Conclusions

We attempted to develop the prediction software by using—as prediction indicators—the information of upstream weather conditions, water level, etc. Since this software can predict weather-induced turbidity increase ahead of its occurrence, it will be an effective tool in daily management of drinking water treatment facilities. For instance, the prediction allows operators of treatment plants to be better prepared for the occurrence of high turbidity. Also, it enables utilities to increase the volume of water intake before the water source is affected or to suspend intake at the time of peak turbidity; as a result, utilities can reduce chemical doses as well as sludge generation in their water treatment processes. These effects are also desirable in terms of less carbon emission and energy conservation.

As to the river systems we analyzed for this research, their data of turbidity and river flow could be divided into four different groups. The difference in their patterns is considered to result from the regional and seasonal characteristics of rainfall and past precipitation which are particular to each region. Thus, in order to improve the prediction accuracy, we believe it necessary to understand qualitative characteristics of target region and apply different prediction equations depending on each case.

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地震被害実態に基づく浄水施設簡易耐震診断手法の検討

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Simplified method on evaluation of water treatment facilities' seismic resistance

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1. はじめに

水道施設は耐震化の取組みが遅れており、特に浄水施設の耐震化率は平成 22 年度末現在で約 19%と低い状況にある。また同時に、多くの施設の経年化が進み、更新時期を迎えつつある。

そこで、水道事業体における耐震化の取組み状況や課題についてアンケート調査を実施した結果、取水・導水施設の多くが詳細耐震診断を未実施であり、特に多くの中小事業体では水道施設の詳細耐震診断の実施割合が低く、耐震化に向けての課題として経済面のほか人材面・技術面が挙げられた。一方、東北地方太平洋沖地震による浄水施設等の被害状況及び兵庫県南部地震以降の地震被害実態を精査した結果、浄水施設等の地震被害は、液状化等の地盤変状に伴い施設は甚大な被害を蒙ったが、それ以外では軽微な被害であったことが分かった。

これらを基に、現行の診断項目と実被害要因との対比によって現診断手法の課題を抽出し、簡易耐震性判定手法の基本的手順を提案する。

本研究は、厚生労働科学研究費補助金により、（公財）水道技術研究センターが、大学、水道事業体及び関係企業の協力を得て、平成 23 年度から 3 ヶ年計画で実施している「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」のうちの「耐震化促進等に関する検討」をテーマにしたものである。

2. 目的

浄水施設の多くは昭和 40～50 年代及びそれ以前に建設されたものであり、経年劣化が進むとともに耐震性も劣っている。特に中小事業体ほど技術者も少なく、これらの耐震性向上の取組みを困難にしている。

これらの課題を解決すべく、特に中小事業体における耐震化促進等を支援するための簡易耐震診断手法等を検討し、更新時における耐震化の促進による適切なリスク低減策を提案することを目的とする。

3. 検討方法

平成 23 年 3 月に発生した東北地方太平洋沖地震による被災浄水施設等を調査し、さらに水道事業体における耐震化の課題について調査・整理を行う。

また、浄水施設等の耐震診断に当たり、診断対象選定のための簡易耐震診断表（昭和 56 年 3 月、厚生省水道環境部）は新震度階に未対応でかつ診断表の提案以来既に 30 年余が経過しているため、耐震化に際しての課題を整理するとともに、詳細耐震診断実施の事業体から詳細診断結果を収集し、現行の簡易耐震診断表との比較により問題点抽出と改善を行い、改定簡易耐震診断表（案）を作成する。

3.1 浄水施設の耐震化取組み状況の調査

厚生労働大臣認可事業体及び水道技術研究センター会員事業体 535 事業体を対象に、浄水施設の耐震化状況や耐震化への課題に関するアンケート調査を行った。

なお、震災影響等の事情に配慮し、岩手県、宮城県、福島県の事業体については対象外とした。

3.2 東北地方太平洋沖地震における被害実態調査

東北太平洋沖地震における被災5県（岩手県、宮城県、福島県、茨城県、千葉県）の水道行政担当部署を対象にアンケート調査によって浄水施設等への被害実態を調査し、顕著な被害のあった浄水場等については、現地調査及びヒアリング調査（津波被害については調査対象外とした。）を行った。

3.3 簡易耐震診断手法改善案

詳細耐震診断済の構造物及び現行の水道施設耐震工法指針により設計された構造物について、現行簡易診断表によるケーススタディを実施した。東北地方太平洋沖地震やその他の地震における被害実態及びこのケーススタディ結果を基に簡易耐震診断手法の改善案を検討した。

4. 検討結果

4.1 浄水施設の耐震化取組み状況等と課題

事業体における耐震化状況や課題を調査した結果、図1に示すとおり取水・導水施設の多くは詳細耐震診断が未実施であった。

多くの中小事業体では水道施設全般の詳細耐震診断の実施割合が低く、耐震化に向けての課題として、以下の事項が挙げられた。

- 経済的課題：耐震化を要する施設が多くあり、多額の費用確保が必要。
- 人材的課題：専門技術を有する職員の確保と技術継承の実施が必要。
- 技術的課題：既存資料の整備が必要。低コストかつ効率的な耐震技術の開発・確立が必要。
- その他：耐震工事中の代替施設の確保が必要。（水運用が困難）

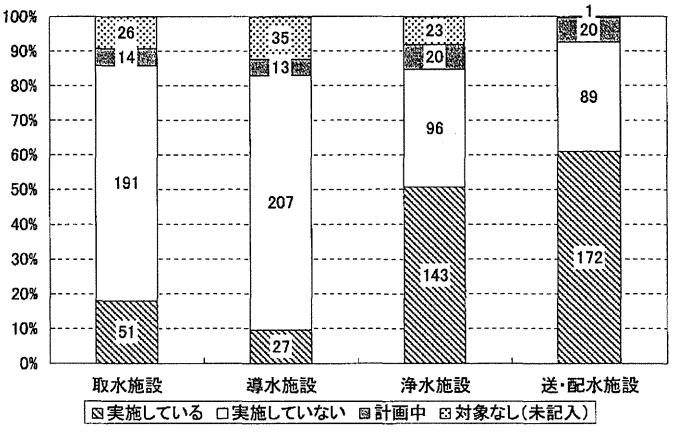

図1 詳細診断の実施状況

また、簡易耐震診断の実施状況は、詳細耐震診断と同様に中小事業体での実施割合が低い状況であり、中小事業体では耐震化に対する取組みが大きく遅れていることが明確になった。

なお、調査結果を基に、詳細耐震診断実施済みの事業体を抽出し、その事業体における水道施設の詳細診断結果を収集した。

4.2 東北地方太平洋沖地震における被害実態

浄水施設の被災状況に関する被災5県の水道行政担当部署へのアンケート調査の結果、福島県を除く4つの県から回答が得られた。浄水施設の被害としては、傾斜板の破損・一部滑落等を生じたが、長期にわたる機能停止を伴う甚大な被害のあった浄水場は、以下の蛇田浄水場など3浄水場であった。これらの浄水場については、現地調査及びヒアリング調査を行った。

- 宮城県：蛇田浄水場　（石巻地方広域水道企業団）
- 茨城県：鰐川浄水場　（茨城県企業局鹿行水道事務所）
- 千葉県：神宿浄水場　（神崎町水道事業）

これらの被害実態調査の結果、地震動そのものによる浄水施設等の地震被害は見当たらず、液状化等の地盤変状に伴う被害がほとんどであった。また、兵庫県南部地震以降の地震被害実態を精査した結果も同様の傾向を示し、浄水施設等の地震被害については、液状化等の地盤変状により施設は甚大な被害を蒙ったが、それ以外では軽微な被害であったことが分かった。

5. 簡易耐震診断手法改善案

現状の簡易診断手法は、耐震性の要因項目を点数化し、その総合評点で耐震性を評価するものであるが、診断のためには全項目の点数化が必要である。人材面・技術面での課題を有する中小事業体における耐震化を促進するためには、極力簡易な手法を提案する必要がある。

そこで、液状化等の地盤変状に伴って施設は甚大な被害を蒙るが、それ以外では軽微な被害に留まるという被害実態を反映し、かつ、全項目点数化を必要としない場合があることを考慮して、

- 被害の有無を左右する液状化等の発生の可能性に基づく「第1次評価」
- 次に、適用した耐震工法指針の変遷を考慮して、建設年代による「第2次評価」
- 次に構造物の地震動への抵抗力すなわち構造的強度に基づく「第3次評価」

による段階的な耐震性診断手順を提案した。

この手順は、診断作業の簡略化とともに、被害実態に見合った評価が可能な上､施設の弱点が明確になる利点を有する。

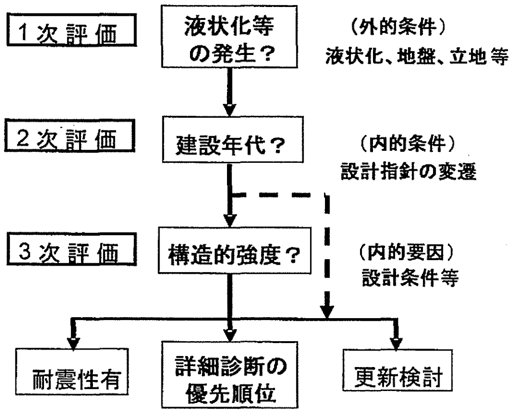

図2　改善診断手順案

また、現行の簡易耐震診断表における構造的強度評価の課題を見出すため、詳細耐震診断を実施済の浄水池・配水池に現行の簡易耐震診断表を適用するケーススタディを行った。表 1 はその対象とした浄水池・配水池の概要であり、A～G は詳細耐震診断を行った結果、耐震性がないと評価された浄水池・配水池である。一方、H 配水池は現行の指針で設計施工され、耐震性ありと評価される構造物である。

表1　ケーススタディ対象の構造物

施設名	建設年度	構造形式等	容量
A浄水池	S55	RC造_ﾌﾗｯﾄｽﾗﾌﾞ	7,200m^3
B浄水池	H1	RC造_ﾌﾗｯﾄｽﾗﾌﾞ	5,000m^3
C浄水池	S52	RC造_ﾌﾗｯﾄｽﾗﾌﾞ	500m^3
D浄水池	S51	RC造_ﾌﾗｯﾄｽﾗﾌﾞ	300m^3
E配水池	S37	RC造_壁	700m^3
F配水池	S52	RC造_壁	330m^3
G浄水池	S55	RC造_壁	200m^3
H配水池	※	RC造_ﾌﾗｯﾄｽﾗﾌﾞ	32,600m^3

※H 配水池は現行の設計指針での設計

表2にケーススタディ結果を示す。この表中の評点が高いほど耐震性が低いが、十分な耐震性を有するH配水池が、耐震性なしと判定されたA～Gの浄水池・配水池よりも低い耐震性の判定結果となるという不合理を生じている。

このことから、簡易耐震診断における構造的強度評価手法の見直しの必要性が示唆された。

表2　ケーススタディ結果

評価項目	A浄水池	B浄水池	C浄水池	D浄水池	E配水池	F配水池	G浄水池	H配水池
位　置	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.0
材　質	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
壁面積／池面積	1.5	1.5	1.0	1.5	1.0	1.5	1.5	1.5
総　深	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.3
型　式	1.4	1.4	1.4	1.4	1.4	1.0	1.0	1.4
上置土厚	1.0	1.2	1.0	1.0	1.0	1.0	1.0	1.0
評点	2.1	2.5	1.4	2.1	1.4	1.7	1.7	2.7

※評点は各評価項目の相乗値

※評価項目は現行の簡易耐震診断表の評価項目の内、構造的強度に係わるものを抜粋

※評点が高いほど耐震性が低い評価となる

6. 考察

6．1 浄水施設の耐震化の取組み状況等と課題

アンケート調査結果から、耐震診断の実施状況及び耐震化に向けた課題が明らかになった。耐震化の取組は中小規模水道において大きく遅れ、その課題として経済面のほか、人材面・技術面が挙げられており、中小事業体での耐震化促進のためには、その取組みを手助けする簡易な手法が求められている。このため、本簡易診断手法による詳細診断施設の優先順位付けや更新への道筋の提示などが有効な方法であると考えられる。

6．2 東北地方太平洋沖地震における被害実態

被害実態調査により、浄水施設の地震動による被害は、傾斜板の破損・滑落等、軽微なものが多く、地震動による直接的な被害はほとんど見当たらないが、液状化等の地盤変状に伴って甚大な被害を生じていることが分かった。この被害実態は浄水施設等の地震に対する弱点を明確に示しており、その弱点を把握する診断手法が今後の耐震化の促進に寄与することができる。

6．3 簡易耐震診断手法改善案

被害実態の調査結果及び詳細耐震診断済構造物に現行簡易耐震診断表を適用するケーススタディにより、現行簡易診断表の課題を見出すとともに、「液状化等の発生」、「建設年代（耐震工法指針の変遷を考慮）」、「構造的強度」の3段階評価の手順を提案した。今後はケーススタディで明らかとなった構造的強度の評価について、必要部材厚や鉄筋量等による判定の導入など、その詳細手法を検討する必要がある。

7. まとめ

耐震化の取組みが遅れていることから、この促進のため、東北地方太平洋沖地震等における水道施設被害実態を調査・把握し、これを基に改善簡易耐震診断手法のコンセプトとして診断手順案を提案した。

今後は、詳細診断法と現行の簡易耐震診断法の比較及び課題整理を継続し、現行の簡易耐震診断表の問題点抽出と改善により現行の簡易耐震診断表の改定案を作成し、ケーススタディでその有効性を確認する。また、その結果に基づく改善簡易耐震診断手法を提案し、中小事業体向けにこの手法の解説等をまとめる。

8. 謝辞

本研究にご尽力いただいた方々に感謝申し上げるとともに、アンケート調査等に御協力いただいた水道事業体及び関係者各位に、厚くお礼を申し上げる。

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キーワード：浄水施設、耐震診断

Key Words：Water treatment facilities , Evaluation of seismic resistance

DAMAGE TO WATER SUPPLY SYSTEM INDUCED BY THE 2011 GREAT EAST JAPAN EARTHQUAKE

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ABSTRACT: This paper is focusing on damage to water supply facilities during the 2011 great east Japan earthquake and tsunami. At first, an outline of damage to water supply facilities is given and the damage to water supply pipelines of Sendai City is analyzed. An abrupt increase in flow rate and a decrease in water pressure of water distribution system in spite of no damage to pipeline were discussed through a questionnaire survey to waterworks bureaus.

Key Words: great east Japan earthquake, water supply system, sloshing of water in receiving tank

INTRODUCTION

This paper deals with damage to water supply facilities during 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 Pacific coast of east Japan. The earthquake and tsunami caused about 20,000 deaths and missing and injured about 6,000 people. This earthquake and tsunami also caused extensive damage to water supply facilities. A suspension of water supply was occurred at about 2,300,000 houses in east Japan just after the earthquake. 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.

At first, an outline of damage to water supply facilities is given and the damage to water supply pipelines of Sendai City is analyzed. Then an unusual phenomenon of distribution system is focused. An abrupt increase in flow rate and a decrease in water pressure of water distribution system were occurred in spite of no damage to pipeline during the earthquake. A questionnaire survey to waterworks bureaus was conducted and situation of the unusual phenomena is revealed. The relation to response velocity spectra of the past earthquakes was investigated and the causes of the unusual phenomena are discussed. Finally, lessons learned from the earthquake and tsunami is considered.

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

Causes of damage to facilities

The damage caused by the earthquake and tsunami seems to be 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 a water pipe bridge by tsunami. The water pipe bridge was completely washed away. Photo 4 shows damage to a buried pipeline. The pipeline appeared above ground after tsunami because of scouring caused by tsunami. The mechanism of damage to pipeline, that is, how much force acts on a pipeline is not sure. The mechanism of this kind of damage must be clarified in future.

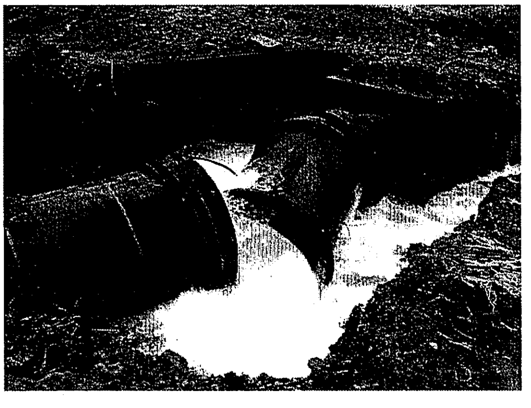


Photo 1 Damage to steel pipe with 2400mm diameter (Miyagi Pref.)[1].

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

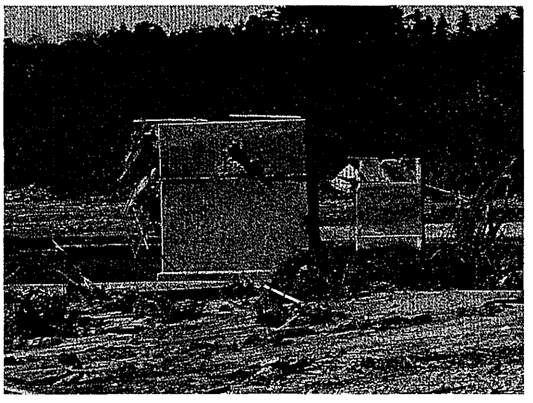


Photo 3 Damage to water pipe bridge (Miyagi Pref.) .

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

DAMAGE IN SENDAI CITY

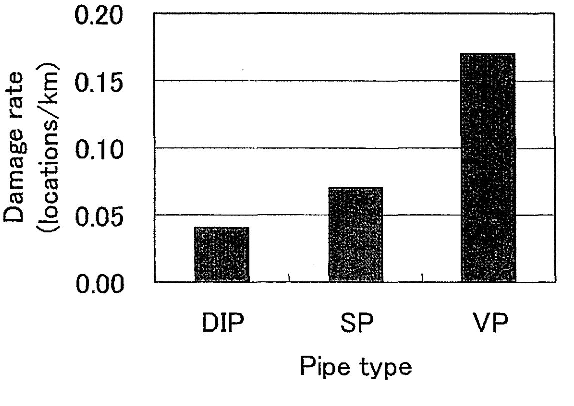
Outline of water supply system of Sendai City

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).

Damage to pipeline

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 Fig. 1 and 2, respectively. Fig. 1 indicates that the damage rate of polyvinyl chloride pipe (VP) is high. Fig. 2 reveals that the smaller the pipe diameter is, the higher the damage rate.



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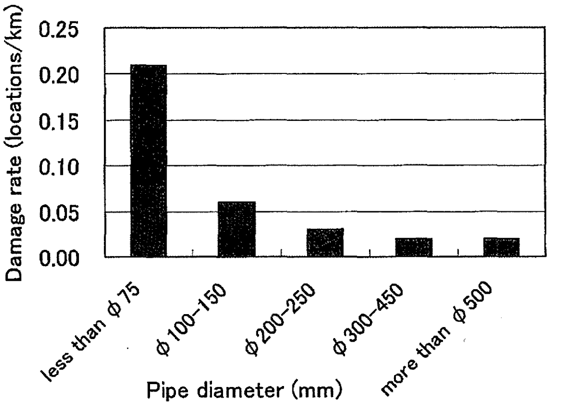

Fig. 2 Damage rate related to pipe diameter.

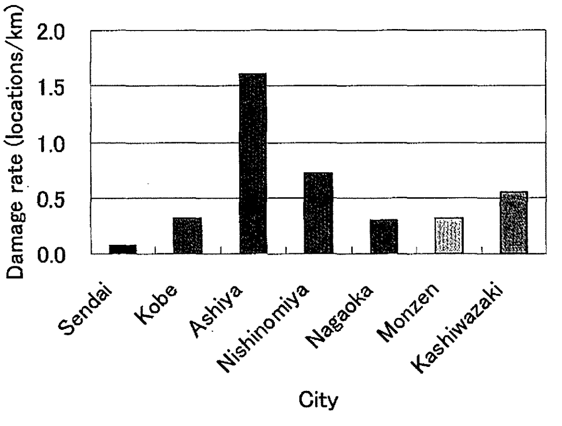

Fig. 3 Comparison of damage rate.

Fig. 3 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 in the 2007 Niigata-ken Chuetsu-oki Earthquake, respectively. This figure revels that the damage rate of Sendai City was very low in comparison with another cities. Magnitude of earthquake and seismic intensity in each city were different. PGA of K-NET Sendai observation station was, however, not small; 1,808 (cm/s/s). This value is higher than most of cities listed in Fig. 3. 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%.

Fig. 4 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. Effect of earthquake-proofing pipe was, therefore, verified by the earthquake.

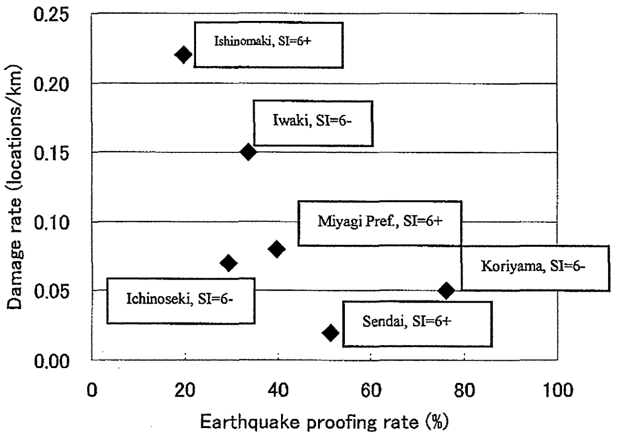

Fig. 4 Relation between earthquake proofing rate and damage rate.

UNUSUAL PHENOMENA OF WATER DISTRIBUTION SYSTEM

Unusual phenomena such as an abrupt increase in flow rate and a decrease in water pressure of water distribution system in spite of no damage to pipeline was occurred in several cities during the great east Japan earthquake. Fig. 5 shows time histories of the flow rate and water pressure at a water distribution plant of the Bureau of Waterworks Tokyo Metropolitan Government. The flow rate increased and water pressure decreased rapidly just after the earthquake. The higher flow rate and lower water pressure were recovered after about 20 minutes. The similar phenomena were occurred again by the aftershock.

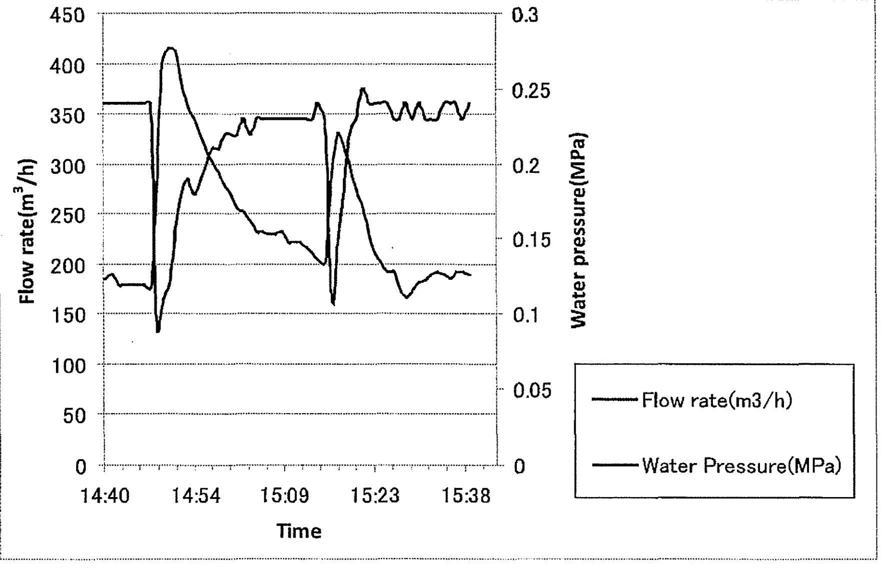

Fig. 5 Time histories of the flow rate and water pressure at a water distribution plant of Tokyo.

A questionnaire survey was conducted on the occurrence of the unusual phenomena of water distribution system after the great east Japan earthquake for twenty large scale waterworks bureaus not only in east Japan but also in west Japan. Table 1 lists the occurrence of the unusual phenomena of water distribution system in each waterworks bureau. The unusual phenomena occurred at even the cities where JMA seismic intensity was less than 5, that is, Yamagata, Nagoya and Osaka Cities. Fig. 6 shows time histories of the flow rate and water pressure at a water distribution plant of the Osaka City Waterworks Bureau. This figure shows that the similar phenomena of the Bureau of Waterworks Tokyo Metropolitan Government occurred in Osaka City where JMA seismic intensity was 3. It suggests that the unusual phenomena depend on not only magnitude of ground shaking but also other factors such as frequency characteristics of ground shaking.

Table 1 Occurrence of the unusual phenomena of water distribution system in each cities.

Name	Seismic Intensity	Occurrence
Sapporo City	3	N/A
Aomori City	4	N/A
Morioka City	5+	N/A
Akita City	5+	N/A
Sendai City	6−	Yes
Yamagata City	4	Yes
Niigata City	4	N/A
Mito City	6−	N/A
Utsunomiya City	5+	Yes
Chiba Prefecture	5+	Yes
Tokyo Metropolitan	5−	Yes
Saitama City	5+	Yes
Yokohama City	5+	N/A
Kofu City	5−	N/A
Nagoya City	4	Yes
Kanazawa City	3	N/A
Osaka City	3	Yes
Kobe City	2	N/A
Hiroshima City	1	N/A

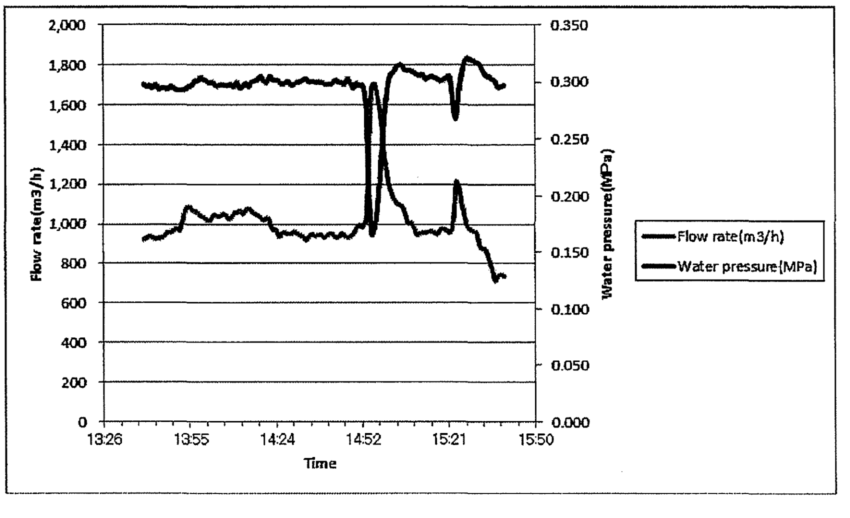

Fig. 6 Time histories of the flow rate and water pressure at a water distribution plant of Osaka.

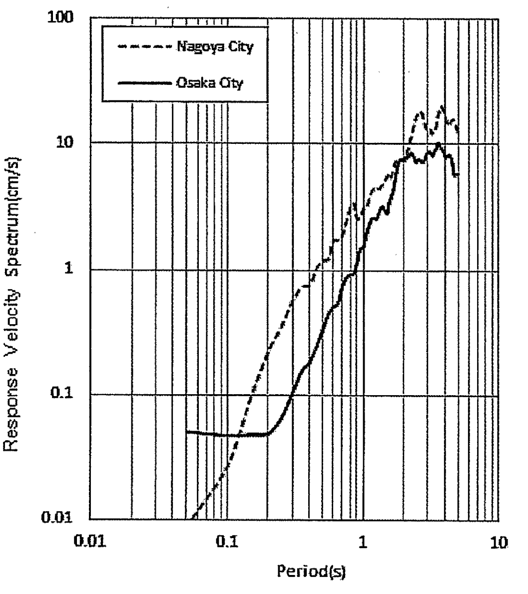

Fig. 7 Response velocity spectra of recorded waveform at Nagoya City (K-NET AIC004) and Osaka City (K-NET OSK005).

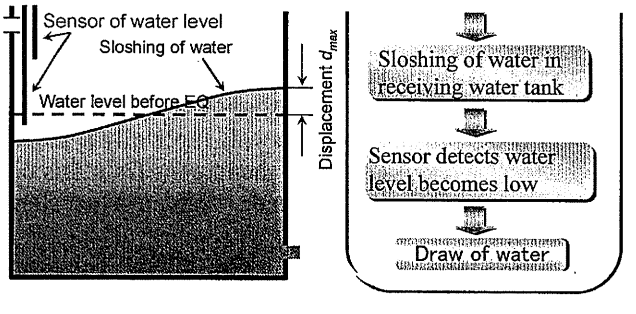

Fig. 8 Mechanism of draw of water from distribution pipe to receiving tank by sloshing during earthquake.

Fig. 7 illustrates response velocity spectra of recorded waveforms of the great east Japan earthquake at Nagoya City (K-NET AIC004) and Osaka City (K-NET OSK005). This figure indicates that the predominant periods are more than one second.

Murata and Miyajima[3)] have considered that one of causes of the unusual phenomena seems to be sloshing of water in receiving water tank. If sloshing of water in receiving water tank is occurred by an earthquake, draw of water to receiving water tank starts by error of a sensor of water level in the receiving water tank as shown in Fig. 8. If sloshing of water in many receiving water tanks occurred simultaneously, an abrupt increase in flow rate and a decrease in water pressure may be occurred. Occurrence of sloshing of water in receiving water tank depends on the dimensions of receiving water tank and the height of water in the tank. Murata and Miyajima[3)] have investigated dimensions of receiving water tank in a water distribution block of Osaka City and estimated the natural period of sloshing of the water. Fig. 9 shows cumulative percentage of natural period of water in receiving water tank in case that the height of water is 3/4 and 1/2 of the height of water tank. The height of water is variable and depends on use of water. The natural period of sloshing is more than 1.0 second

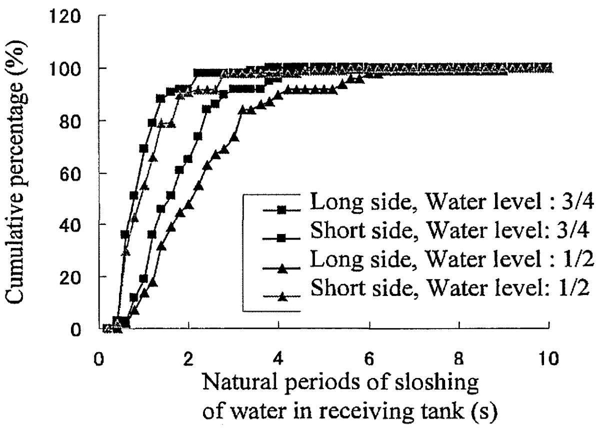

Fig. 9 Cumulative percentage of natural period of water in receiving water tank

of more than 80% of the water tank in the direction of long side in the water distribution block in Osaka City. This is one example, but long period ground motion more than one second can be caused sloshing of water in receiving water tank. However, the further study is needed to clarify the cause of an abrupt increase in flow rate and a decrease in water pressure of water distribution system in spite of no damage to pipeline and its effects to emergence response just after large scale disaster.

CONCLUDING REMARKS

An outline of the damage to water supply facilities from the 2011 great eat Japan earthquake and tsunami was presented and the unusual phenomena of water distribution system just after the event was discussed. The following conclusions may be drawn based on the present study.

(1) 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.

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

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

(4) If sloshing of water in receiving water tank is occurred by an earthquake, draw of water to receiving water tank from pipeline starts by error of sensor of water level in the receiving water tank. Sloshing of water in receiving water tank, therefore, may be one of the causes of unusual phenomena.

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. This study was supported in part by the Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology, Japan (No. 20310108).

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1) http://www.pref.miyagi.jp/kigyo/
2) http://www.minami-nagareyama.org/20110311/report03a.htm
3) Murata, K. and Miyajima, M.: Influence of Receiving Water Tank Sloshing on Water Distribution System, Journal of Japan Earthquake Engineering, Vol. 7, No. 1, pp. 27-42, 2007 (in Japanese).

Damage Analysis of Water Supply Facilities in the 2011 Great East Japan Earthquake and Tsunami

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LISBOA 2012

M. Miyajima
Kanazawa University

SUMMARY:
This study is focusing on damage to water supply facilities during the 2011 great east Japan earthquake and tsunami. At first, an outline of damage to water supply facilities is given and the damage to water supply pipelines of Sendai City is analyzed. An abrupt increase in flow rate and a decrease in water pressure of water distribution system were occurred in spite of no damage to pipeline just after the earthquake. We clarified the situation through a questionnaire survey to waterworks bureaus. The relation of response velocity spectra of the earthquake ground motion to the unusual phenomena was investigated and the causes of the unusual phenomena are discussed.

Keywords: Great east Japan earthquake, water supply system, earthquake damage, sloshing of water in receiving tank

1. INTRODUCTION

The present paper deals with damage to water supply facilities during 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 Pacific coast of east Japan. The earthquake and tsunami caused about 20,000 deaths and missing and injured about 6,000 people. This earthquake and tsunami also caused extensive damage to water supply facilities. A suspension of water supply was occurred at about 2,300,000 households in east Japan just after the earthquake. 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 the damage data except flooded areas are analyzed in this paper.

At first, an outline of damage to water supply facilities is given and the damage to water supply pipelines of Sendai City is analyzed. Then an unusual phenomenon of distribution system is focused. An abrupt increase in flow rate and a decrease in water pressure of water distribution system were occurred in spite of no damage to pipeline just after the earthquake. A questionnaire survey to waterworks bureaus was conducted and situation of the unusual phenomena is revealed. The relation of response velocity spectra of the earthquake ground motion to the unusual phenomena was investigated and the causes of the unusual phenomena are discussed. Finally, lessons learned from the earthquake and tsunami is considered.

2. OUTLINE OF DAMAGE TO WATER SUPPLY FACILITIES

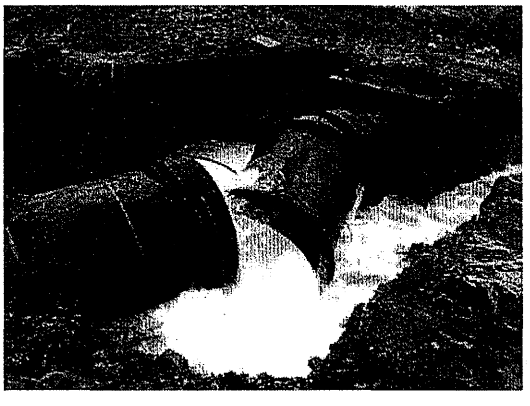
2.1. Suspension of water supply

A suspension of water supply was occurred at about 2,300,000 households 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, occurred by the strong aftershocks happed in the middle of April.

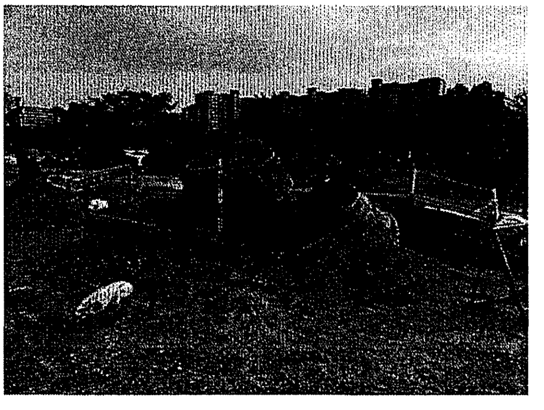
2.2. Causes of damage to facilities

The damage caused by the earthquake and tsunami seems to be 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 a water pipe bridge by tsunami. The water pipe bridge was completely washed away. Photo 4 shows damage to a buried pipeline. The pipeline appeared above ground after tsunami because of scouring caused by tsunami. The mechanism of damage to pipeline, that is, how much force acts on a pipeline is not sure. The mechanism of this kind of damage must be clarified in the future.



Photograph 1 Damage to steel pipe with 2400mm diameter (Miyagi Pref.).
(http://www.pref.miyagi.jp/kigyo/)



Photograph 2 Uplift of underground water tank (Chiba Pref.).

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

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

3. DAMAGE IN SENDAI CITY

3.1. Outline of water supply system of Sendai City

Since the damage to pipeline of Sendai City was 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).

3.2. Damage to pipeline of Sendai City

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 Figs. 1 and 2, respectively. Fig. 1 indicates that the damage rate of polyvinyl chloride pipe (VP) is high. Fig. 2 reveals that the smaller the pipe diameter is, the higher the damage rate.

Fig. 3 illustrates a comparison of damage rate of Sendai City with those of other cities suffered damage to pipeline in the past earthquakes in Japan. 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 in the 2007 Niigata-ken Chuetsu-oki Earthquake, respectively. This figure revels that the damage rate of Sendai City was very low in comparison with another cities. Magnitude of earthquake and seismic intensity in each city were different. PGA of K-NET Sendai observation station was, however, not small; 1,808 (cm/s/s). This value is higher than most of cities listed in Fig. 3. 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%.

Fig. 4 illustrates the relation between the earthquake-proofing rate and damage rate of each waterworks bureau 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 shows JMA (Japan Meteorological Agency) seismic intensity scale in each area. 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. Effect of earthquake-proofing pipe was, therefore, verified by the earthquake.

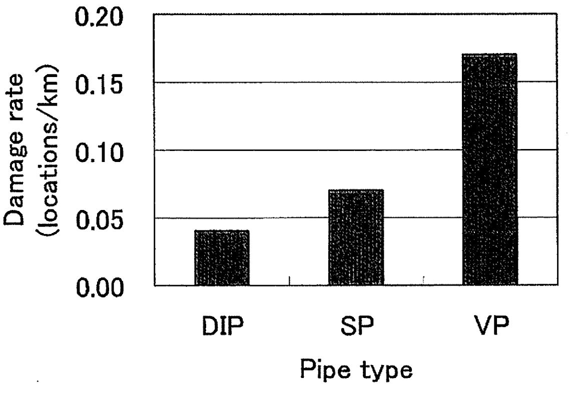


Figure 1 Damage rate related to pipe type.

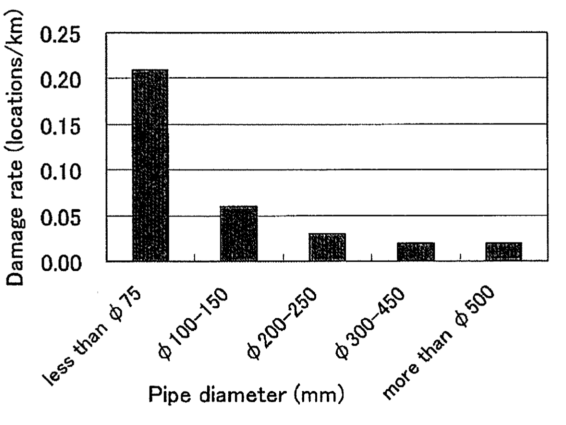


Figure 2 Damage rate related to pipe diameter.

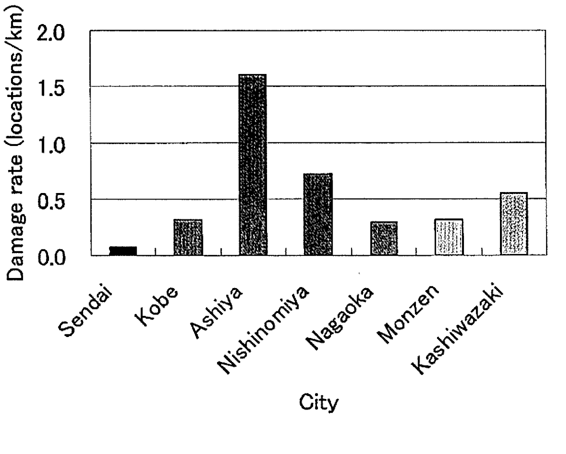


Figure 3 Comparison of damage rate.

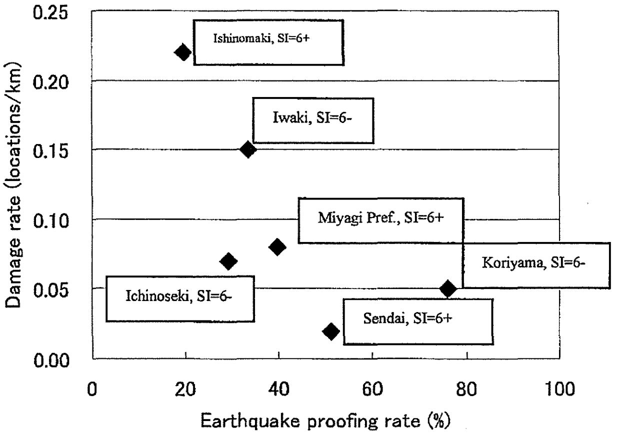


Figure 4 Relation between earthquake proofing rate and damage rate.

4. UNUSUAL PHENOMENA OF WATER DISTRIBUTION SYSTEM

Unusual phenomena such as an abrupt increase in flow rate and a decrease in water pressure of water distribution system in spite of no damage to pipeline was occurred in several cities during the great east Japan earthquake. Fig. 5 shows time histories of the flow rate and water pressure at a water distribution plant of the Bureau of Waterworks Tokyo Metropolitan Government. The flow rate increased and water pressure decreased rapidly just after the earthquake. The higher flow rate and lower water pressure were recovered after about 20 minutes. The similar phenomena were occurred again by the aftershock.

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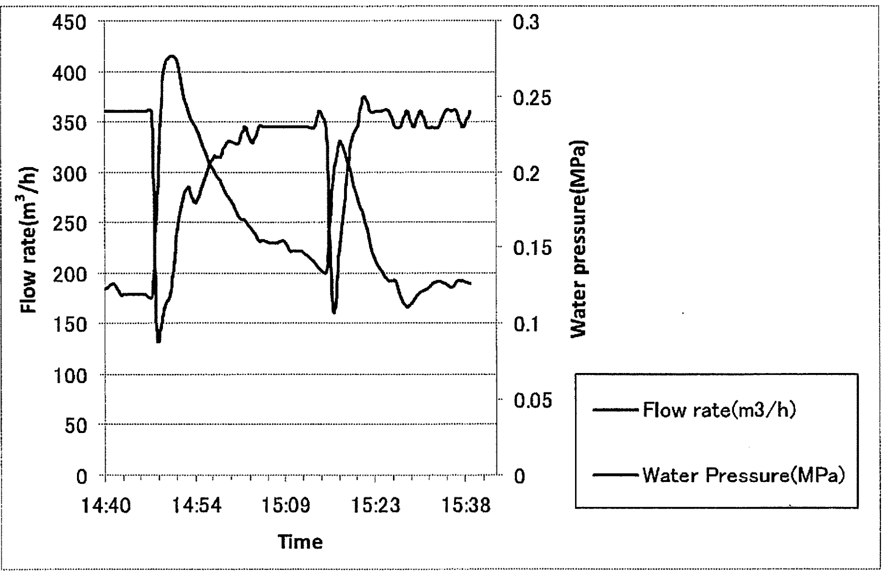

Figure 5 Time histories of the flow rate and water pressure at a water distribution plant of Tokyo.

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Chiba Prefecture	5+	Yes
Tokyo Metropolitan	5−	Yes
Saitama City	5+	Yes
Yokohama City	5+	N/A
Kofu City	5−	N/A
Nagoya City	4	Yes
Kanazawa City	3	N/A
Osaka City	3	Yes
Kobe City	2	N/A
Hiroshima City	1	N/A

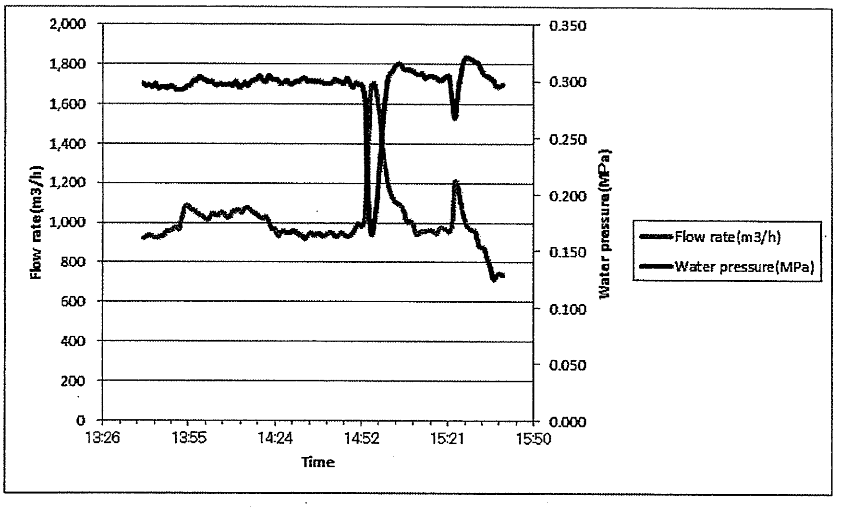

Figure 6 Time histories of the flow rate and water pressure at a water distribution plant of Osaka.

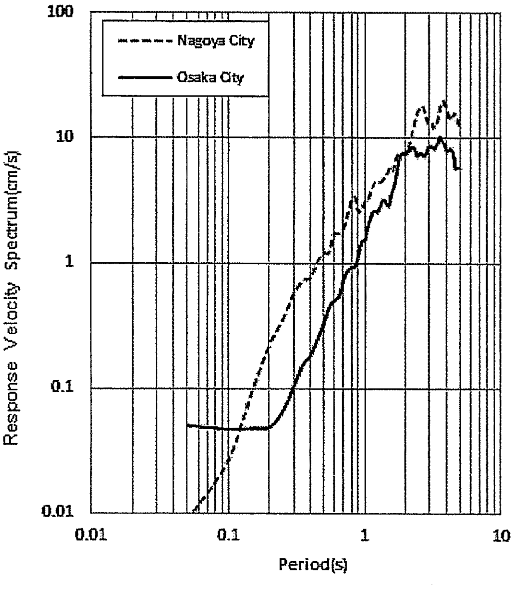

Figure 7 Response velocity spectra of recorded waveform at Nagoya City (K-NET AIC004) and Osaka City (K-NET OSK005).

Fig. 7 illustrates response velocity spectra of recorded waveforms of the great east Japan earthquake at Nagoya City (K-NET AIC004) and Osaka City (K-NET OSK005). This figure indicates that the predominant periods are more than one second.