Procedure of the new and Revised SEM. The Diagnostic Sheet approach needs to be simplified if an increased number of smaller utilities are to be encouraged to undertake more appropriate seismic countermeasures. Based on the two observations (1) grading every index can be difficult in some cases, and (2) that the critical damage was the result of the liquefaction effect, we propose the Revised SEM procedure as follows (Figure 1):

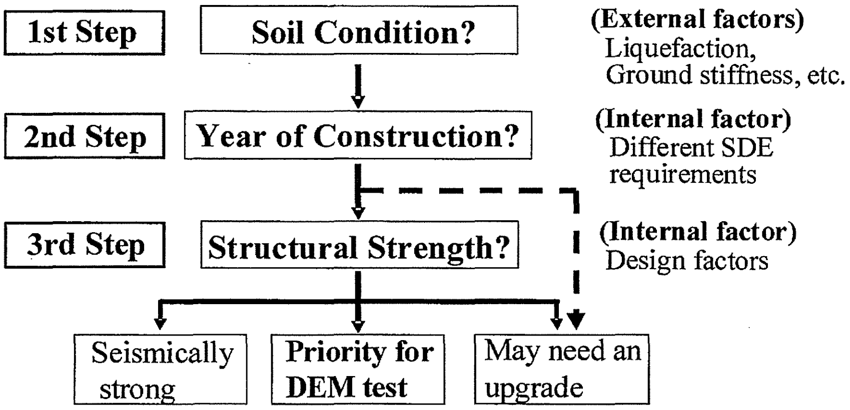

Figure 1. Procedure of Revised SEM

First step: Evaluate the target structure according to external factors. External factors include ground stiffness, possibility of liquefaction, and ground formation. This evaluation is reasonable as these factors seem to account for far more cases of damage than other factors.

Second step: Evaluate the target structure by the year of construction. As we have mentioned, structures must be designed in compliance with the latest SDC available at the time, and the SCD's requirements vary depending on its edition. The year of construction helps to identify the levels of seismic design adopted by the target.

The first and second step can be done in the reversed order or simultaneously.

Third step: Assessment of structural load-bearing capacity. For the structures that passed the first and second steps, assess their structural resistibility against seismic motion, that is, their structural load-bearing capacity.

Considerations on structural load-bearing capacity. To find issues of the current Diagnostic Sheet in assessing the structural resistibility against seismic motion, and to examine the appropriateness of the indices adopted in the Sheet, we applied the current SEM to two groups of rectangular clear-water tanks/distribution reservoirs (reservoirs) in several water utilities.

The first group of reservoirs (Group 1) is shown in Table 2. Group 1 was designed based on older SDCs and, as a result of DEM by the respective utilities, assessed to be seismically vulnerable. The DEM result indicated that major defective structural members were the side walls and pillars, with their edges especially vulnerable as the stress concentrates due to ground shaking.

Table 2. Reservoirs conforming to older SDCs (Group 1)

Facility	Construction Year	Structure Type	Capacity	Water Depth	Foundation Type
Reservoir A	1980	RC Flat slab (inground)	7,200 m^3	4.5m	Piled
Reservoir B	1989	RC Flat slab (inground)	5,000 m^3	4.5m	Spread
Reservoir C	1977	RC Flat slab (inground)	500 m^3	4.3m	Spread
Reservoir D	1976	RC Flat slab (inground)	300 m^3	3.2m	Spread
Reservoir E	1962	RC Wall (inground)	700 m^3	3.5m	Spread
Reservoir F	1977	RC Wall (semi inground)	330 m^3	3.5m	Spread
Reservoir G	1980	RC Wall (inground)	200 m^3	2.7m	Spread

Table 3 shows the second group of reservoirs (Group 2). Group 2 conforms to the latest SDC and thus considered seismic proof. For this reason this Group had not been DEM-tested.

Table 3. Reservoirs conforming to the latest SDC (Group 2)

Facility	Construction Year	Structure Type	Capacity	Water Depth	Foundation Type
Reservoir H	2011	RC Flat slab (inground)	32,600 m^3	6.4m	Spread
Reservoir I	1999	RC Flat slab (inground)	24,000 m^3	5.3m	Spread
Reservoir J	1999	RC Flat slab (semi inground)	4,500 m^3	4.4m	Spread
Reservoir K	2000	RC Flat slab (semi inground)	8,500m^3	3.5m	Spread
Reservoir L	2008	RC Flat slab (semi inground)	700m^3	4.0m	Spread
Reservoir M	2000	RC Flat slab (semi inground)	1,000m^3	5.0m	Spread
Reservoir N	2007	RC Flat slab (semi inground)	130m^3	5.0m	Spread

We applied the current SEM to Group 1 and Group 2. As shown in Table 4, Group 1 reveals the seismic resistance of either Low or Middle, while Group 2 marks Middle or High. Although some reservoirs in Group 1 get better points than ones in Group 2, the result seems relatively reasonable.

Table 4. Result of Diagnostic Sheet assessment

	Group 1 (Seismically Vulnerable)							Group 2 (Seismic Proof)						
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Ground Stiffness	1.5	1.5	1.8	0.5	0.5	0.5	0.5	1.5	1.5	0.5	0.5	0.5	0.5	0.5
Liquefaction	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Ground Formation	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Basement Level	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0	1.1	1.1	1.1	1.1	1.2
Material	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Wall Area/Water Area	1.5	1.5	1.0	1.5	1.0	1.5	1.5	1.5	1.5	1.5	1.5	1.0	1.0	1.0
Depth of Reservoir	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.3	1.3	1.3	1.0	1.0	1.3	1.3
Modeling Type	1.4	1.4	1.4	1.4	1.4	1.0	1.0	1.4	1.4	1.4	1.4	1.4	1.4	1.0
Upper Load	1.0	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.2	1.0	1.2	1.0	1.2	1.0
Construction Year	1.5	1.0	1.5	1.5	1.5	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Flexible Joint (pipe)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Expansion Joint (wall)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Aging	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Seismic Intensity	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Score	**51.0**	**40.8**	**40.8**	**17.0**	**11.3**	**13.4**	**13.4**	**14.7**	**17.7**	**5.4**	**5.0**	**2.8**	**4.3**	**2.8**
Seismic Resistibility	Low	Low	Low	Low	Mid.	Mid.	Mid.	Mid.	Mid.	High	High	High	High	High

On the other hand, Table 5, which is an extract from Table 4, shows the indices related to the structural resistibility. On average, Group 2 marks higher scores (meaning seismically weaker) than Group 1, and this symptom is obvious in some of the shaded reservoirs in Table 5.

Table 5. Result of Diagnostic Sheet assessment for structural resistibility (extract)

	Group 1 (Seismically Vulnerable)							Group 2 (Seismic Proof)						
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Basement Level	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0	1.1	1.1	1.1	1.1	1.2
Material	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Wall Area/Water Area	1.5	1.5	1.0	1.5	1.0	1.5	1.5	1.5	1.5	1.5	1.5	1.0	1.0	1.0
Depth of Reservoir	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.3	1.3	1.3	1.0	1.0	1.3	1.3
Modeling Type	1.4	1.4	1.4	1.4	1.4	1.0	1.0	1.4	1.4	1.4	1.4	1.4	1.4	1.0
Upper Load	1.0	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.2	1.0	1.2	1.0	1.2	1.0
Score	**2.1**	**2.5**	**1.4**	**2.1**	**1.4**	**1.7**	**1.7**	**2.7**	**3.3**	**3.0**	**2.8**	**1.5**	**2.4**	**1.6**

While Group 2 showed high scores in the overall assessment result (Table 4), it did not perform as well in the structural resistibility analysis (Table 5).

The current structural analysis works in disfavor of a structure with a wider wall and/or area. The water area of a larger reservoir naturally becomes wider, but this translates into a lower assessment of “Wall area/Water area,” and thus into a lower structural resistibility assessment, whereas the same structure may be assessed “seismic proof” in the overall assessment. The main cause of the problem is: whereas five indices in Table 5 (basement level, material, reservoir depth, modeling type, upper load) only represent design conditions having little impact on the structural resistibility assessment, “Wall area/Water area” influences the assessment disproportionately as the single most important index.

Judging from the above, it seems that the current Diagnostic Sheet needs to incorporate other indices more relevant to the structural resistibility. These indices may include “thickness of structural components,” “weight of reinforcement bars” or “ratio of wall thickness to water depth.” Factoring in these aspects could make the structural assessment more accurate and in turn improve the Diagnostic Sheet approach.

From this standpoint, we continue to collect more DEM test results on structures based on older SDCs, as well as the structural design information from latest-SCD-based structures. By analyzing these data through the current SEM and then comparing its results with the Revised SEM test results, we will appraise its applicability to assessing actual facilities.

CONCLUSIONS

The investigation into the damage by the Great East Japan Earthquake showed the facilities had suffered most from the ground failure due to liquefaction. On the other hand, the impact from other effects was almost insignificant.

The observations from this investigation and the case study made it possible for us to identify some weaknesses of the current Diagnostic Sheet. In response we proposed a Revised SEM procedure consisting of three steps factoring in the possibility of liquefaction, year of construction, and structural strength. Founded on the observations from the current SEM Diagnostic Sheet as well as the recent earthquakes, this approach will be simpler and easier-to-use than the current SEM, allowing for more practical assessment of “seismic preparedness” of the target structure.

One of the items for further consideration is to develop a more suitable assessment method of the structural resistibility. One promising revision is to add new indices which may allow for a more accurate structural analysis. After combining all these updates in the current framework of the Revised SEM, we will compile its methodology into a guidebook for practical application in small-scale water systems.

We hope this research and its fruit will contribute to promotion of earthquake proofing of drinking water infrastructure in Japan.

ACKNOWLEDGEMENT

We extend our sincere gratitude to everyone involved in this research project for their generous support.

REFERENCES

M. Miyajima. (2011). "Characteristics of damage to drinking water facilities in the 2011 Great East Japan Earthquake." *Proceedings of the 3rd Symposium on Impact Reduction Measures for Lifeline Systems considering their Interrelations*, 43-47.

Japan Water Works Association. (1997). *Guidelines for Earthquake-Resistant Design Methods for Waterworks Facilities 1997.*

Damage to Water Supply Pipelines in the 2011 Great East Japan Earthquake

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ABSTRACT

This paper is focusing on damage to water supply pipelines during the 2011 great east Japan Earthquake. Severe damages were occurred not only to houses and buildings but also lifeline facilities including water supply facilities by this earthquake and tsunami. Water supply pipelines were damaged by strong ground motion and/or soil liquefaction. Outline of the damage is given first. Then the damage analysis is done by using GIS database of water supply pipelines and its damage. Lessons learned regarding the earthquake performance of water supply pipeline are summarized.

INTRODUCTION

The earthquake occurred on March 11, 2011 at 14:46 JST in the north-western Pacific Ocean at a relatively shallow depth of 32 km, with its epicenter approximately 72 km east of the Oshika Peninsula of Tohoku region, Japan. A JMA (Japan Meteorological Agency) seismic intensity of 7, that is, the maximum grade of JMA scale was recorded at K-NET Tukidate 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 about 20,000 deaths and missing and injured about 6,000 people.

Water supply facilities were damaged severely and a suspension of water supply was occurred at about 2.57million houses in the wide area from Tohoku to Kanto regions just after the earthquake. This paper introduced an outline of the damage to water supply pipelines during this earthquake and the damage analysis done to the pipelines buried in liquefied areas and strong ground motion areas.

OUTLINE OF EARTHQUAKE AND DAMGE TO WATER SUPPLY FACILITIES

The earthquake was initially reported as 7.9 *Mw* by the United States Geological Survey (USGS) before it was quickly upgraded to 8.9 *Mw* then finally to 9.0 *Mw*. This earthquake is the fourth largest in the world since 1900 and largest in Japan recording started 130 years ago. Figure 1 shows a distribution of JMA seismic intensity. This figure indicates large seismic intensity over 6- was recorded at many

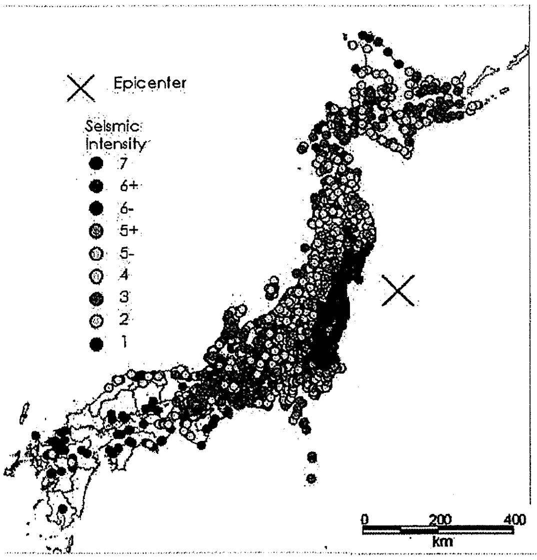

Figure 1. Distribution of JMA seismic Intensity (Japan Meteorological Agency).

Table 1. Large PGA observation stations (National Research Institute for Earth Science and Disaster Prevention).

	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

sites not only at Tohoku region but also at Kanto region. Table 1 lists observation sites where large peak ground acceleration (PGA) was recorded. PGA and PGV (peak ground velocity) listed here are vectorial summation of three components. The maximum PGA was 2,933 (cm/s/s) at K-NET Tsukidate observation station and the maximum PGV also recorded at Tsukidate. More than 1G (=980 cm/s/s) of PGA was observed at the nineteen observation stations of K-NET and KiK-NET observation networks.

Damage to water supply facilities was slight for the scale of the earthquake. Main facilities of water supply system are usually set in hill side far from sea. They did not suffer severe damage by the tsunami. Water resources and water pipe bridges on river near coastal area, however, suffered typical tsunami damages. Some points of ground water from well nearby coast were salinated for a long time and water pipe bridges were flowed out by the tsunami. The severest damage to water treatment facilities occurred by liquefaction. The typical cases happened in Chiba and Ibaragi Prefectures in Kanto region. Pipeline damage was also slight correspond to the past severe earthquake such as the 1995 Kobe Earthquake. This paper focuses on damage to pipeline buried in liquefaction area and strong ground motion area where the relatively severe damages to pipeline were occurred.

PIPELINE DAMAGE IN LIQUEFACTION AREA

Extensive liquefaction happened in Chiba and Ibaragi Prefectures in Kanto region. Especially liquefaction in filled land in Urayasu City of Chiba Prefecture caused large ground settlements and severe damage to buried pipelines. The to water supply pipeline damages in the filled land in Urayasu City is introduced here.

Figure 2 illustrates a water supply pipeline network and sites of damage to buried pipeline in a part of Urayasu City. The area in a yellow line in this figure is a filled land and severe liquefaction occurred in this area. The total piping length in this area was 200.93 km and the number of damage was 321, so the damage rate is 1.60 cases/km. The damage rate of pipeline buried in the reclaimed land of Kobe, Ashiya and Nishinomiya Cities in the 1995 Kobe Earthquake was 1.77 cases/km. So, degree of damage was seems to be similar. PGV of about 30 cm/s of Urayasu City was, however, much less than that at Kobe area in the 1995 Kobe Earthquake.

So, degree of damage was seems to be similar. PGV of about 30 cm/s of Urayasu City was, however, much less than that at Kobe area in the 1995 Kobe Earthquake.

PIPELINE DAMAGE IN STRONG GROUND MOTION AREA

Maximum JMA seismic intensity of this earthquake was 7 in Kurihara City and the JMA seismic intensity in the surrounding cities and a town of Kurihara City was 6+. The damage to buried pipeline in Kurihara City and the surrounding cities and town, that is, Osaki City, Tome City and Wakuya Town is discussed here. Figure 3 illustrates distribution of JMA seismic intensity estimated by QuakeMap (National Institute of Advanced Industrial Science and Technology) and sites of damage to each pipe type of water supply pipeline in three cities and a town mentioned above. JMA seismic intensity estimated by QuakeMap is given in each 250 m cell. Table 2 lists a number of cells in each level of JMA seismic intensity of three cities and a town. 7.6% of the total area is 7 of JMA seismic intensity and 33.6% is 6+, 23.8% is 6- according to QuakeMap. Figure 4 illustrates an accumulated damage rate of each pipe type.

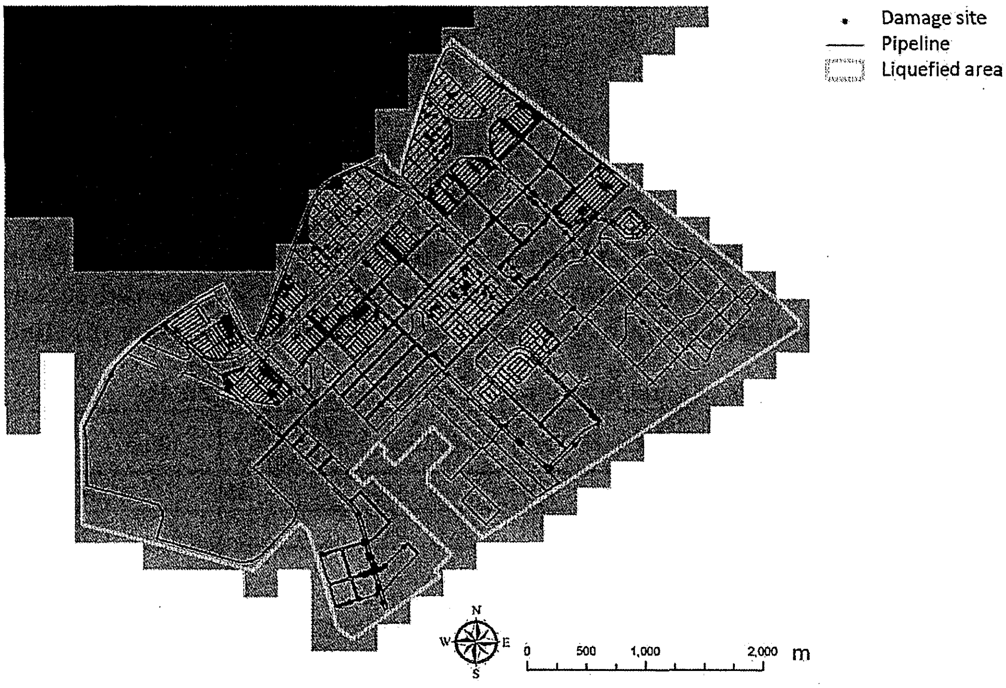

Figure 2. Water supply pipeline network and sites of damage to buried pipeline in a part of Urayasu City.

Figure 4 indicates that the damage to pipeline starts to occur at 5+ of JMA seismic intensity and the damage rapidly increases at 6+.

Micro topography classification map of J-SHIS surface ground (National Research Institute for Earth Science and Disaster Prevention) is used here. This data is also organized in 250 m cell. Micro topography classification is divided into two categories as same manner of "Handbook for help to determine earthquake-resistant compatibility of ductile iron pipe with K-type joints etc." shown in Table 3. Figure 5 illustrates distribution of ground categories, JMA seismic intensity and the sites of damage to each pipe type. Many damages occurred at the boundary between

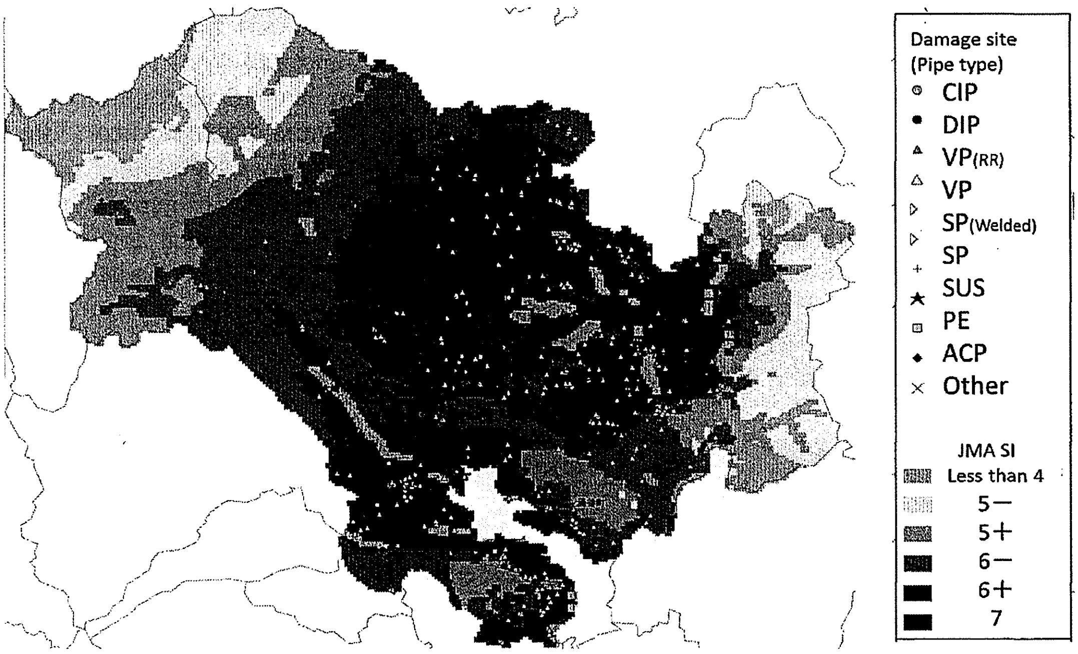

Figure 3. Distribution of JMA seismic intensity estimated by QuakeMap (National Institute of Advanced Industrial Science and Technology) and sites of damage to each pipe type of water supply pipeline.

Table 2. Number of cells in each level of JMA seismic intensity

JMA SI	Kurihara City	Osaki City	Tome City	Wakuya Town	Sum	Percentage
others	156	297	543	35	1,031	2.8%
less than 4	80	1,403	294		1,777	4.8%
5−	1,448	855	1,902	12	4,217	11.4%
5+	1,647	2,486	1,292	465	5,890	16.0%
6−	3,452	3,456	1,209	672	8,789	23.8%
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sum	13,235	13,340	8,888	1,427	36,890	100.0%

bad of micro topography classification category and more than 5+ of JMA seismic intensity, and others. Figure 6 illustrates a comparison of damage rate of each pipe type in micro topography classification category. This figure suggests that the damage rates in category of bad are much greater than those in category of good. It is also clarified that the damage rate of pipelines buried in the strong ground motion area and micro topography classification category of bad was lower than that in liquefaction area such as in Urayasu City.

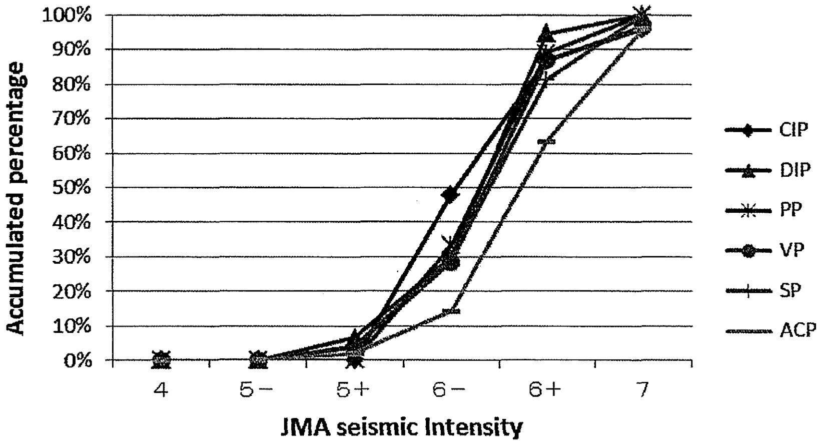

Figure 4. Accumulated damage rate of each pipe type.

Table 3. Micro topography classification and categories.

No	Microtopography	Category
1	Mountains	Good
2	Piedmont areas	
3	Hill	
4	Volcanic areas	
5	Volcanic piedmont areas	
6	Volcanic hills	
7	Mesa	
8	Quality gravel plateau	
9	Rohm plateau	
10	Lowland valley	Bad
11	Alluvial fan	
12	Natural levee	
13	Backswamp	
14	Old River Road	
15	Delta· Coastal lowland	
16	Reef· In gravel	
17	Dune	
18	Reef· Between the lowland dunes	
19	Reclaimed land	
20	Filled land	
21	Rocky· reef	
22	Riverside	
23	River channel	
24	Lake	

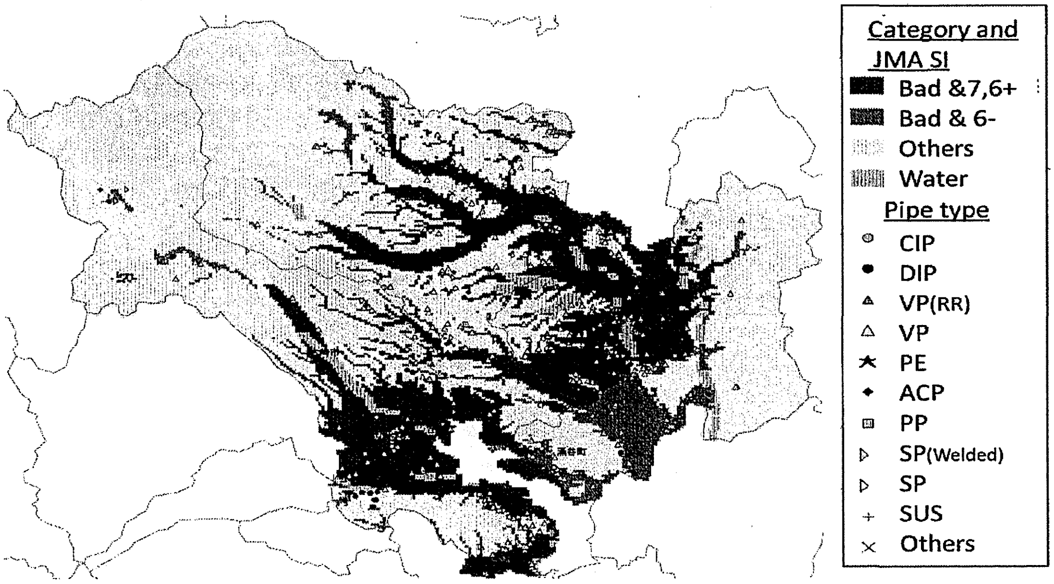

Figure 5. Distribution of ground categories, JMA seismic intensity and the sites of damage to each pipe type.

Table 4 lists a piping length in each level of JMA seismic intensity, categories of micro topography classification and pipe type. There was no damage to ductile iron pipe with earthquake resistant joint and polyethylene pipe with fusion bounding in this earthquake. According to Table 4, about 45km of earthquake resistant DIP and about 15km of PE with fusion bounding survived in the strong ground motion area, that is, JMA seismic intensity was more than 6- and micro topography classification category of bad.

CONCLUSION

An outline of the damage to water supply pipelines by the 2011 great east Japan Earthquake was given and the damage rate of pipeline was discussed. The following conclusions may be drawn based on the present study.

(1) The damage rate of water supply pipeline in filled land in Urayasu City was 1.60 cases/km. This value was similar to the damage rate of pipeline buried in the reclaimed land of Kobe, Ashiya and Nishinomiya Cities in the 1995 Kobe Earthquake.
(2) According to the data of Kurihara City, Osaki City, Tome City and Wakuya Town in Tohoku region, the damage to pipeline starts to occur at 5+ of JMA seismic intensity and the damage rapidly increases at 6+.
(3) The damage rates in micro topography classification category of bad were much greater than those in category of good.
(4) There was no damage to ductile iron pipe with earthquake resistant joint and polyethylene pipe with fusion bounding in this earthquake. About 45km of earthquake resistant DIP and about 15km of PE with fusion bounding survived in

the strong ground motion area, that is, JMA seismic intensity was more than 6- and micro topography classification category of bad.

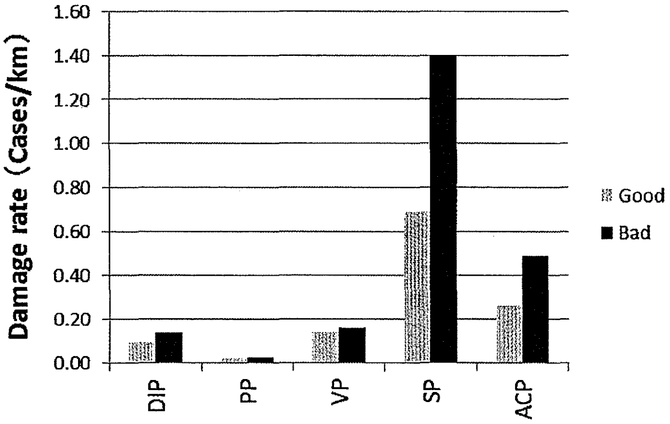

Figure 6. Comparison of damage rate of each pipe type in micro topography classification category.

Table 4. Piping length in each level of JMA seismic intensity, categories of micro topography classification and pipe type.

Unit:m

Category	JMA SI	CIP	DIP(ERJ)	DIP	PE(Fusion)	PP	VP	SP	SUS	ACP	other	Sum
Good	less than 4		1,499	1,232	12	4,860	10,915	180	75	52	0	18,825
	4					435	445	0			0	881
	5-		1,076	10,020	409	4,949	17,681	892	34	35	0	35,095
	5+	627	4,767	45,326	9,500	23,730	115,270	3,116	132	4,726	41	207,235
	6-	404	14,017	90,504	9,083	63,873	265,575	5,561	306	10,929	1,118	461,380
	6+	930	11,337	82,438	5,687	57,004	357,647	2,667	92	14,935	275	533,009
	7		900	21,545	613	10,029	79,164	682		15,743	53	128,730
Sum of good		1,961	33,596	251,064	25,304	164,880	846,696	13,098	639	46,420	1,487	1,385,154
Bad	less than 4	536	842	17,739	1,572	13,663	54,481	2,831	560	3,985	14	96,223
	5-			113		200	587	30	10		0	940
	5+		1,905	14,022	2,576	16,908	42,309	1,255	331	562	101	79,967
	6-	4,344	20,551	87,439	16,536	68,613	288,032	7,157	778	10,648	176	504,358
	6+	15,863	44,501	329,648	13,155	142,744	839,706	15,029	1,545	34,686	592	1,437,468
	7	4,499	1,974	38,234	1,614	28,999	154,013	1,582	140	23,753	333	255,139
Sum of bad		25,241	69,773	487,195	35,453	271,127	1,379,127	27,884	3,364	73,632	1,215	2,374,096
Sum		27,202	103,369	738,259	60,757	436,007	2,225,824	40,982	4,004	120,052	2,702	3,759,250

ERJ: Earthquake Resistant Joint

ACKNOWLEDGMENTS

The work described in this paper was supported by the Ministry of Education, Culture, Sports, Science and Technology, Grant-in-Aid for Scientific Research (B), No. 25289139. Staff of the waterworks of Urayasu, Kurihara, Osaki and Tome Cities and Wakuya Town is gratefully acknowledged for offer of rich data of pipeline and its damage.

REFERENCES

Japan Meteorological Agency (2011) *About the 2011 off the pacific coast of Tohoku earthquake (28th report), (written in Japanese)*

Japan Water Research Center (2011) *Handbook for help to determine earthquake-resistant compatibility of ductile iron pipe with K-type joints etc., pp.5-11.*

National Institute of Advanced Industrial Science and Technology, QuiQuake, http://qq.ghz.geogrid.org/QuakeMap>(July, 2012).

National Research Institute for Earth Science and Disaster Prevention, J-SHIS Geomorphologic surface ground, http://www.j-shis.bosai.go.jp>(July, 2012).

National Research Institute for Earth Science and Disaster Prevention, K-NET, http://www.kyoshin.bosai.go.jp/kyoshin>(July, 2012).

Resilient Water Supply System for Earthquake and Tsunami

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Abstract
This paper focuses on resilient water supply system for earthquake and tsunami. The 2011 off the Pacific coast of Tohoku Earthquake generated not only strong ground vibration but also tremendous tsunami. Although some of water supply system suffered damage and water suspension occurred extensively, earthquake resistant pipe was survived and quick recovery of water delivery was done. We must learn many lessons from the earthquake and tsunami disasters and exchange the lessons internationally. The international collaboration between Kubota and Los Angeles Department of Water and Power on an earthquake resistant joint ductile iron pipe is introduced.

Keywords
Earthquake; international collaboration; seismic guideline; tsunami; water supply system

INTRODUCTION

An earthquake resistance of water supply facilities against earthquake was verified by recent huge earthquakes such as the 1995 Hyougo-ken Nambu Earthquake (Kobe Earthquake) and the 2011 off the Pacific coast of Tohoku Earthquake (Tohoku Earthquake). A seismic guideline of water supply facilities was revised based on lessons learned from the past earthquakes continuously. An earthquake resistant technology has been advanced through several damaging earthquakes. The earthquake resistant joint ductile iron pipes did not suffer damage in the 1995 Kobe and the 2011 Tohoku Earthquakes. On the other hand, the 2011 Tohoku Earthquake generated a tremendous tsunami and the tsunami hit at extensive areas. Since it was the first tsunami in its history to directly hit a water supply system, we must learn new lessons from the tsunami disaster. The present paper summarizes lessons from the recent earthquakes and tsunami, and introduces a new movement of international exchange on earthquake resistant technology for establish of resilient water supply system for earthquake and tsunami.

DAMAGE CHARACTERISTICS BY TSUNAMI

The 2011 Tohoku Earthquake generated a tsunami of unprecedented height and special extent along the north east coast of Japan. 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. But following damages to water supply system was revealed.

Causes of damage by tsunami are roughly 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 1). Photo 2 shows damage to a water pipe bridge by tsunami. The water pipe bridge was completely washed away. It is not sure which water pressure, floating wreckages or both caused this kind of damage. We should study the force acted on the water pipe bridge during tsunami. Photo 3 shows damage to buried 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.

It was the first tsunami in its history to directly hit a water supply system. Although most of damaged pipelines in the flooded areas are not repair yet, we must learn the lessons from the tsunami disaster. So we need to continue to collect the entire data of damage to water supply facilities and analyze them.

Photo 1. Inundation of intake facilities (Magosuke No.2).

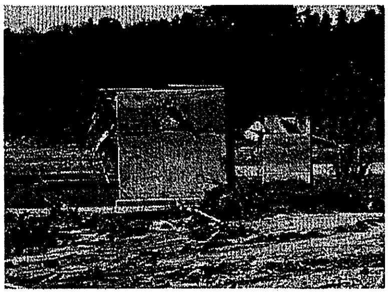


Photo 2. Wash-away of water pipe bridge.

Photo 3. Damage to pipe by scouring induced by tsunami.

EARTHQUAKE RESISTANT DESIGN AND TECHNOLOGY

A seismic guideline of water supply facilities was revised based on lessons learned from the past earthquakes continuously. The 1995 Kobe Earthquake had a significant impact on the nation because it was the first earthquake in its history to directly hit a modern large city, Kobe City. The seismic guidelines were promptly revised after the event. Level 1 and Level 2 earthquake ground motion, importance of facility Ranks A and B were introduced in the 1997 revision. The required earthquake resistant performance was regulated as listed in Table 1.

Table 1. Level of required earthquake resistant performance.

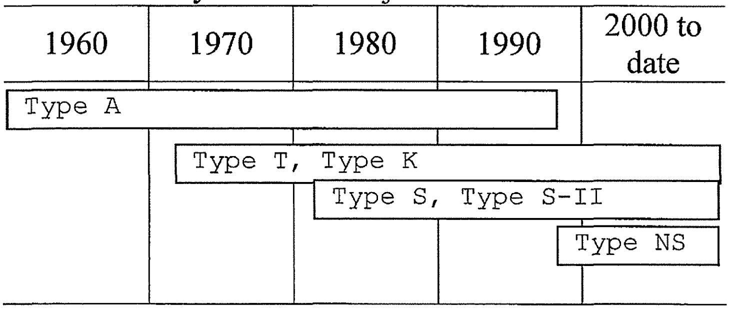
Degree of importance	Earthquake level	
	Level 1	Level 2
Rank A	Operational capacity is not affected.	Seismic damage is minor and does not severely affect operational capacity. Restoration requires minimum effort.
Rank B	Seismic damage is minor and does not severely affect operational capacity. Restoration requires minimum effort.	Seismic damage is minor and does not severely affect operational capacity, but restoration is necessary.

On the other hand, earthquake resistant technology for water pipelines is advanced. The main types of buried water pipes in Japan are ductile cast iron pipes (DIP), grey cast iron pipes (CIP), steel pipes (SP), polyethylene pipes (PE), polyvinyl chloride pipes (PVC), and asbestos cement pipes (ACP), and ductile cast iron pipes account for 60% of the total length of buried water pipes. Since earthquake damage to these pipes primarily consists of pull-out at joint, 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 2). Types S, S-II, and NS are seismic joints with high earthquake resistance. Initially, joints did not have a disengagement prevention mechanism (Types A, T, K), and thus Types S and S-II were developed in 1982 (Table 3). The more recent joints bend and expand substantially to accommodate differential settlement of soft ground and large ground deformation induced by soil liquefaction so as to prevent joint disengagement. In the 1995 Kobe Earthquake, no damage was caused to pipes with a joint disengagement prevention mechanism, demonstrating the high earthquake resistance of Types S and S-II. These joints are rated as seismic joints. Subsequently, based on damage data from this earthquake, an easy-to-install NS joint was developed to promote the widespread use of seismic pipes and currently GX joint was also developed. These earthquake resistant joint ductile iron pipes did not suffer damage at all in the 2011 Tohoku Earthquake.

Table 2. Characteristics of joint types.

Joint	Characteristics
Type A	A rectangular rubber gasket is placed around the socket and the joint bolts are tightened with a gland.
Type T	A rubber gasket is placed around the socket and the spigot is inserted into the socket.
Type K	A modified version of Type A. This has only a rubber gasket which a rectangular one and a round one are combined.
Type S, Type S-II	A rubber gasket and a lock ring are placed around the socket and the spigot is inserted into the socket. The joint has good earthquake resistance with high elasticity and flexibility and a disengagement prevention mechanism.
Type NS	Same earthquake resistance as Type S but is easier to use than Type S.

Table 3. History of the use of joints.



Source: Japanese Industrial Standards (JIS)

INTERNATIONAL EXCHANGE OF EARTHQUAKE RESISTANT TECHNOLOGY

An earthquake resistant joint ductile iron pipe (ERDIP) is only available and used in Japan. Kubota and Los Angeles Department of Water and Power (LADPW) have, however, collaborated on a proposal to implement a pilot project to install ERDIP in Los Angeles. LADWP would be 1st to use ERDIP in USA. Purpose of the pilot project is to allow the LADWP to become acquainted with the ERDIP, to obtain direct observations and experience of the design and installation procedures, to compare the design and installation of ERDIP with pipes normally installed by LADWP, and to make own assessment on suitability for using the ERDIP to improve network reliability

The pilot project firstly starts to identify areas damaged by ground failure during the 1994 Northridge Earthquake such as Balboa Blvd region, Roscoe Blvd Region and Studio City/Sherman Oaks Region (Figure 1). Then, two pilot areas were determined as relatively level ground in San Fernando Valley (Roscoe or Balboa Blvd.) and sloped and curvy roads in Studio City/Sherman Oaks area.

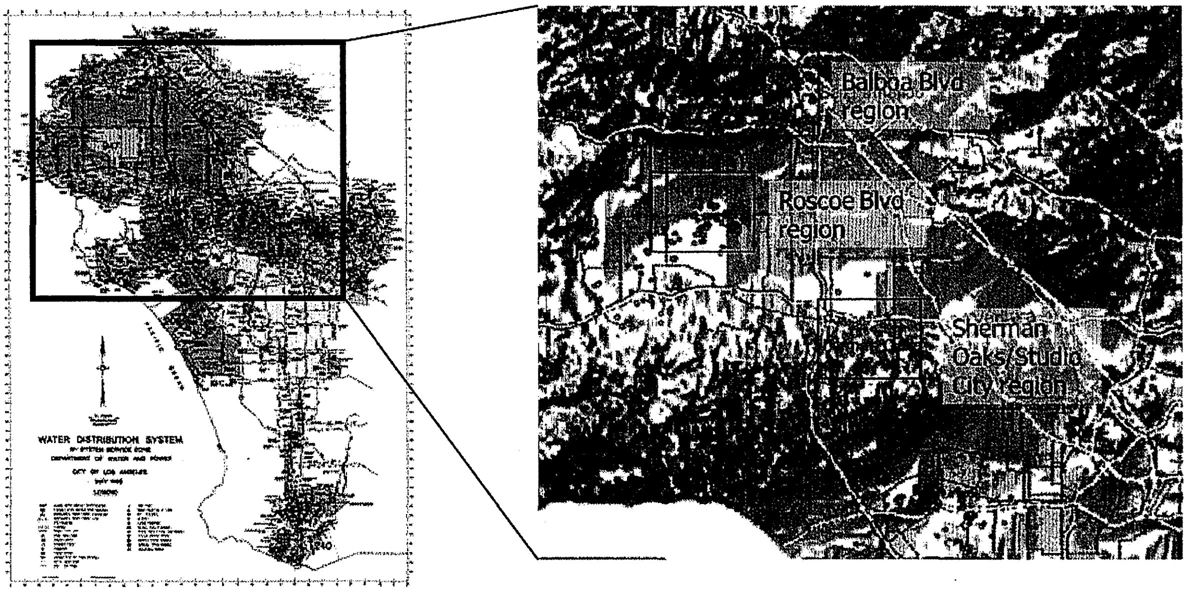


Figure 1. Locations of pilot projects in Los Angeles.

The pilot project in Roscoe Blvd. & Reseda Blvd. aims at direct comparison of installing standard US manufactured push-on DIP with Japanese ERDIP joints in same street with same diameter pipe with same crews and improving seismic performance of area previously damaged from permanent ground deformations. Proposed main replacement in Contour Drive is not completely consistent with proposed long-term seismic improvement program, but is consistent with pilot project for benchmarking pipe installation in hillside area while meeting current pipe replacement needs.

Kubota had meetings with LADWP in Los Angeles in January, 2012 and presentation and demonstration of ERDIP to 17 waterworks communities in California in USA. This is a good example of an international exchange of earthquake resistant technology. We must continue to exchange valuable information of earthquake resistance not only in an international symposium but also in presentation and demonstration mentioned above.

CONCLUDING REMARKS

The water supply system in Japan has experienced huge earthquakes and tremendous tsunami such as the 1995 Kobe Earthquake and the 2011 Tohoku Earthquake and tsunami. We learned many lessons from the disasters and analysis of damage caused by the disasters is going on. The problems of earthquake and tsunami are not only in Japan but also in many countries around Pacific Ocean such as New Zealand, California of USA, China, Taiwan etc. So we must continuously exchange lessons learned from damaging earthquake and tsunami and collaborate to establish resilient water supply system for earthquake and tsunami.

References

Adachi, W., Uchikoshi, S., Takahashi, Y., Fujiwara, M. and Miyajima, M. (2011), Research Activities on Earthquake-Proofing of Waterworks Facilities in the Japan Water Research Center. Proceedings of International Conference on Drinking Water Safety, Security and Sustainability, 104-108, Hangzhau, China.

Davis C. (2012), LADWP Earthquake Resistant DI Pipe Pilot Project. PPT file.

Miyajima, M. (2011), Characteristics of damage to drinking water facilities in the 2011 Great East Japan Earthquake. Proceedings of the 3rd Symposium on Impact Reduction Measures for Lifeline Systems considering their Interrelations, 43-47, Niigata, Japan.

Japan Water Works Association. (1997), Guidelines for Earthquake-Resistant Design Methods for Waterworks Facilities 1997.

Raw water turbidity prediction corresponding to weather variation

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Abstract: The purpose of this research is to develop an application software that can predict raw water turbidity at the point of water intake in the event of heavy rainfall. In order to make the programme, we analyzed different upstream river information such as rainfall, river flow and water level. The result shows that it is possible to predict raw water turbidity from these data.

Keywords: Climate change; Weather variation; Water quality prediction

Introduction

There has been a growing concern over the influences of global climate change in recent years. In Japan, heavy rainfall is increasingly observed and its greater frequency is thought to be part of regional weather variation. Heavy rainfall causes rapid change in raw water quality and affects water treatment processes. In order to ensure long-term, stable water treatment, it is desirable to predict this weather-induced change of raw water quality and take appropriate measures against it.

Rapid increase of raw water turbidity is one of the effects of heavy rainfall on water treatment. By using the Internet that allows easy access to weather information such as upstream rainfall, river flow and water level, it will be possible to predict behaviour and attributes of high-turbidity water—its arrival time at water intake point, peak turbidity level and duration of the highly turbid state.

Accordingly, the Japan Water Research Center (JWRC) conducted research aimed at designing an application software that can predict raw water turbidity from data of upstream river conditions: rainfall, river flow and water level.

This research is part of a JWRC's joint-programme on climate change and drinking water system in collaboration with a university, utilities and private companies.

Methods

We analyzed the basic relations among raw water turbidity, upstream rainfall and water level in order to make the prediction software. The turbidity data used for the analysis were obtained at water intake points managed by Kanagawa Water Supply Authority and Yamagata City Waterworks and Sewerage Bureau. Figure 1.1 shows the data-collecting locations of the Authority.

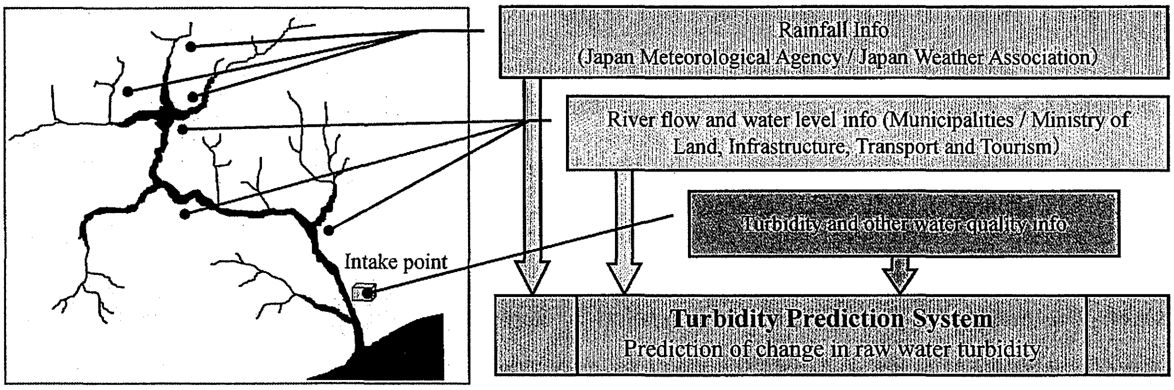

Figure 1.1 Data-collecting locations

Results and Discussion

Figure 1.2 illustrates the upstream rainfall of the intake point and the raw water turbidity, taking the time difference of their occurrences into consideration. It shows that the turbidity tends to increase as the total upstream rainfall goes up. The same tendency is also seen in the relation between the river flow and the turbidity while their relational patterns can be classified into four different groups (Figure 1.3). This might be due to regional and seasonal characteristics of rainfall, precipitation, and past history of rainfall. A positive correlation was similarly found between the water level and the turbidity. These observations indicate a possibility to predict raw water turbidity from upstream river information: rainfall, river flow and water level. Below is an example of a prediction equation based on upstream river flow:

$$\mathrm{Log}\,(Tu) = A \times \mathrm{Log}\,(Fr) + B \tag{1}$$

$$Fr = p \times (Lw)^2 + \mathrm{q}\,(Lw) + r \tag{2}$$

where *Tu* means turbidity, *Fr* means river flow, and *Lw* water level. *A*, *B*, *p*, *q*, and *r* are coefficients.

Figure 1.4 shows two kinds of turbidities: one was calculated by the equation and the other from actual measurement (with their time lags corrected). The two turbidities display almost the same tendency, demonstrating that it is possible to predict raw water turbidity from upstream river flow.

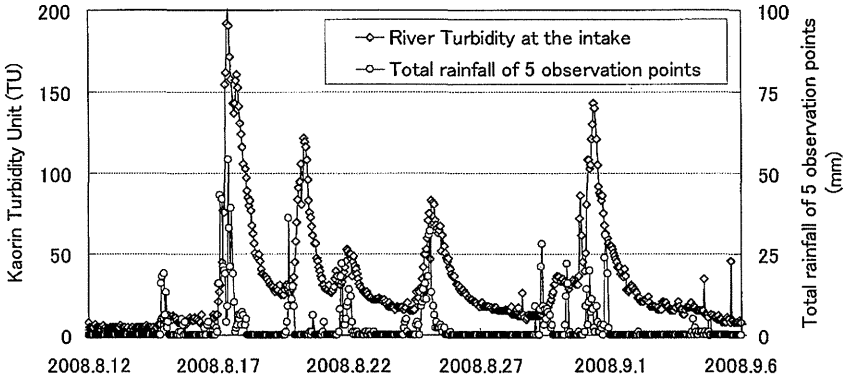

Figure 1.2 Relation of turbidity and rainfall

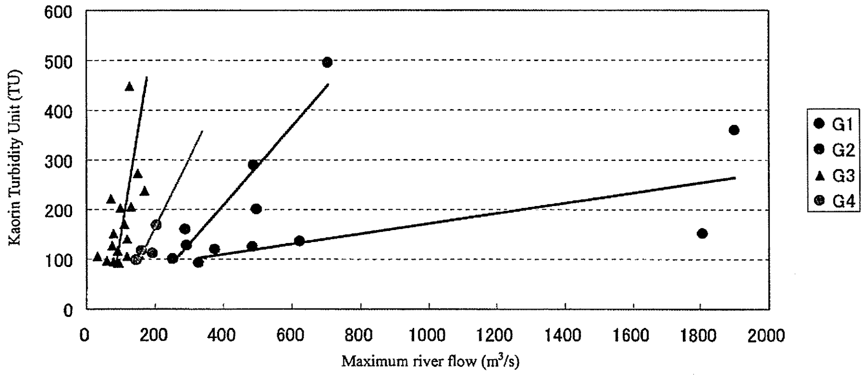

Figure 1.3 Relation of turbidity and river flow

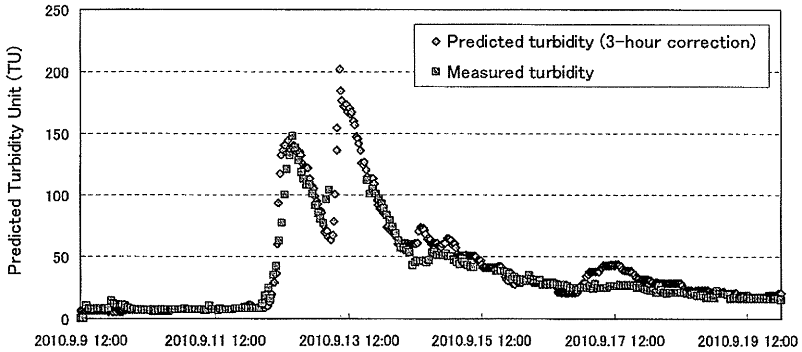

Figure 1.4 Result of turbidity prediction

Encouraged by this result, we developed the software programme to predict raw water turbidity. Figure 1.5 represents its schematic picture. From the Internet, it collects publicized information of target river system such as rainfall, river flow and water level in order to calculate arriving time of high-turbidity water at water intake point, its peak turbidity and duration. On the screen, the server displays the latest information of the river system including rainfall, river flow and water level; each datum is updated automatically as it fluctuates.

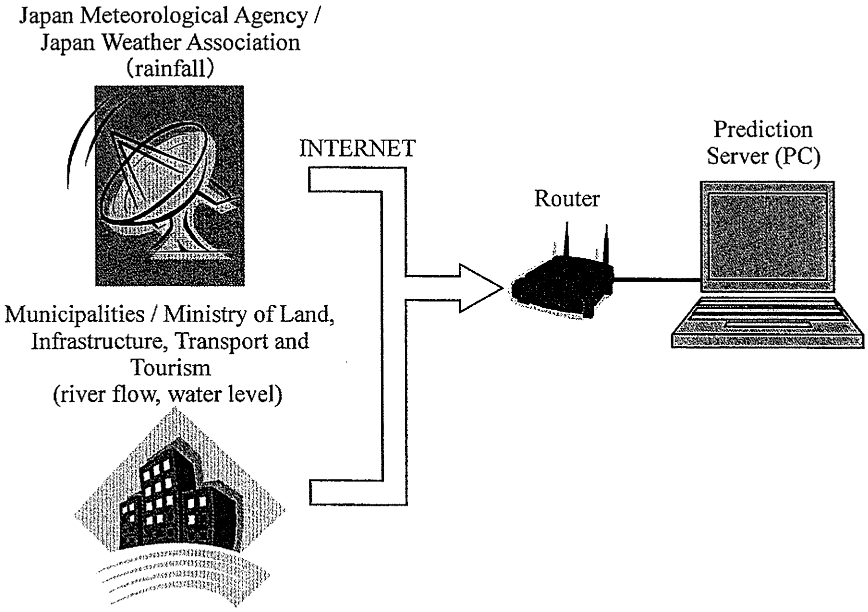

Figure 1.5 Overview of prediction model