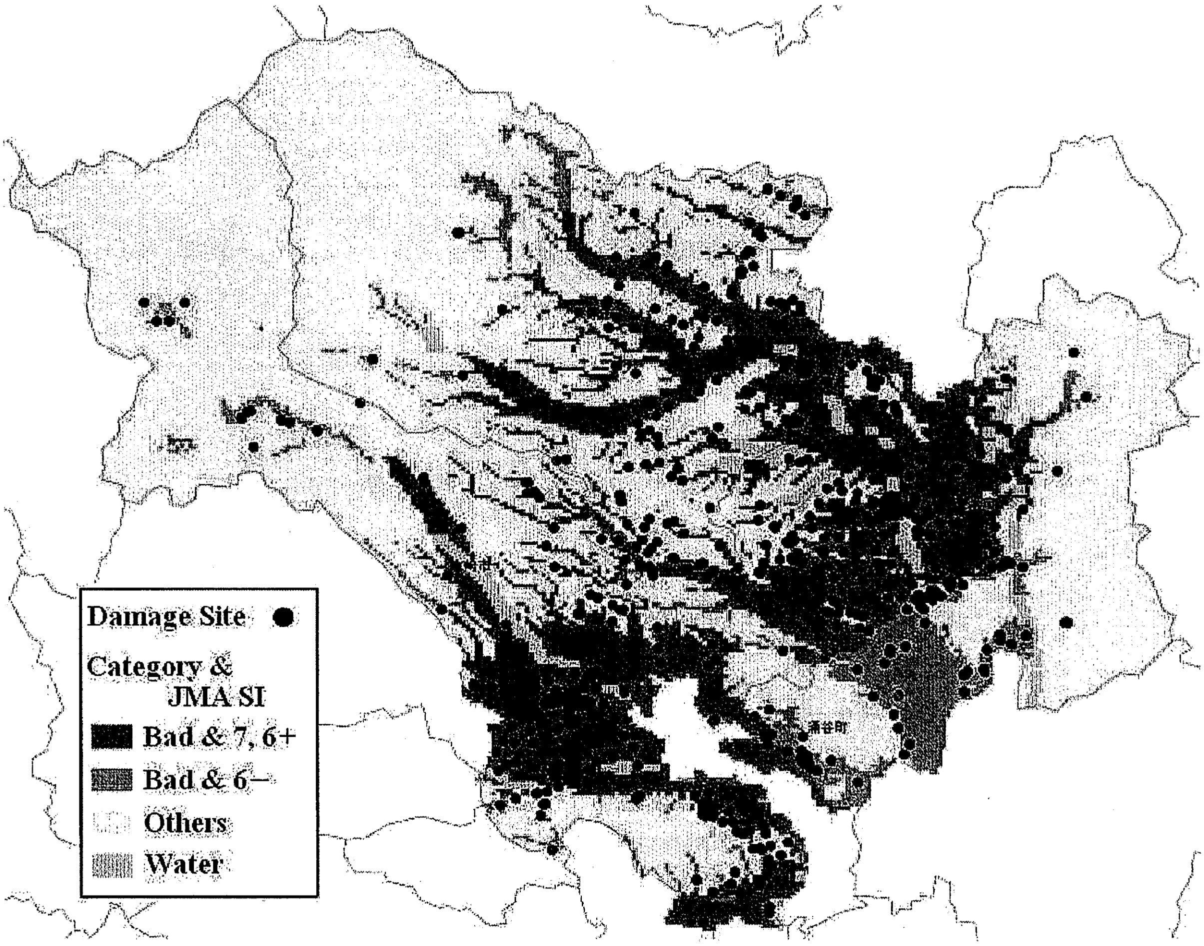

Figure 6 | Distribution of ground categories, JMA seismic intensity and the sites of damage.

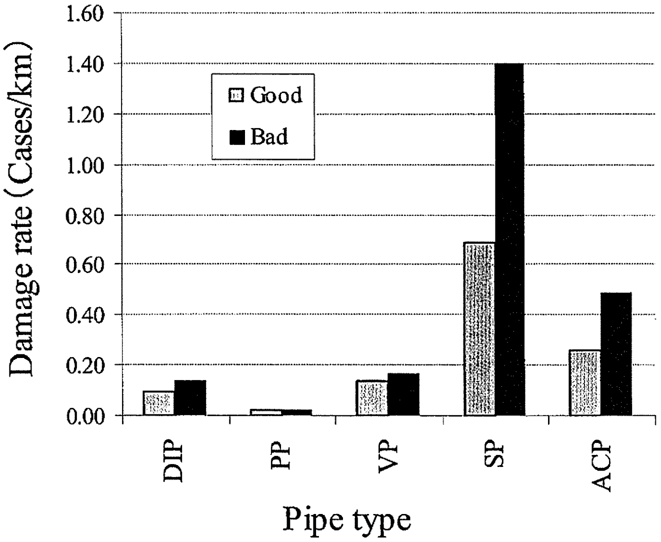

Figure 7 | Comparison of damage rate of each pipe type in micro topography classification category.

Table 3 | 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	Others	Sum
Good	<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	≤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

Note: ERJ: Earthquake Resistant Joint

EARTHQUAKE RESISTANT DESIGN AND TECHNOLOGY

Seismic design guidelines for drinking water facilities have been revised several times based on lessons learned from the past major earthquakes. The 1995 Kobe Earthquake had a significant impact on the earthquake-related policies in Japan because it was the first earthquake in its history to directly hit a modern large city, Kobe. Promptly after the event, in 1997, major revisions were made to the seismic design guidelines with the concepts of Level 1 and Level 2 earthquake ground motion and Rank A and Rank B facility importance rating newly introduced. As a result, the earthquake resistant performance was regulated as listed in Table 4.

Table 4 | 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.

Notes:

Level 1:	The maximum level of earthquake which may occur during the service period of the facility
Level 2:	The maximum level of earthquake which may occur at the site of the facility in the future. Generally, level 2 ≥ level 1.
Rank A:	High-priority facilities (such as intake stations, purification plants and trunk pipelines)
Rank B:	Other facilities.

Experiences of hazardous earthquakes have also advanced earthquake resistant technology for water pipelines. DIP accounts for 60% of all the buried pipes. Since earthquake damage to these pipes primarily consists of pull-out at joint, joint structures have been improved following major earthquakes. DIP joints are mainly divided into Types A, T, K, S, S-II, NS, and GX (Table 5). Older joints of Types A, T, and K do not have a joint disengagement prevention mechanism. On the other hand, Types S and S-II, developed more recently in 1982 (Table 6), are seismic joints with high earthquake resistance, bending and expanding substantially to accommodate differential settlement of soft ground and large ground deformation induced by liquefaction, keeping pipe from being pulled out of joint. In the wake of the 1995 Kobe Earthquake, an easy-to-install Type NS joint was developed to promote widespread use of seismic pipes. In the Kobe Earthquake and the 2011 Tohoku Earthquake, no damage was caused to these three seismic pipes, demonstrating their high earthquake resistance. The most recent development of seismic DIP joint is Type GX.

Table 5 | Characteristics of different joint types

Joint type	Characteristics
A	A rectangular rubber gasket is placed around the socket and the joint bolts are tightened with a gland.
T	A rubber gasket is placed around the socket and the spigot is inserted into the socket.
K	A modified version of Type A. This has only a rubber gasket which a rectangular one and a round one are combined.
S, 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.
NS	The same level of earthquake resistance as Type S but is easier to install.
GX	Even easier to install than Type NS and have longer service life.

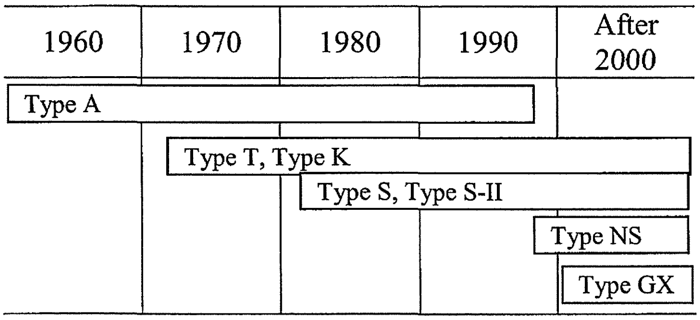

Figure 8 | History of DIP joints.

APPLICATION OF EARTHQUAKE RESISTANT TECHNOLOGY IN LOS ANGELES

ERDIP is available and used only in Japan. A Japanese pipe manufacturing company and the 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 the United States of America. 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 started 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 9). Then, two pilot areas were determined: relatively level ground in San Fernando Valley (Roscoe or Balboa Blvd.) and sloped and curvy roads in Studio City/Sherman Oaks area.

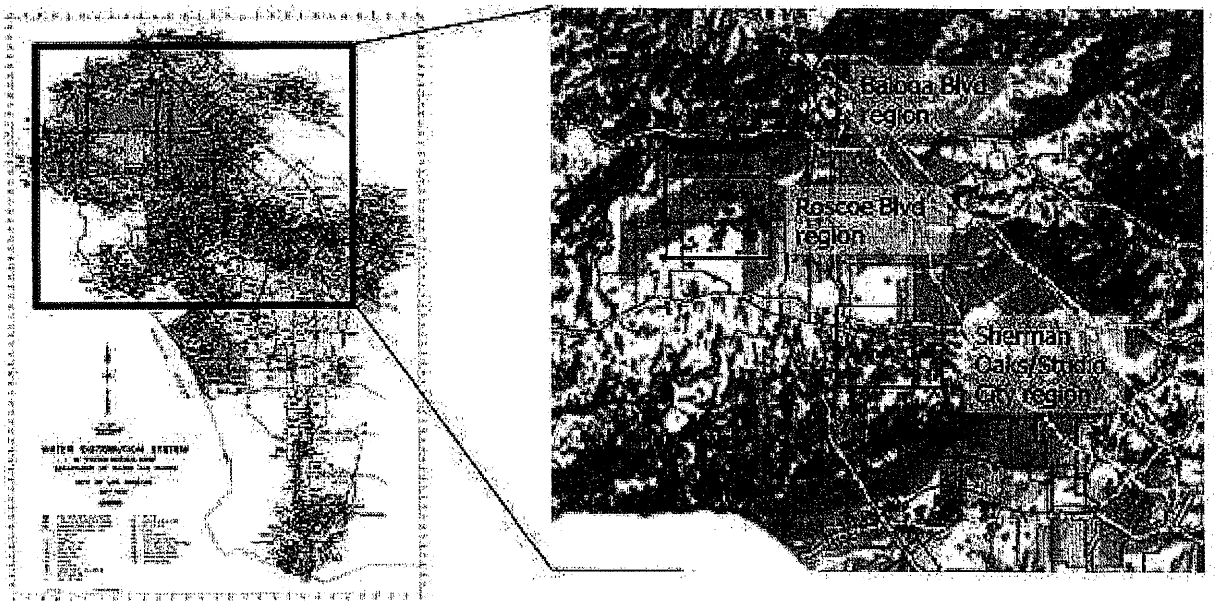

Figure 9 | Locations of pilot projects in Los Angeles.

The pilot project in Roscoe Blvd. & Reseda Blvd. aims at direct comparison of installing standard US manufactured push-on DIP with Japanese ERDIP in the same street with the same diameter pipe with the same crews and improving the seismic performance of an 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.

CONCLUSIONS

In the past 20 years, the water supply system in Japan has experienced huge earthquakes such as the 1995 Kobe Earthquake and the 2011 Tohoku Earthquake, which was followed by tsunami. We have learned many lessons from the disasters while their damage analysis is still being conducted. Challenges posed by earthquake and tsunami are not specific to Japan but are faced by many other countries around the Pacific Ocean such as New Zealand, California of the USA, China, Taiwan etc. Therefore, we must continuously exchange lessons learned from these damaging events and collaborate to establish resilient water supply system for earthquake and tsunami.

ACKNOWLEDGMENTS

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高濁度原水における二段凝集処理最適化の検討

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1. はじめに

(1) 研究背景

気候変動に伴うゲリラ豪雨や長時間にわたり局地的な豪雨が降ることで原水の急激な濁度上昇が発生するケースが多く報告され，取水や給水を停止する事例の報告が相次いでいる．水道事業体はこのような急激な濁度変動や高濁度原水への対応が急務であるが，特に中小規模の水道事業体では施設更新等の大規模な改修は困難であり，また，技術者が不足している水道事業体も多いことから簡便かつ低コストで対応できる浄水処理技術が求められている．

(2) 研究目的

これまでの研究より，急激な濁度変動に対応する簡便かつ低コストな対策として，凝集剤種類を変更すること，具体的にはより塩基度の高い凝集剤を使用することや二段凝集処理を行うことが有用であること示されてきた．本研究では浄水場内の設置した模擬実験プラントを使用し，高濁度原水を対する二段凝集および凝集剤の種類が与える処理水に与える影響について検討し，高濁度原水に対応可能な浄水処理技術について検討を行う．

2. 実験方法

(1) 実験方法

今回の実験は，実際の浄水場と同様の処理を行うことができる凝集沈殿砂ろ過プラン（METAWATER社製）（図1）を浄水場内に設置し，浄水場に流入する原水を用い，急速撹拌及び緩速撹拌の撹拌強度，前段凝集剤注入率を実験プラントを設置した浄水場と同等程度に設定し，より浄水場に近い条件で実験を行った．実験は二系統ある実験装置を1回の実験を180分の連続運転とし，砂ろ過塔損失水頭以外の数値においては，数値が安定した実験開始より150～180分における測定値の平均を用い，異なる二条件で処理した際の処理性比較を行った．具体的には，粒径別に二段凝集の効果を確認するため，砂ろ過水濁度測定の際に粒子径別に粒子数をカウントすることのできる卓上形ハイブリッド微粒子計（METAWATER社製）を用い，ろ過水濁度・各粒径の粒子数の測定を行った．

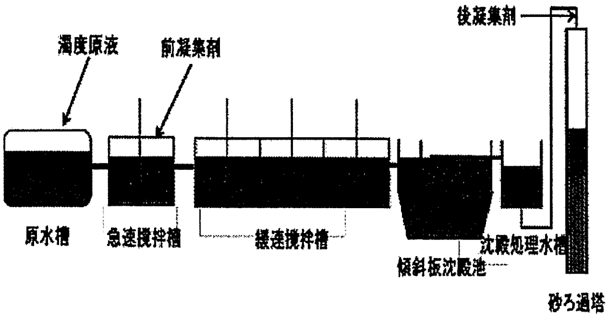


図1　模擬実験プラントの処理フロー

(2) 実験条件

今回の実験では凝集剤として，塩基度のことなるポリ塩化アルミニウム（PACl）を使用した．使用したPAClの塩基度は，塩基度52～56（通常塩基度PACl），塩基度68～72（超高塩基度PACl）の二種類である．

濁度溶液として，取水口にて原水を採取し減圧濃縮により高濁度の原液を作成し，濁度溶液を添加することで擬似的に高濁度原水を発生させ実験を行った．

今回の実験における設定濁度は50度，100度とし，前段凝集剤の注入率は，浄水場の過去の注入率をもとに決定し，後凝集剤の注入率は，0，2，5mg/Lの三条件ににおける沈殿水濁度，砂ろ過損失水頭，砂ろ過水濁度，砂ろ過水における粒子径0. 5～1μm，1～2μm，2～3μmの粒子数の測定を行い比較検討を行った.

3. 実験結果

(1) 実験結果

原水濁度50度における両凝集剤を使用した際の砂ろ過水の粒径別粒子数を図2および図3に示す．尚，粒子数の単位は粒子径0. 5～1μmがCount/mL，粒子径1～2μm，2～3μmがCount/100mLである．この際の沈殿水濁度は通常PAClでは3. 2～3. 7度，超高塩基度PAClでは2. 8～3. 4度であり，大きな差は認められなかった．また，原水濁度100度における両凝集剤を使用した際の砂ろ過水の粒径別粒子数を図5および図6に示す．この際の沈殿水濁度は通常PAClで5. 0～6. 7度，超高塩基度PAClで4. 2～4. 8度であり，原水濁度50度の場合と比較すると凝集剤による違いが認められた．図2，3より原水濁度が50度場合，沈殿水濁度がほぼ同じにも関わらず，後段凝集に用いる凝集剤の違いにより，特に粒子径0. 5～1μmの粒子数に大きな違いが認められた．また，凝集剤の注入率によっても粒子径0. 5～1μmの粒子数に違いが認められ，凝集剤の種類，注入率を最適化することでより清澄な砂ろ過水を得られることが示された.

図4，5より原水濁度が100度の場合，どちらの凝集剤を使用した場合でも注入率が高い実験条件で粒子径0. 5～1μmの粒子数の増加が見られた．図4に示した後段凝集剤注入率が5mg/Lの際の砂ろ過損失水頭は実験期間で約6. 7kPa増加していたことから破過の前兆であると考えられる．比較的高い濁度でも二段凝集は砂ろ過水の濁質低減に有用な方法ではあるが，注入率が高い場合には破過を起し，砂ろ過水の水質が低下する可能性があることが示された.

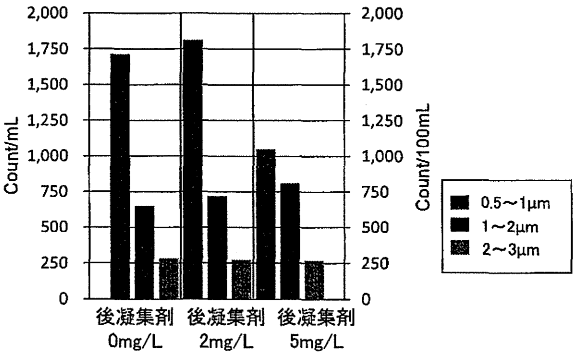


図2 原水濁度50度における通常塩基度PACl使用時の砂ろ過水の微粒子数

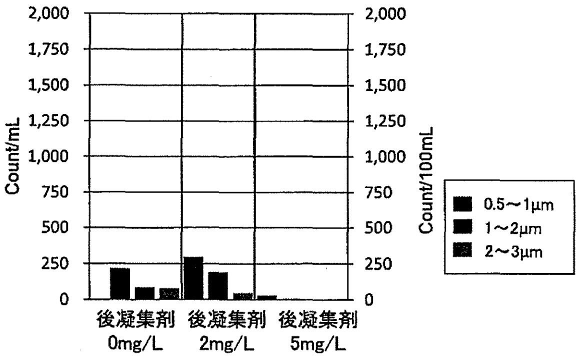


図3 原水濁度50度における超高塩基度PACl使用時の砂ろ過水の微粒子数

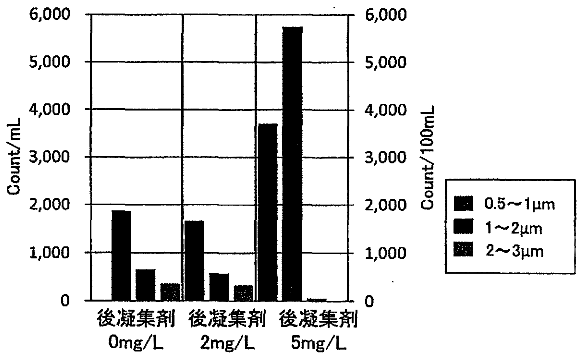
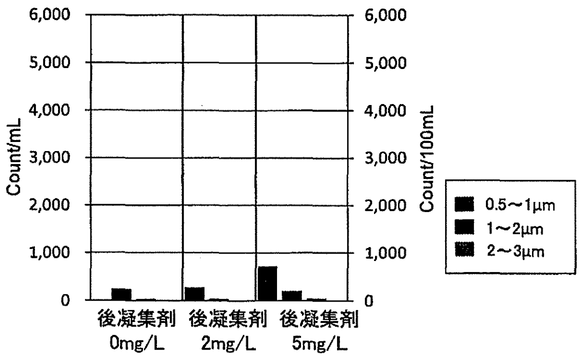


図4 原水濁度100度における通常塩基度PACl使用時の



砂ろ過水の微粒子数

図5 原水濁度50度における超高塩基度PACl使用時の砂ろ過水の微粒子数

4. まとめ

安価で簡易な設備で実施が可能である二段凝集に関して，凝集剤の種類，注入率等を変化させて模擬実験プラントで実験を行ったところ，塩基度の高い凝集剤を使用することで，特に粒子径0. 5～1μmの粒子数を再凝集により砂ろ過で捕捉し，低減できることが示された．しかし，原水濁度が高く，後段凝集剤注入率が過剰になると砂ろ過への負荷が過大となり破過を起す可能性があり，適正なタイミングで砂ろ過の逆洗を行わないと逆効果となることも示された.

Performance of Drinking Water Pipelines in Liquefaction Areas in the 2011 Great East Japan Earthquake

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Keywords: Liquefaction; drinking water pipeline; the 2011 Great East Japan Earthquake

1 Introduction

An 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. 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 about 6,000 people missing and injured.

Many other kinds of geo-disaster such as liquefaction, landslide, etc. were triggered by this earthquake. Liquefaction occurred extensively at Tohoku region which is close to the epicenter of the earthquake and also at Kanto region which is 300 km away from the epicenter. Many houses and underground infrastructures were damaged severely by liquefaction. The damage to the drinking water pipelines by liquefaction is focused in this study.

Water supply facilities were damaged severely and water supply to about 2.57million houses in the wide area from Tohoku to Kanto regions were disrupted just after the earthquake. This paper deals with a performance of drinking water pipeline in liquefied areas.

2 Damage rate of drinking water pipelines in liquefaction area

Extensive liquefaction occurred 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 damage to drinking water pipelines installed in the filled land in Urayasu City is introduced here.

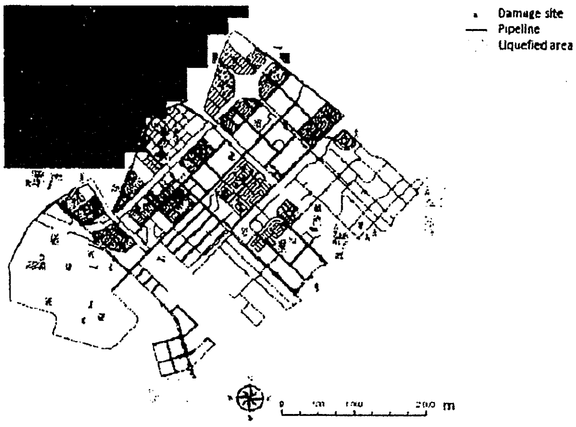

Fig 1. Drinking water pipeline network

Fig. 1 illustrates a drinking water pipeline network and sites of damage to buried pipeline in a part of Urayasu City. The area in a yellow line in this figure shows 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, the degree of damage seemed to be similar in both cases. Peak ground velocity was about 30 cm/s in Urayasu and in Kobe area in the 1995 Kobe Earthquake was around 100 cm/s. The peak ground velocity of Urayasu was much smaller than that at Kobe area in the 1995 Kobe Earthquake, but the degree of the damage was similar. This means that the effect of liquefaction on pipeline damage may be nearly constant and it is independent of peak ground velocity when liquefaction occurred.

3 Performance of earthquake resistant pipelines in liquefied area

Performance of actual installed pipelines was surveyed at the eastside of Sendai City where liquefaction occurred. This area was flooded about 2m by the tsunami after the earthquake. Road was undulated, utility pole and traffic sign subsided about 1m by liquefaction as shown in Photo 1. The measured pipeline is earthquake resistant ductile iron pipes with S2 type joint in the nominal diameter 300 mm as shown in Fig. 2. The behavior of the pipes of about 80m intervals was measured by TV camera inserted in the pipelines.

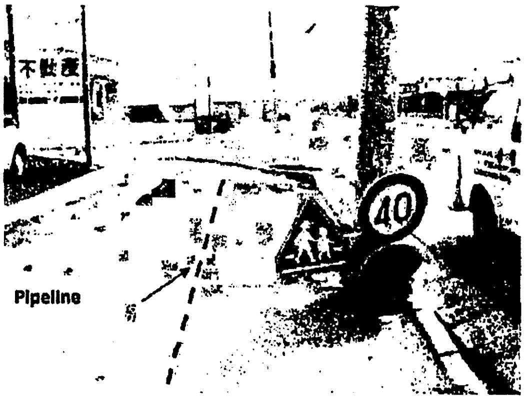

Photo. 1 Subsidence of utility pole induced by liquefaction in Sendai City

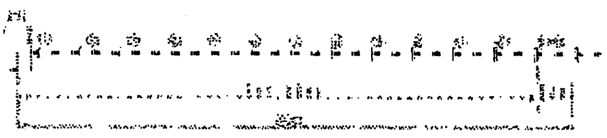

Fig 2. Measured pipeline (DN300×80m) in Sendai City

Settlement of the ground surface of the study site occurred about 0.3m in a section of about 50m from the threshold by the earthquake as shown in Fig.3. The pipelines followed the ground displacement. Two consecutive joints near 70m point were fully expanded. The sum of the amount of expansion and contraction of each joint is 240 mm; amount of expansion was equivalent to 0.3% of the pipeline length. This amount was within the capacity of 1 percent expansion amount of the pipeline.

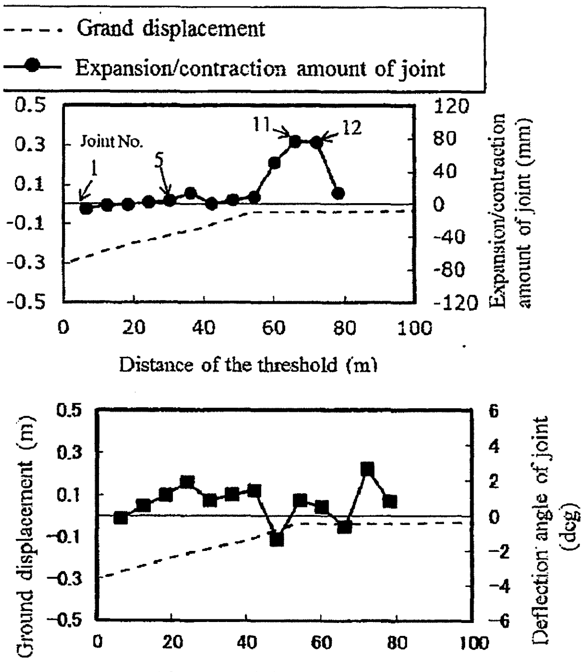

Fig 3. Expansion/contraction amount of joints and vertical displacement of ground surface

The measured pipelines could absorb ground displacement by expansion/contraction performance to allowance limit of some joints. Moreover, the behavior of the joints was found to be locally concentrated. It is considered that this was due to the ground strain was concentrated locally because of ground uniformity. In such places, the pipelines had absorbed the large ground strain by expanding the adjacent joints, even if a joint expanded up to allowance limit. In other words, the effectiveness of the chain structure pipeline absorbed ground deformation has been demonstrated.

4 Concluding remarks Pipeline

The performance of the drinking water pipelines in liquefaction areas caused by the 2011 great east Japan Earthquake was focused in this study. The following conclusions may be drawn based on the present study.

(1) The damage rate of drinking water pipeline in filled land in Urayasu City was 1.60 cases/km. This value is similar to the damage rate of pipeline buried in the reclaimed land of Kobe, Ashiya and Nishinomiya Cities in the 1995 Kobe Earthquake.

(2) The effect of liquefaction on pipeline damage may be nearly constant and it is independent of peak ground velocity when liquefaction occurred.

(3) Photo. 1 Subsidence of utility pole induced by liquefaction in Sendai City

The earthquake resistant ductile iron pipe had absorbed the large ground strain by expanding the adjacent joints in liquefaction area in Sendai City.

Acknowledgements

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Evaluation of Water Quality Indicators Related to Water Treatment Processes and Practical Treatment Method against High Turbidity Raw Water

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Abstract

This paper reviews a study where we examined issues and challenges facing small water utilities in managing high turbidity raw water in the conventional treatment processes, with a special focus on its impacts upon coagulation and sedimentation, based on the findings of which we proposed treatment measures and evaluated their effectiveness. This study concludes that turbidity, alkalinity, pH, and organic matters are important indicators; EC is available as an alternative indicator of alkalinity; exponentiation equation ($Al=a \cdot T^{b+1}$) is useful to determine the coagulant dose best fit to address high turbidity caused by heavy precipitation events; and that the re-coagulation (two-step coagulation) is an easy method to guarantee stable treatment of raw water with high turbidity, based on the data from actual and pilot plants.

Keywords
Coagulation; high turbidity; sedimentation; small water utility; water treatment

INTRODUCTION

The increased occurrence of heavy precipitation events associated with global warming presents a challenge to water treatment systems, raising turbidity levels much higher in surface waters. The high turbidity is particularly a problem in coagulation and sedimentation processes, often surpassing sand filtration capacity for proper turbidity reduction. Such problems related to very high turbidity are presented and their measures are reported in Taiwan and Pakistan (Lin W.W. et al., 2004; Zahiruddin K., 2011).

In Japan, the questionnaire and interview research by Aizawa et al. (2012) reports that many Japanese small water utilities are in trouble of managing coagulation and sedimentation treatment processes for high turbidity raw water and need an easy method to guarantee its stable treatment to keep the filtrate turbidity equal to or below 0.1 degrees (0.14NTU).

First, this paper reviews important water quality indicators concerning coagulation and sedimentation control in the conventional treatment processes during high turbidity periods, in which the turbidity of raw water could reach several hundred degrees. Second, the paper proposes simple and easy measures for small water utilities to better manage high turbidity raw water, by analyzing actual water treatment plants (WTPs) data and evaluating their treatment measures with a pilot plant. In the context of this paper, a small water utility means a utility serving under tens of thousands of people.

RESEARCH AND EXPERIMENTAL METHOD

Table 1.Outline of actual water treatment plants (WTPs)

WTP	Plant capacity (m^3/d)	Characteristics of raw water			Raw water source	Remarks
		color	alkalinity	pH		
A	64,400	high	low	medium	river water, peaty	
B.	7,200	high	low	medium	river water, peaty	
C	937,700	low	high	high	lake	acid adding
D	126,700	low	high	high	lake	
E	22,800	low	low	medium	river	
F	200,000	low	low	medium	river	

Analysis of WTPs data on high turbidity raw water. Table 1 shows the six WTPs in Japan we analyzed in this study. These WTPs draw from different water sources and the data of their water samples were abstracted under high turbidity conditions. The data was analyzed to evaluate water quality indicators affecting coagulation and sedimentation processes for high turbidity raw water.

Identification of challenges and treatment measures with the pilot plant. Based on the data analysis, experiments were conducted at the pilot plant ($3.6m^3/d$) to identify the most effective treatment method for high turbidity raw water when using the PACl (Poly Aluminum Chloride) as coagulant. The schematic diagram of the pilot plant is shown in Figure 1. To use as raw water, artificial turbid water was made from mixing kaolin and bentonite (1:1) and diluting the mixture with tap water whose chlorine had been removed by GAC.

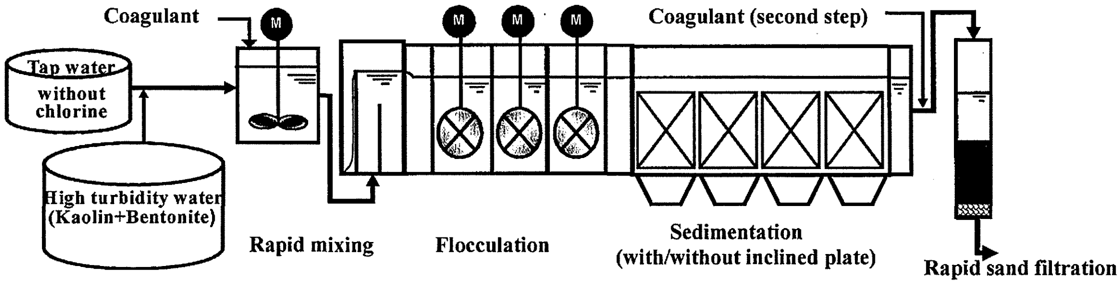

Figure 1. Schematic diagram of pilot plant

RESULTS AND DISCUSSION

Analysis of water treatment plants (WTPs) data to investigate important water quality indicators for coagulant dose control during high turbidity

Behavior of color during high turbidity and the coagulant dose for color. Figure 2 shows a correlation between color and turbidity during high turbidity periods at A and B WTPs, which use raw water sources of high color originated from peat. As is shown in the figure, the color increases with the increase in turbidity, meaning it would be more difficult to control coagulation and sedimentation processes for high turbidity raw water due to higher coagulant consumption caused by color.

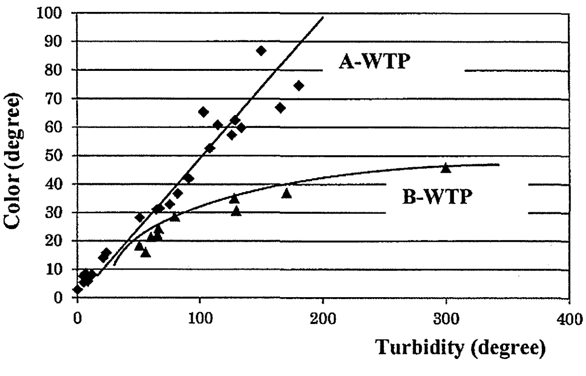

Figure 2. Correlation between color and turbidity of raw water

Influence on coagulant dose in high color raw water is shown in Figure 3. A-WTP needs much more coagulant dose at almost the same pH and temperature than C-WTP which uses raw water of low color (less than about 10 degrees). The data of WTPs shows that high turbidity raw water of high color consumes lots of coagulant, as is reported in the research on turbidity with color by Tambo (1984) and Hozumi et al. (1994). This suggests that color is an important indicator of coagulant dose control for high turbidity raw water, especially at small water utilities using high color raw water sources.

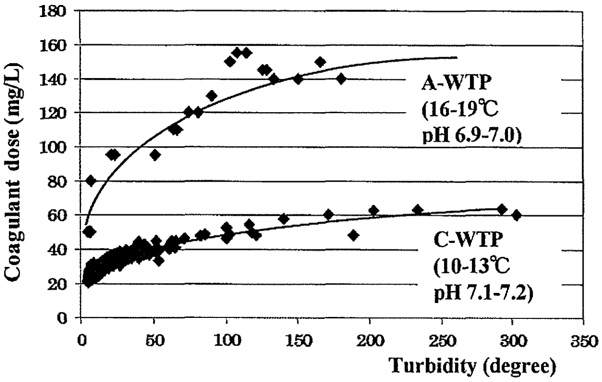

Figure 3. Correlation between coagulant dose and turbidity of raw water

Behavior of Alkalinity during high turbidity. Alkalinity is an important factor for optimum coagulation (David Hendricks 2006, Tseng et al. 2000), and it is necessary to understand alkalinity changes during high turbidity periods. Figure 4 shows a correlation between alkalinity and turbidity; as the turbidity increases, the alkalinity decreases for both D-WTP and F-WTP, which use high alkalinity raw water and low alkalinity raw water, respectively. On the other hand, the alkalinity at E-WTP does not change even if the turbidity of raw water increases. This indicates that alkalinity changes during high turbidity periods depend on the raw water source. From these results, it is suggested that alkalinity measurement of raw water is very important for high turbidity raw water in order to control optimal coagulation.

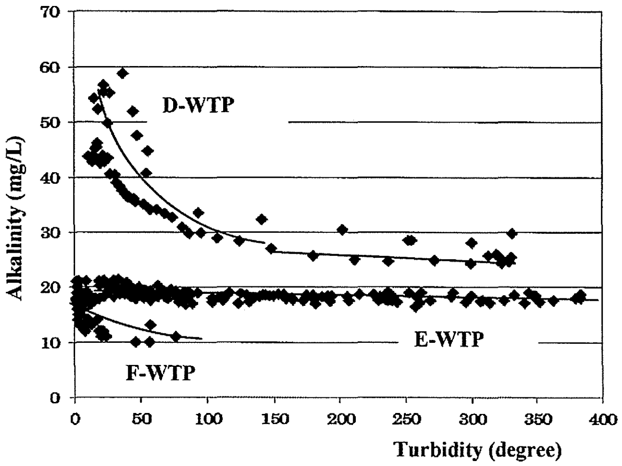

Figure 4. Correlation between alkalinity and turbidity of raw water

Alkalinity consumption by coagulant. Alkalinity consumption is calculated to be 0.15mg/L for 1mg/L of PACl (10%) and 0.24mg/L for 1mg/L of aluminum chloride (alum, 8%). Figure 5 plots the alkalinity consumption by PACl and alum for D-WTP and F-WTP. Poor correlations exist between the two plants' consumption patterns, and the 0.18mg/L for PACl and 0.33mg/L for alum in Figure 5 are a little higher than 0.15mg/L and 0.24mg/L. It is clear from these results that coagulants consume alkalinity constantly. Therefore, considering that the alkalinity reduces as the turbidity increases, monitoring alkalinity is indispensable for controlling coagulant dose when raw water has high level of turbidity.

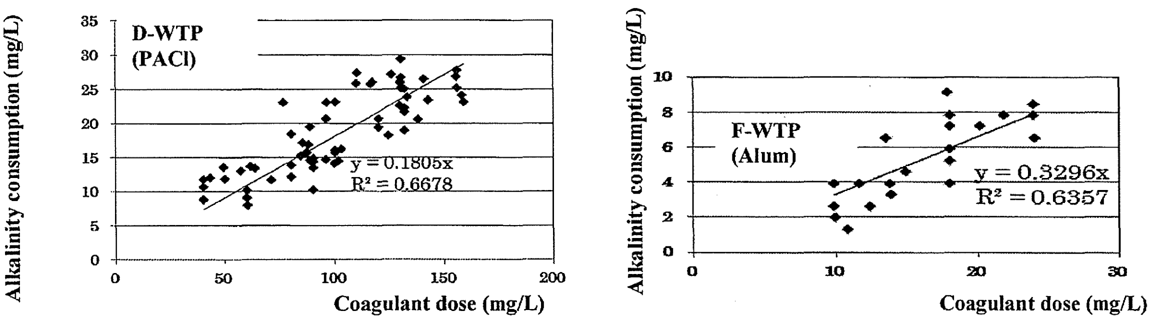

Figure 5. Correlation between alkalinity consumption and coagulant dose

EC as alternative indicator of alkalinity. In spite of being an important indicator for coagulation process, alkalinity is not analyzed at WTPs in small water utilities in Japan, due to time-consuming analysis. Also, automatic analyzers of alkalinity are not introduced to small water utilities because of the high cost and the difficulty of maintenance. Therefore, small water utilities need alternative indicators of alkalinity. Because electric conductivity (EC) automatic analyzer is widely used for monitoring of raw water, correlation between EC and alkalinity was analyzed for four WTPs using different raw water sources to see the EC's feasibility as an alternative indicator of alkalinity (Figure 6). The raw water of each WTP has high correlation between EC and alkalinity. On the other hand, as the figure shows, a close overall correlation is found for D-, E-, and F-WTPs except C-WTP. This result shows that EC would be an alternative indicator of alkalinity for each WTP's raw water, though a correlation equation between EC and alkalinity in each WTP would be necessary. Overall, EC measurement as alternative indicator of alkalinity would be a sufficiently reliable indicator of coagulation and sedimentation control in small water utilities.

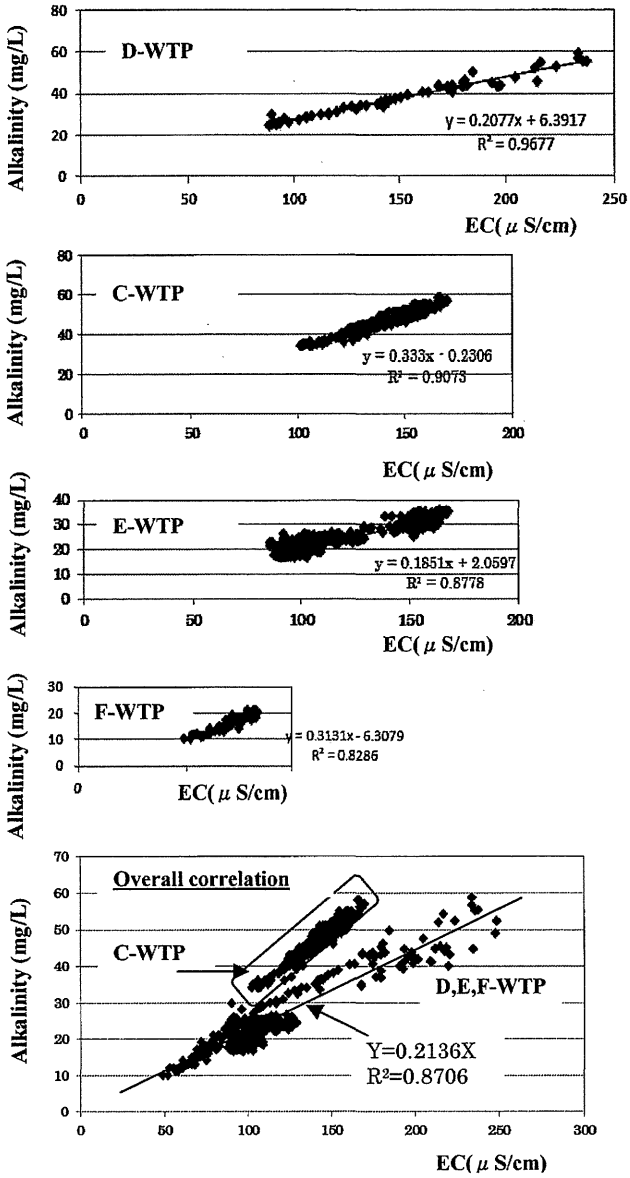

Figure 6. Correlation between EC and alkalinity for raw water of some WTPs

Optimal coagulant dose for pH variation. Figure 7 shows the results of coagulant dose by pH adjustments with and without acid. Raw waters at C-WTP and D-WTP are from different lakes affected by eutrophication and the pH goes up to about 8.0 or more. C-WTP adjusts pH by sulfuric acid and D-WTP does not use acid. Compared with C-WTP, D-WTP consumes more than twice as much of coagulant PACl to keep optimal coagulation conditions. This result proves that pH adjustment by acid is an effective and easy way to control coagulation and sedimentation for high pH raw water during high turbidity periods, as explained in the coagulation theory by Weber Jr. (1972).

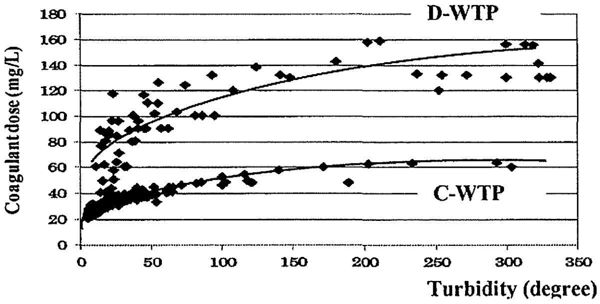

Figure 7. Optimization of coagulant dose by pH adjustment with acid

Calculation method for optimal coagulant dose. In larger water utilities, coagulant dose is determined by performing jar test for high turbidity raw water. It is difficult, however, for small water utilities to perform jar test during high turbidity periods, due to limited work force. Hence it is necessary to propose a simple and comprehensive coagulant dose method not requiring jar test, to assist small water utilities. As one of the factors for optimal coagulation, the ratio of Al (coagulant dose) / T (turbidity) is reported by Tambo et al. (1972), but this factor is rarely utilized in Japanese WTPs. To evaluate this method, the data of four WTPs are plotted by Al/T ratio and T in Figure 8. The figure shows that each WTP has a higher correlation up to 600 degrees of turbidity. This result indicates that an exponentiation equation for AL/T ratio and T could be adopted as a control method of coagulant dose for high turbidity in small water utilities using various raw water sources. The figure also shows the results when PACl was used as coagulant. The same results are obtained in other WTPs using alum as coagulant. Each exponentiation equation obtained from Figure 8 is as follows.

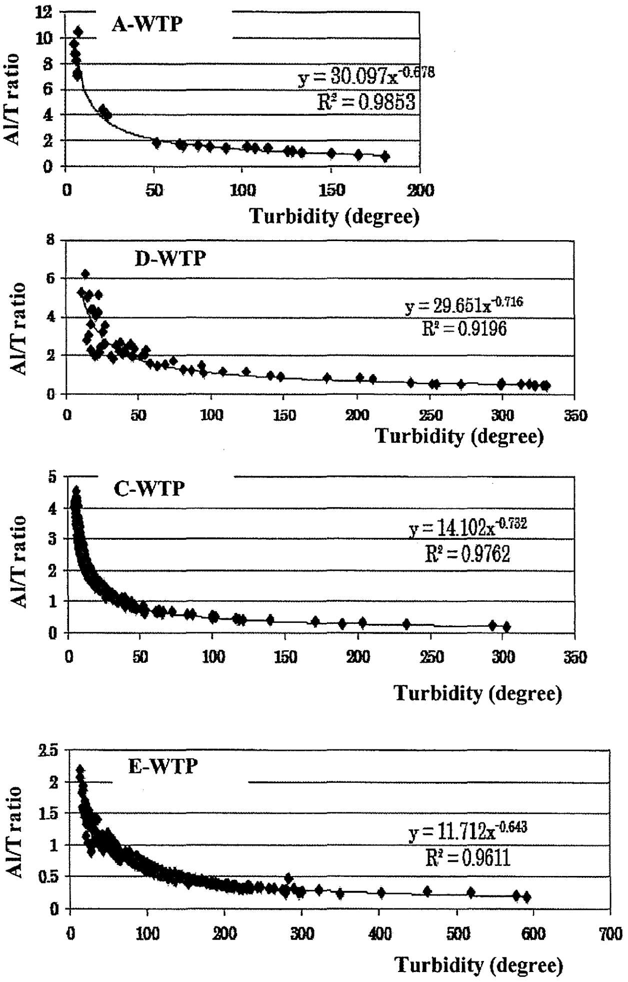

Figure 8. Correlation between Al/T ratio and T for raw water of some WTPs

$Y=a \cdot X^{b}$ ------- (1)

Y : Al/T Al (Coagulant dose(mg/L))

T (Turbidity(degree))

X : Turbidity(T)

a, b : coefficient

$Al=a \cdot T^{b+1}$ ------- (2)

To evaluate what kind of water quality for various raw waters affects coefficients *a* and *b*, coefficients *a* and *b*, which are calculated from Figure 8, and characteristics of raw water for each WTP are shown in Table 2. As shown in Figure 8, the Al/T ratio of A-WTP, which has high color , is twice higher than that of E-WTP with low color, and coefficients *b* in A-WTP and E-WTP are very close and coefficient *a* differs considerably between A-WTP and E-WTP. This result shows that coefficient *a* is much affected by color. Similarly, as coefficients *b* in D-WTP and C-WTP are close, coefficient *a* might be affected by pH of coagulation. The comparison between low coefficients *b* such as observed at A-WTP and E-WTP and high coefficient *b* such as observed at D-WTP and C-WTP indicates that coefficient *b* might be affected by alkalinity of raw water. To summarize the evaluations above, it is suggested that factors of water quality associated with coefficient *a* are color and pH, and that factor of water quality associated with coefficient *b* is alkalinity. These results indicate possibility to make overall calculation method of coagulant dose for various raw waters.

Table 2. Coefficients a and b and characteristics of raw water

	Exponentiation equation coefficients		Characteristics of raw water		
WTP	a	b	color	alkalinity	pH
A	30.097	-0.678	high	low	medium
D	29.651	-0.716	low	high	high
C	14.102	-0.732	low	high	high (acid adding)
E	11.712	-0.643	low	low	medium

From these results, it is demonstrated that the exponentiation equation $(Al=a \cdot T^{b+1})$ for each WTP is more successful to decide coagulant dose less than 600 degrees of raw water turbidity than many other coagulant dose equations (Nakamura 1974), though it is necessary to calculate coefficients *a* and *b* for each WTP by plotting Al/T ratio and T as shown in Figure 8. Therefore it is considered that the exponentiation equation would help small water utilities which have difficulty of performing jar test during high turbidity periods.

Easy method to guarantee stable treatment of raw water with high turbidity

Evaluation for re-coagulation (two-step coagulation) method in actual facilities. Re-coagulation (two-step coagulation) is a method that adds a little dose of coagulant to settled water between sedimentation and filtration processes. This method has been introduced to some of the Japanese WTPs lately, as on-site trials, for the purpose of measuring algae and controlling turbidity of sand filtered water. In this study this method's effectiveness during high turbidity periods was tested, based on WTPs' data. Figure 9 shows filtrate treatability of turbidity and particle numbers at 0.5mg/L and 1.0mg/L of coagulant dose (as PACl) as re-coagulation trials in A-WTP during different high turbidity periods. It is clear from turbidity and particles numbers that a 1mg/L dose of PACl as a re-coagulation coagulant obtains a better filtrate water quality than in case of 0.5mg/L, and the filtrated water is very stable under 0.01 degrees of turbidity by 1mg/L of PACl dose. In WTP having introduced re-coagulation, it is important to confirm the increase of the head loss of sand filter and aluminum outbreak to filtered water. In some results of A-WTP, a little increase of head loss of sand filter is shown to occur, but it is actually not affected for filtration and backwash interval in case of under 1mg/L coagulant dose. Also, aluminum outbreak of filtered water with re-coagulation is almost as low level as that with conventional coagulation. Mixing intensity in some WTPs was also investigated. It is indicated that an additional mechanical mixing is not necessary and that coagulant only dropped at effluent of sedimentation basin before sand filtration. Re-coagulation has a great effect on the stabilization of turbidity of sand filtered water. It is expected that re-coagulation will be applied in small water utilities for the backup against imperfect coagulation and sedimentation to deal with high turbidity raw water.

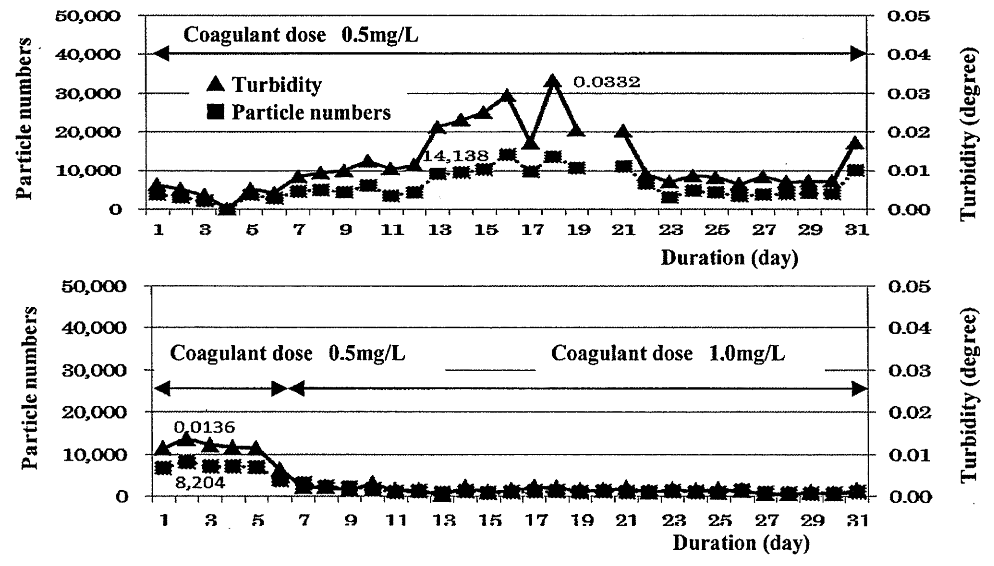

Figure 9. Treatability of turbidity and particle numbers by re-coagulation in actual facility

Identification of re-coagulation (two-step coagulation) method by the pilot plant. The pilot plant experiment by using equipment shown in Figure 1 was conducted in order to get the backup data in detail. The experiment conditions are shown in Figure 10. Setup turbidity is 5 degrees for the regular raw water and 1000 degrees as the highest turbidity. Process of turbidity is 5 degrees for 90min., 1000 degrees for one hour, 500 degrees for 90min., 200 degrees for 90min., and 50 degrees for two hours as show in Figure 10. 100 times diluted PACl is prepared. In case of re-coagulation (two-step coagulation), 1000 times diluted PACl is added at the constant dose of 2mg/L on the outlet of sedimentation tank. Optimal coagulation dose was determined by jar test. Figure 11 presents the results of Case 1 (optimal coagulant dose), Case 2 (insufficient coagulant dose), Case 3 (insufficient coagulant dose + re-coagulation). Figure 12 presents the results of Case 1 (optimal dose), Case 4 (imperfect sedimentation), Case 5 (imperfect sedimentation + re-coagulation).

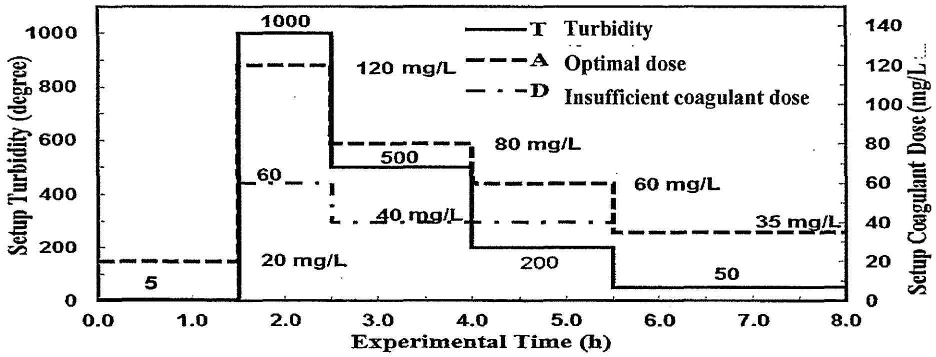

Figure 10. Setup turbidity and coagulant dosage (as PACl)

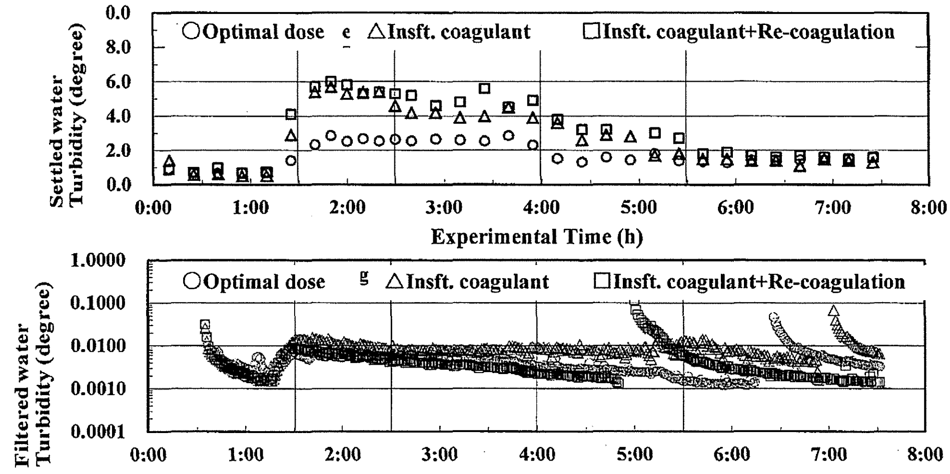

Figure 11. Comparison between optimal dose and insufficient dose of coagulant with/without re-coagulation

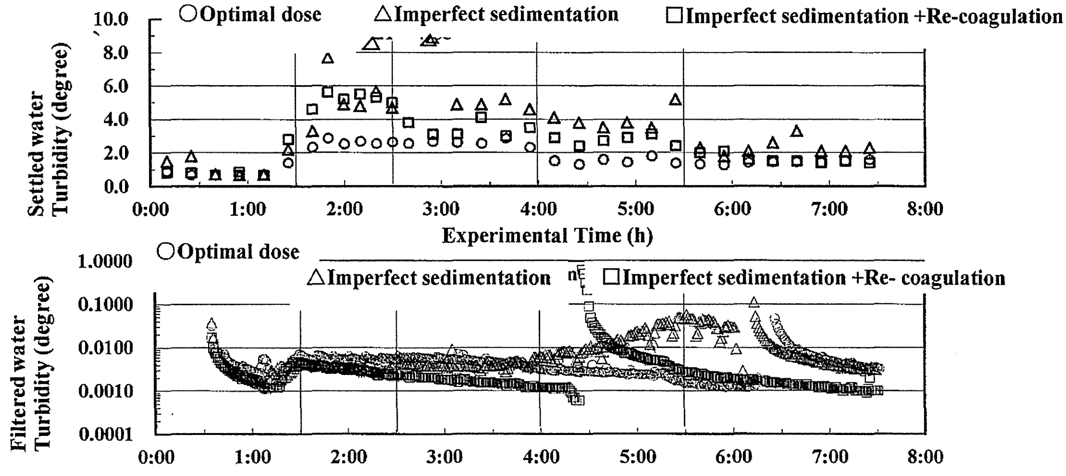

Figure 12. Comparison between optimal dose and imperfect sedimentation with/without re-coagulation

Results of insufficient coagulant dose are shown in Figure 11. The settled water turbidity increased around 2 times of optimal coagulant dose in the range from 1000-200.The filtrate turbidity also increased highly in case of 1000-degree raw water turbidity and it decreased in case of 50-degree raw water turbidity. In re-coagulation, settled water shows that the coagulant dose is insufficient but that filtrate turbidity decreases more than in case of optimal coagulant dose. However, filtrate duration time tends to be short in case of 2mg/L dose rate. In Figure 12, in the conditions of imperfect sedimentation, the change of sedimentation turbidity is around the same as the case of insufficient coagulant dose. But the filtrate turbidity tends to increase during the filtration time. By the pilot plant test it is also proved that re-coagulation (two-step coagulation) is effective to guarantee stable treatment of raw water with high turbidity with decreasing filtrate turbidity.

CONCLUSIONS

Based on the data from the actual and pilot plants, this study concludes that (1) Turbidity, Alkalinity, color (organics originated to peat) and pH are important indicators that mainly affect coagulation and sedimentation control during high turbidity as data analysis for various raw water, (2) EC is available for alternative indicator of alkalinity to manage coagulation and sedimentation, (3) exponentiation equation ($Al=a \cdot T^{b+1}$) by calculating coefficient *a* and *b* in each WTP could be adopted to control the automatic coagulant dose without jar test, and (4) re-coagulation (two-step coagulation) is an easy and effective measures for small water utilities to guarantee stable treatment of raw water with high turbidity.

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Water Quality Surveys of Shallow Wells Damaged by Tsunami in the Great East Japan Earthquake

～Case of Minamisanriku-cho in Miyagi prefecture～

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Kenji Taira**, Takako Aizawa***

ABSTRACT

There are many shallow wells used as a water source near the coast of Minamisanriku-cho in Miyagi prefecture. However, most of them were damaged by seawater of the tsunami resulting from the Great East Japan Earthquake that occurred on 11 March, 2011. Most of the damaged water sources thus proved difficult to use as water supplies because of increased chloride ion concentrations and possibility of contamination.

Therefore, The Yokohama waterworks bureau assigned water quality survey teams to the sites to survey their water quality and the possibility of them being used in the future in accordance with a request from the "Waterworks reconstruction support for the Great East Japan Earthquake liaison council."

The survey was implemented 4 times from August to November of 2011. Result of the survey confirmed there to be no contamination except chloride ion. However, the downward tendency of chloride ion was not uniform, and it might be affected by sodium remaining in the surrounding soil and changes in the tide level. For this reason, continuous survey is conducted to ascertain these effects, although chloride ion concentration is decreased to drinkable level.

The results of the above mentioned surveys and future outlook are reported in this paper.

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1. Background and purpose

There are a number of shallow wells that are used as sources of water near the coast of Minamisanriku-cho in Miyagi prefecture (about 2 km area from the coast) (figure 1), with the majority of them having been damaged by seawater from the tsunami which resulted from the Great East Japan Earthquake of March 11, 2011. Most of the damaged water sources have therefore proved difficult to use as water supplies because of increased chloride ion concentrations. In addition, a number of gas stations and fish farms were located near those water sources and the possibility exists that toxic substances from those facilities also contaminated them.

The water and sewage services division of Minamisanriku-cho,, which manages the damaged water sources, therefore requested the "Liaison Council for Supporting the Restoration of Water Supply Facilities Affected by the Great East Japan Earthquake" (established by the Ministry of Health, Labour and Welfare as a framework to use in providing technical support in the damaged area) to dispatch a "Field Water Quality Survey Team" and investigate the water quality as part of a water treatment facility restoration plan.

This paper provides an outline of the surveys that were conducted by the Yokohama Waterworks Bureau, which dispatched water quality survey teams to the sites in accordance to the request made by the "Liaison Council for Supporting the Restoration of Water Supply Facilities Affected by the Great East Japan Earthquake".

The purpose of the surveys was to investigate any water sources affected by the seawater from the tsunami, assess the water quality and situation with damage at each of them, and determine a future plan that includes the possibility of them being used in the future or the need to change water sources and construct new water treatment facilities.

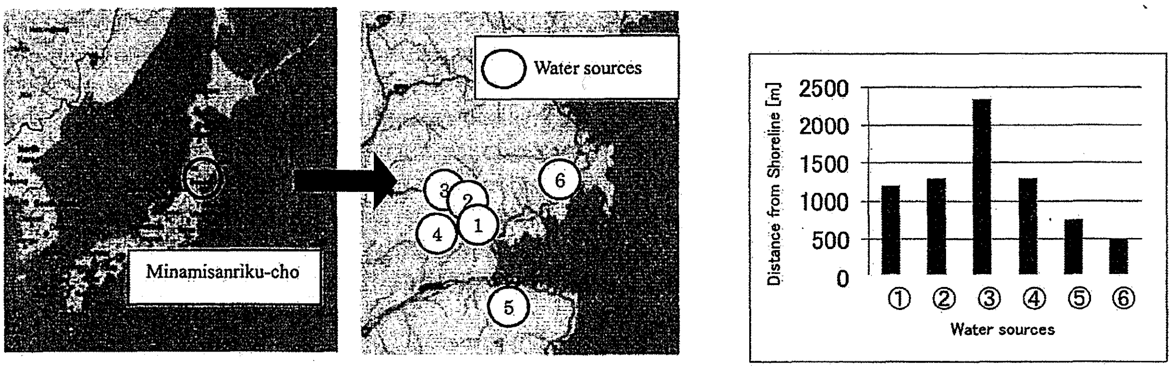

Figure 1. Location of damaged water sources and their distance from shoreline
(Water source name:①Sukezukuri No.1②Sukedukuri No.2③Komori④Tajiribatake⑤Tokura⑥Isatomae)

2. DETAILS OF THE SURVEY

(1) Outline of damaged water sources

The six water sources that were surveyed and the situation with the facilities surrounding them are explained below. Seawater from the tsunami reached upstream of all the water sources. A number of gas stations and other facilities were also located nearby.

a. Sukezukuri No.1 and No.2 water sources (figure 2)

The Sukezukuri water source consists of a No.1 water source, which is about 1.2 km away from the coast, and a No.2 water source, which is about 100m closer inland than the No.1 water source. The Sukezukuri water source was used as the primary water source for the Sukezukuri Water Treatment Facility, which provided water to about 2,700 households in the Shizugawa area where administrative bodies that included the Minamisanriku-cho town hall were located. Water pumped from the water source was simply chlorinated before then being made available for use. The treatment capability was 4,896 m^3/day (3,633 m^3/day in fiscal 2009), or quite a large volume of water.

*b. Komori water source (figure 2) *developed after the disaster*

Located 1km closer inland than the Sukezukuri No.1 water source and which was developed as an alternative source to the Sukezukuri water source, which was severely damaged by tsunami and therefore incapable of being used. The Komori water source was originally used with a pump dedicated for use with a trout and salmon farm, but the farm ceased operating after the earthquake and is in current use as a secondary water source.

*c. Tajiribatake water source (figure 2) *developed after the disaster*

Located about 1.3km inland from the coast and which was developed as an alternative source to the Sukezukuri water source, similar to the abovementioned Komori water source. One well had already been excavated prior to the disaster for use as a secondary water source but no intake pump had been installed. After the disaster two new wells (No.2 and No.3) were then excavated and pumps installed to utilize the water from all three.

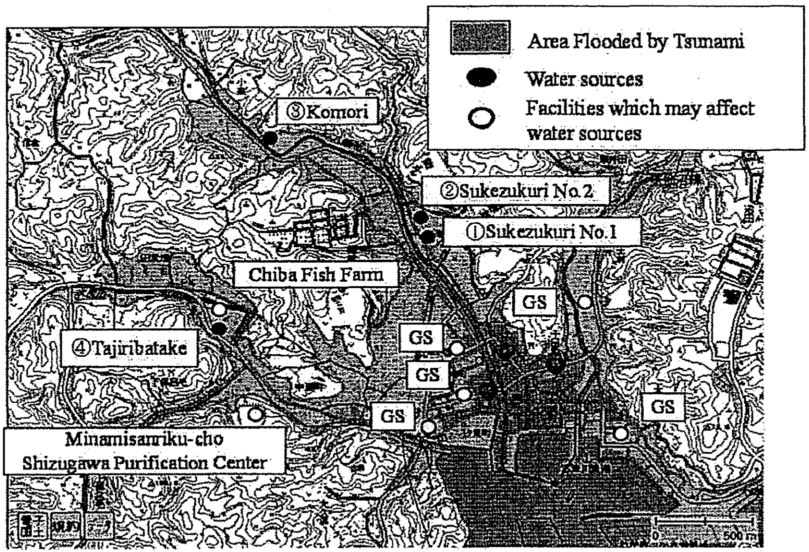

Figure 2. Location of Sukezukuri・Komori・Tajiribatake water source
(Reference: Association of Japanese Geographers HP)

d. Isatomae water source (figure 3)

Located about 700m inland from the coast and which was used as a primary water source for the Isatomae Water Treatment Facility, which provided water to about 1,450 households within the former Utatsumachi before the towns and villages were combined. Water pumped from the water source was chlorinated before being made available. The treatment capability was 2,300 m^3/day (1,800 m^3/day in fiscal 2009), or quite a large volume of water.

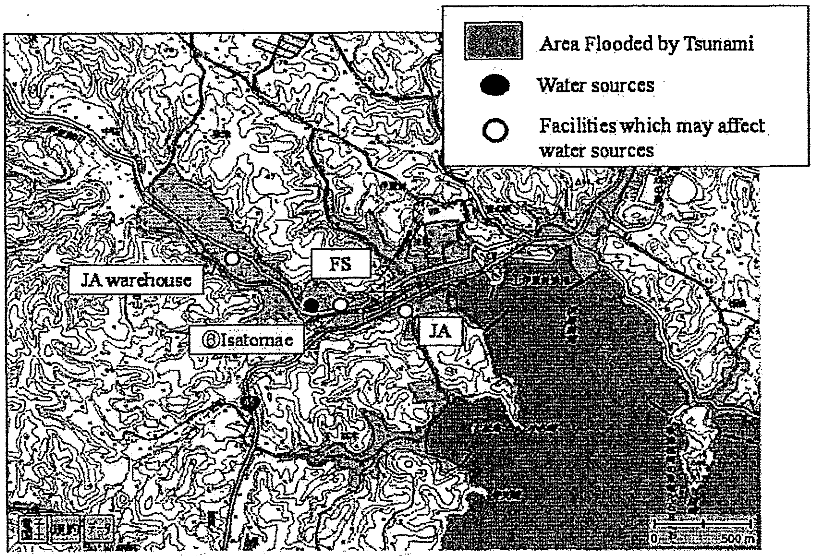

Figure 3. Location of Isatomae water source
(Reference: Association of Japanese Geographers HP)