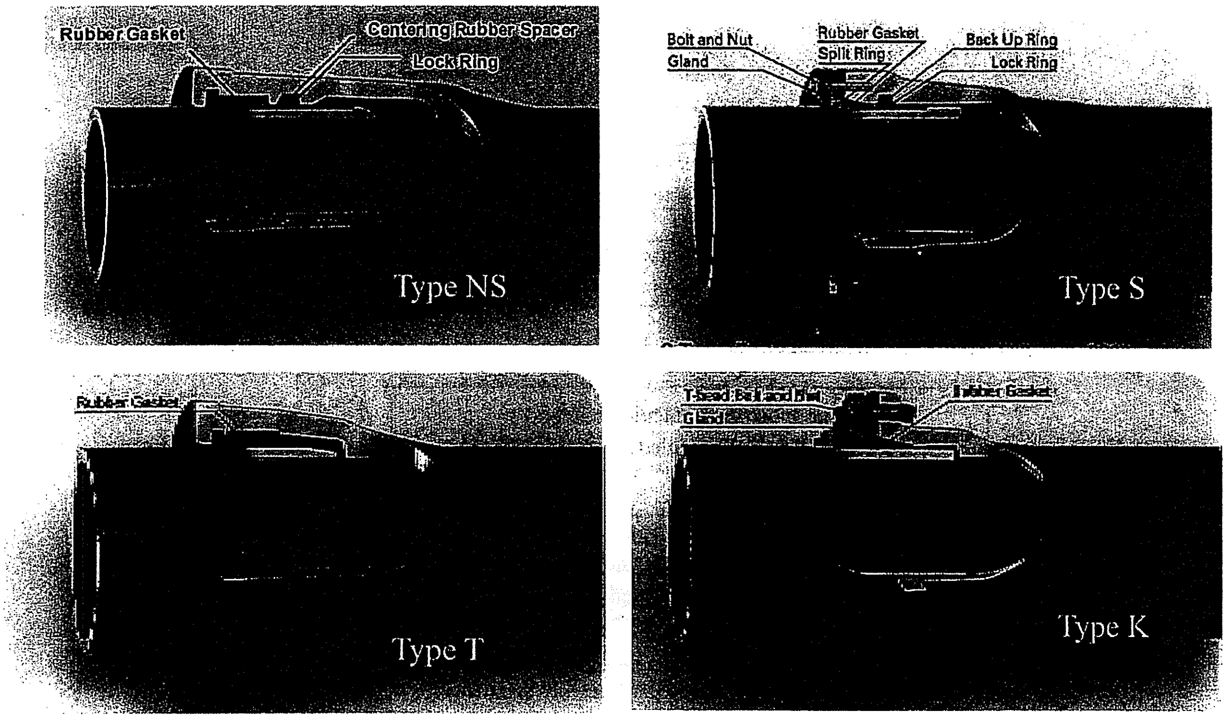


Fig. 4: Structural drawing of ductile cast iron pipe.

damage sustained by pipelines during previous earthquakes shows that the condition of the ground where the pipes are laid has a large effect on the damage. According to the *Report of the Review Commission on the Improvement of the Earthquake Resistance of Water Pipelines* (March 2007, Ministry of Health, Labour and Welfare), a type K joint (including type T joints shipped after 1999) DCIP laid in ground in good ground condition can be deemed earthquake resistant. However, although many methods have been proposed to evaluate ground conditions to determine whether pipelines are earthquake resistant, none offered a tangible and unified method that could be used by small to middle-sized utilities to form a judgment with ease.

For this reason, JWRC set up a review team to develop a tool to help in judging ground condition in June 2010 and compiled the *Handbook for Judging Ground Conditions for Earthquake-Resistant K-DCIP*. This handbook describes a method to judge from ground conditions whether DCIPs with various types of joints have the required earthquake resistance. At the same time, it can assist in prioritizing and planning infrastructure works and provide information that can be used when supporting documents are prepared for securing budgets.

Method for Judging Ground Conditions

The approach behind ground conditions. Earthquake damage to pipelines occurs in areas where ground strain caused by seismic motion is large and where ground failure (deformation, liquefaction, etc.) occurs. As it is impossible to comprehend all necessary ground information on these areas, the method uses a landform classification that provides general information such as terrain morphology and period of formation to produce a comprehensive prediction of the extent of earthquake damage to pipelines.

Summary of judgment methods. The handbook describes a comparatively simple method using a 1-km mesh and a comparatively detailed method using a 250-m mesh.

Judgment method 1. 1-km-mesh landform classification data provided by the National Land Numerical Information service are used to make simple judgments on earthquake resistance from ground conditions.

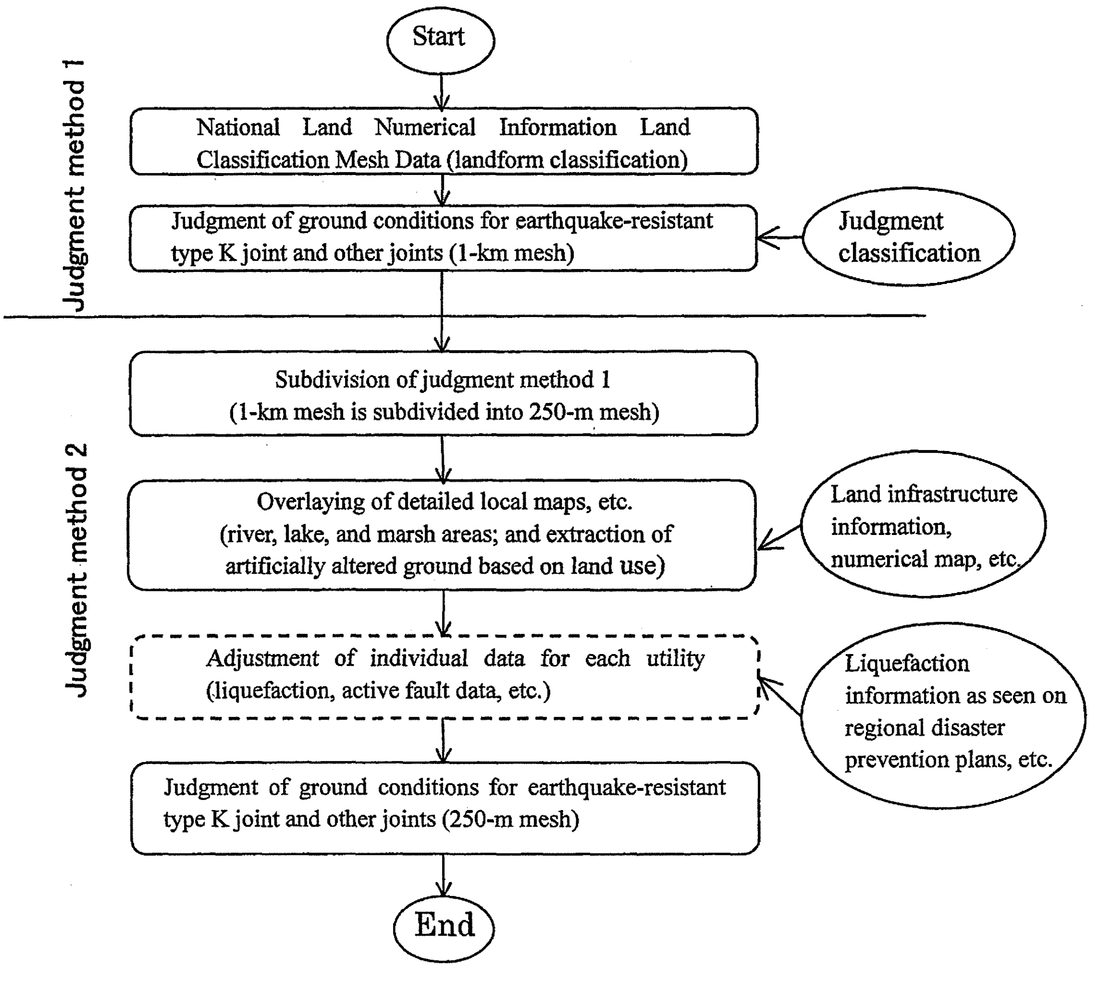


Fig. 5: Flowchart for ground condition judgment

The classification of ground conditions for earthquake resistance is shown in Table 5, and the judgment of ground conditions based on method 1 is shown in Fig. 6.

Judgment method 2. 250-m-mesh data are used, and other data such as landfill and liquefaction maps are overlaid. Two methods were considered. The first method uses the 1-km-mesh used in method 1 along with a landform classification map to enable detailed judgment. The second method uses the Japan Seismic Hazard Information Station (J-SHIS) data created by the National Research Institute for Earth Science and Disaster Prevention. Although the second method can give a more accurate judgment, it requires more time and cost for collecting information and for making judgments.

The result of a judgment is shown in Fig. 7.

Verifying the Validity of the Judgment Methods

The judgment achieved by method 2 and the actual location of water pipeline damage that occurred as a result of the 2007 Chūetsu offshore earthquake are overlaid for comparison in Fig. 7. The bulk of the damage caused by the earthquake occurred in the areas judged as having no earthquake resistance. Thus, method 2 has high accuracy and high validity. Judgment method 2 using the J-SHIS data achieved a similar validity.

Table 5: Judgment of ground conditions for DCIP type K joint

Classification (judgment)	Ground conditions for DCIP type K joint (National Land Numerical Information land classification mesh data)	Referenced documents		
		FY 2007 Drinking Water Statistics Questionnaire (MHLW)	Estimation of earthquake damage to pipeline (JWWA)	Manual for zoning areas of liquefaction (Disaster Prevention Bureau of National Land Agency)
Areas with earthquake resistance	High-, middle-, and low-relief mountains, foothills; high-, middle-, and low-relief volcanic mountains, foothills; high, low, and volcanic hillocks; volcanic alluvial fan, volcanic sand plateau, loam upland, *shirasu* plateau, sandy gravel plateau and terrace, bedrock plateau and terrace, lava plateau, limestone plateau	Good ground conditions Ground other than the soft grounds listed below	Good ground conditions High-quality ground, alluvial plains, (modified mountain land, modified hillock)	No liquefaction Upland, hillock, mountain land
Areas without earthquake resistance	Natural levee and sandbar, alluvial lowland and lowland colluvium, lowland flood plain, delta lowland, dune lowland, lakes and marshes, rivers, former lake basin infilled lowland, artificially modified land, reclaimed land, dyked land, tidal flat, volcanic ash- and sand-strewn area, lava field, landslide terrain, colluvial terrain	Poor ground conditions ① Reclaimed land and landfill ② Possible liquefaction and lateral flow areas ③ Landslide zone ④ Soft ground ⑤ Active fault zone	Poor ground conditions Valley, former water areas (re-claimed land)	Possible liquefaction Ground other than listed above

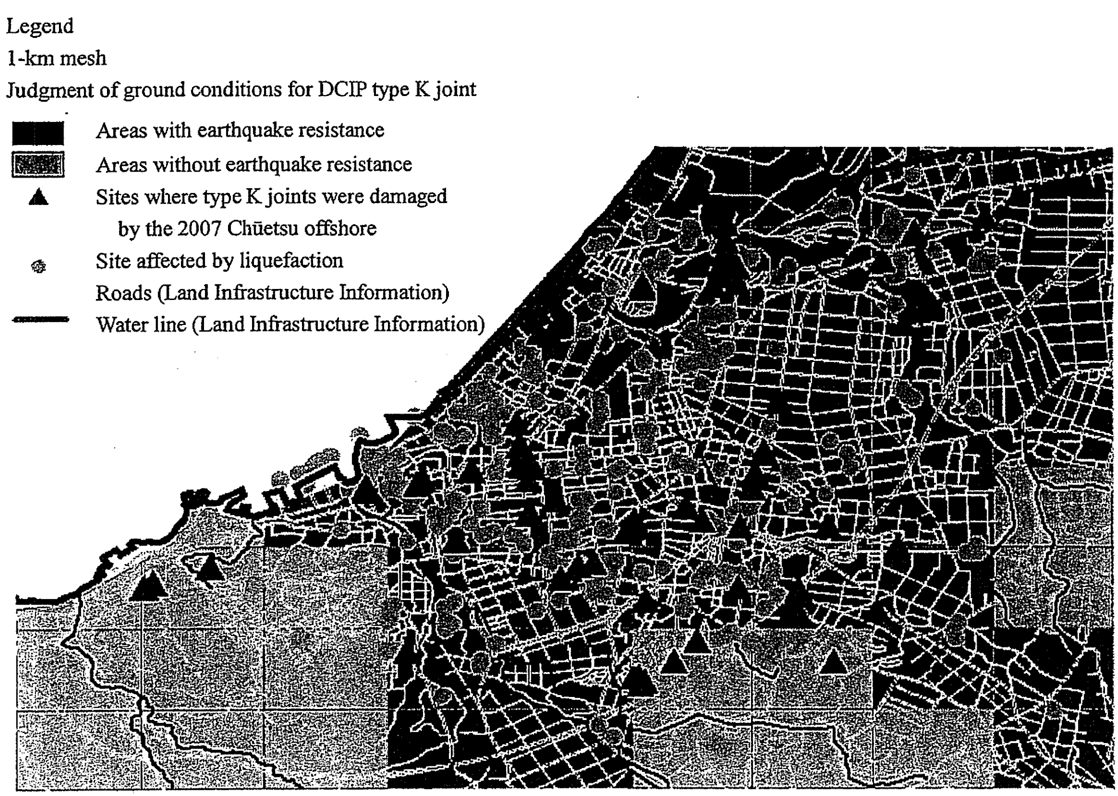


Fig. 6: Judgment of ground conditions based on method 1

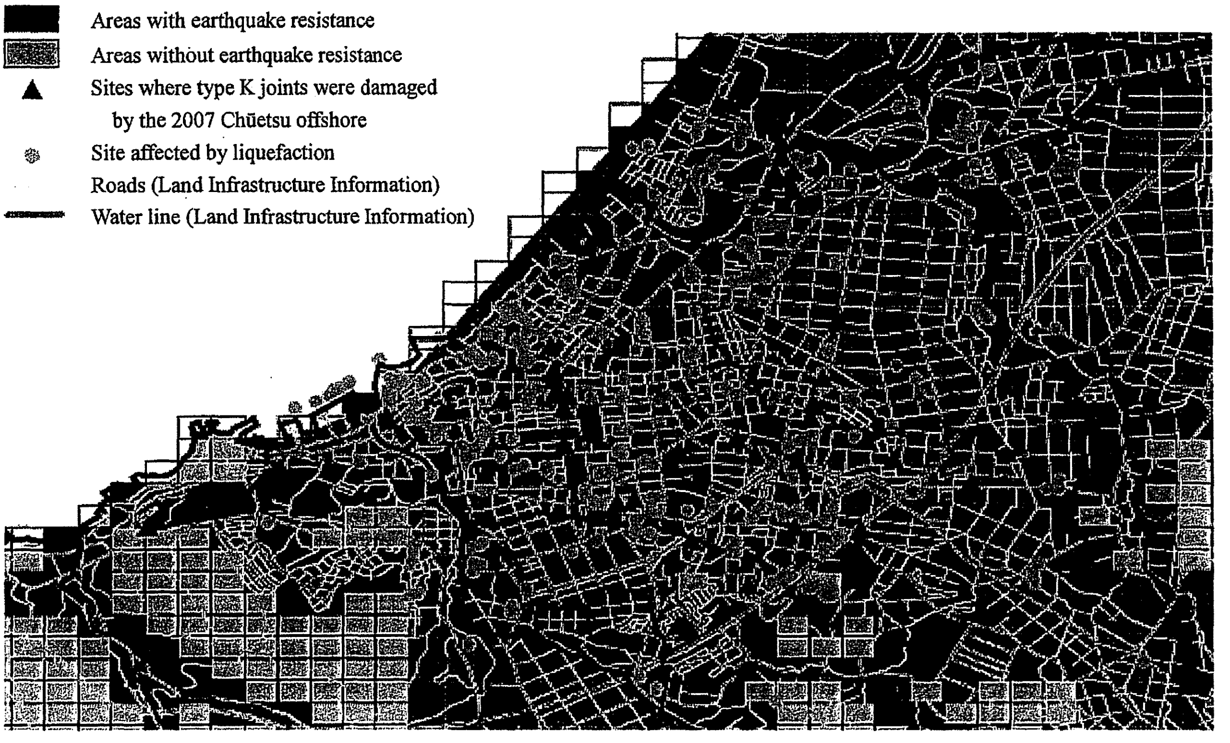


Fig. 7: Judgment of ground conditions based on method 2

CONCLUSIONS

• To overcome the inherent vulnerability of drinking water infrastructure associated with deterioration, its current condition must be properly evaluated, and optimum but realistic plans to improve weakening functions must be formulated and promptly executed. The performance assessment manual was created to achieve this at small-scale drinking water utilities. It is recommended that utilities use this manual to systematically and efficiently renovate their infrastructure.

• Simple methods for judging the earthquake resistance of ground where ductile cast iron pipes with type K joints are laid are based on landform and ground condition classifications. Although the methods are simple and can offer only a broad judgment, they can be used by utilities all over Japan. The handbook for judging ground conditions can be of great use in the reviewing of the earthquake resistance of current pipelines and in the planning of renovations. We believe that it will prove useful when utilities plan the enhancement of earthquake resistance and the required finances.

経年化浄水施設における

原水水質悪化等への対応に関する研究

総合研究報告書

添付資料

添付資料　目次