The 10th JWWA/WRF/CTWWA Water System Seismic Conference

Program

Chinese Taiwan Water Works Association

2017

Contents

The 10th JWWA/WRF/CTWWA Water System Seismic Conference

1. Organization

Organized by:

Chinese Taiwan Water Works Association (CTWWA)
Japan Water Works Association (JWWA)
Water Research Foundation (WRF), USA

Co-organized by:

Taiwan Water Corporation, Sixth Branch Office
National Center for Research on Earthquake Engineering

Supported by:

Water Resources Agency, Ministry of Economic Affairs
Taiwan Water Corporation
Taipei Water Department

2. Agenda

Day 1 (2017/10/18, Wednesday)	
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09:35-09:55	Lessons Learned from Damage to Drinking Water Supply System in the 2016 Kumamoto Earthquake in Japan Masakatsu MIYAJIMA, Kanazawa University
09:55-10:15	Developing a Seismic Resilient Pipe Network Using Performance Based Seismic Design Procedures Craig DAVIS, Los Angeles Department of Water and Power
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11:10-11:25	Performance Test of Steel Pipe for Crossing Fault in United States Hayato NAKAZONO, JFE Engineering Corporation
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13:55-14:10	'Disaster-resistant waterworks model, connecting all to the water life' and the countermeasures against natural disasters – examples sharing the specific measures of cooperation with major cities and mutual help to community groups Takuya NAKAGAWA, Sendai City Waterworks Bureau
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14:50-16:05	**Session 3: Evaluation of Water System Components** Chair: Xavier IRIAS
14:50-15:05	Main Shock and After Shock Impact to Water System Seismic Fragility of Embankment Dams, Tank Reservoirs, and Large Diameter Pipelines Andrea CHEN, East Bay Municipal Utility District
15:05-15:20	Review of an Equation to Estimate Seismic Damage to Water Mains in Light of the 2016 Kumamoto Earthquake Yuko TSURUDA, Japan Water Research Center
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15:35-15:50	Damage Analysis of Air Valves of Drinking Water Pipeline in the 2016 Kumamoto Earthquake Taichiro INUI, Kanazawa University
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09:15-09:30	An Investigation of the Seismic Performance of Portland Water Bureau's Water System in an M 9.0 Earthquake Michael SALING, Portland Water Bureau
09:30-09:45	Formation of Information Transfer Methods for Envisaged Disasters Kazunori IWAMOTO, Yokohama Waterworks Bureau
09:45-10:00	Application of a Mesh-based Earthquake Impact Assessment Tool for Water Supply System on Policy Support Bing-Ru WU, National Science and Technology Center for Disaster Reduction
10:00-10:15	Study Report of Priority Evaluation of Earthquake Resistance on Water Supply Facilities Focused on the Restoration Process of Water Supply Akihisa ISHIDA, NJS CO., LTD
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13:00-13:15	Determining Water Distribution System Pipe Replacement Given Random Defects – Case Study of San Francisco's Auxiliary Water Supply System Charles SCAWTHORN, SPA Risk LLC
13:15-13:30	Seismic Screening of Large Water Pipelines for TWC's Seismic Improvement Program Gee-Yu LIU, National Center for Research on Earthquake Engineering
13:30-13:45	Mitigation of Potential Impacts of Seismic Events on a Regional Water Distribution System Gordon JOHNSON, Metropolitan Water District of Southern California

13:45-14:00	TWC's Thoughts on Implementing Seismic Improvement to Large Water Pipelines Sheng-I Tseng, Taiwan Water Corporation
14:00-14:15	Mitigating Water System Pipeline Damage – Seattle Public Utilities Case Study William F. HEUBACH, Seattle Public Utilities
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16:30-16:40	**Closing Ceremony**
16:40-17:00	Group Photo

3. Abstract of Papers

Damage and Restoration of Drinking Water Systems Caused by 0206 Tainan Earthquake and Future Mitigation Measures

Nan-Tzer Hu

1. Overview of 0206 Earthquake's

At 03:57 local time (19:57 UTC) on 6 February 2016, an earthquake with a moment magnitude of 6.4 struck 28 km (17 mi) northeast of Pingtung City in southern Taiwan[1], in the Meinong District of Kaohsiung, Caoling of Yunlin County magnitude of 6, Tainan City, and Chiayi City areas of the earthquake level of 5. The earthquake struck at a depth of around 23 km (14 mi). Its comparatively shallow depth caused more intense reverberations on the surface[2]. The earthquake had a maximum intensity of VII (Very strong) on the Mercalli intensity scale, causing widespread damage and 117 deaths. Almost all of the deaths were caused by a collapsed residential building, named Weiguan Jinlong in Yongkang District, except two others, who were killed in Guiren District[3][4], both Districts are in Tainan City. Sixty-eight aftershocks have occurred[5]. The earthquake was the deadliest earthquake in Taiwan since the 921 earthquake in 1999.

The 6th branch office of Taiwan Water Corporation (TWC) immediately set up an emergency response team at 05:00 am, and recalled employees to inspect damage to water system infrastructure due to the earthquake. TWC found some transmission lines (1 meter or greater in diameter) were seriously damaged, thousands of distribution pipelines were damage due to shifting ground and soil liquefaction, resulting in water loss, water service interruptions, low pressure, contamination and sinkholes and/or large pools of water throughout the service area in the city.

The disaster has left 400,000 homes without water service. TWC dispatched several emergency repairing teams corporate with outsourcing contractors to repair leaky pipeline and buried new pipes, gradually reduced the number of households affected by the water-supply outage due to the earthquake until on the February 25th morning to restore water supply. Fig.1 shows restoration of water supply system in 0206 Earthquake in 2016.

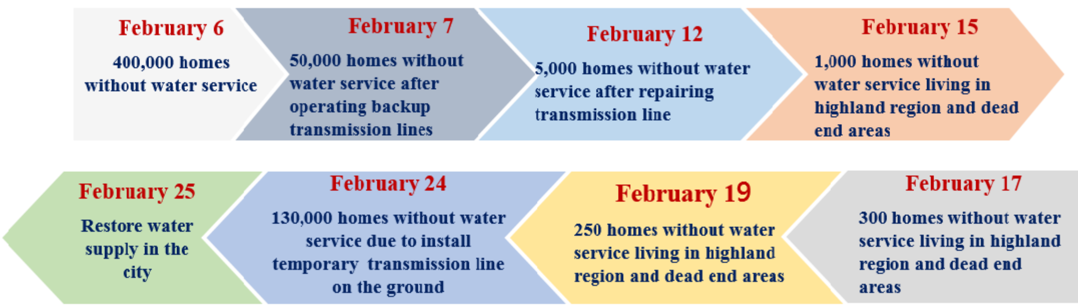

Fig.1 Restoration of water supply system in 0206 Earthque in 2016

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Lessons Learned from Damage to Drinking Water Supply System in the 2016 Kumamoto Earthquake in Japan

Masakatsu Miyajima

ABSTRACT

This study is focusing on damage to drinking water supply system in the 2016 Kumamoto Earthquake and the lessons learned are given. Mw 6.2 earthquake struck in and around Kumamoto City in Japan at a depth about 11 km at 21:26 JST on April 14, 2016. Around twenty eight hours later, at 01:25 JST on April 16, an Mw 7.0 stronger earthquake occurred in the same area at a depth of about 12 km. More than 8,000 houses were totally collapsed. Total fatality after the main shock was 49 dead with 1 missing. The main shock triggered many geo-hazards such as landslides, surface faulting and liquefaction. Drinking water supply system were heavily damaged by not only strong ground motion but also large ground deformation induced by the geo-hazards.

Damage analysis was conducted and the following findings are clarified.

1. The damage rate of pipelines of Kumamoto City is 0.08 cases/km. This value is similar to that of Sendai City in the 2011 Tohoku Earthquake, that is, 0.07 cases/km. The damage rate of Kobe City in the 1995 Kobe Earthquake was 0.32 cases/km and 0.30 cases/km in Nagaoka City in the 2004 Niigata-ken Chu-etsu Earthquake. These earthquakes recorded JMA seismic intensity 7. This difference seems to depend on percentage of installation length of seismic resistant pipe.
2. Pipe length of liquefied area is about 0.8% of the total length in Kumamoto City. The damage rate of pipelines in liquefied area was however about ten times of that in non-liquefied area.
3. The pipelines crossed a surface faulting suffered severe damage. The countermeasure for pipeline crossed a fault is necessary in the future.
4. Damage to air valve also affected suspension of water supply. The damage was caused by not only strong ground motion but also abrupt increase of water pressure in a pipe. The cause of abrupt increase of water pressure in a pipe just after an earthquake should be clarified.

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Developing a Seismic Resilient Pipe Network Using Performance Based Seismic Design Procedures

Craig A. Davis

ABSTRACT

The Los Angeles Water System is implementing a Seismic Resilience Program which comprehensively covers all aspects of water system business. A key component to the program is developing a seismic resilient pipe network. A seismic resilient pipe network is designed and constructed to accommodate damage with ability to continue providing water or limit water outage times tolerable to community recovery efforts. The challenges to creating a seismic resilient network is described through the four subsystems making up a water system, namely the supply, treatment, transmission, and distribution subsystems and how each must operate consistently given the numerous earthquake hazards using a performance-based design approach. The resilience of each subsystem is critical to supporting community resilience and are important for providing water delivery, quality, quantity, fire protection, and functionality services. Assessing the risks for fire following earthquake and identifying critical facilities and their locations throughout the city are important to defining the resilient pipe layout.

INTRODUCTION

The Los Angeles Department of Water and Power (LADWP) Water System is undertaking a seismic resilience program as outlined in [1] and [2]. As part of the program, these two documents recommended developing a Seismic Resilient Pipe Network (SRPN) recognizing it is a long-term mitigation effort with a commitment for using seismically resilient pipes across the city. A focus is given to improving the pipe network because most other components have been updated using modern seismic design over the past 40 years and were proven effective in the 1994 Northridge earthquake. However, to ensure consistency for design and construction across the entire system, the LADWP is also proposing the development of system-wide and component level seismic performance and design criteria.

The intent of a SRPN is to improve the existing network knowing earthquake damage cannot cost-effectively be completely prevented in the near-term, but may be better controlled with a focus of providing improved customer service. A resilient network places seismically robust pipes at key locations and alignments to help increase the probability of continuous water delivery and reduce the time to restore areas suffering a loss of water services after an earthquake. Seismically robust pipes are designed to accommodate earthquake forces meeting defined performance criteria. Damaged portions of the water system preventing flow capabilities can be isolated from the earthquake resistant pipes to increase service restoration rates.

This paper proposes methodologies for developing a SRPN for the Los Angeles Water System. The first section defines a SRPN. The following section presents a performance based seismic design procedure applicable to the water system. This information provides the basis forming the framework and criteria for transforming the existing transmission and distribution networks into a SRPN, which is described in the last section. The performance based seismic design and SRPN concepts are applicable to other water systems.

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Verification of Design Method of Pipeline Crossing Fault with Earthquake Resistant Ductile Iron Pipe using Large-scale Split-box Test

Keita Oda, Shozo Kishi, Masakatsu Miyazima,
Chalermpat Pariya-Ekkasut, Brad Parker Wham, and Thomas Denis O'Rourke

ABSTRACT

This paper describes a safety verification result of the design method of a pipeline crossing fault using Earthquake Resistant Ductile Iron Pipe (ERDIP). In order to confirm the performance limit of the joint and pipeline behavior, we performed ultimate four-point bending tests and a fault rupture test using the test equipment at Cornell University in the U.S.

Consequently, no leakage immediately occurred even though the test pipes exceeded the design performance limit of the joint. Thus, the result showed that a pipeline design method based on the performance limit of the ERDIP joint can result in a satisfactory advantage. The following are the details of the test results.

(a) Four-point bending test: A joint bending test was performed on the ERDIP joint (DN150, GX-type) under water pressure of 0.55 MPa. No leakage was found until the joint deflection of 12.2°. Subsequently, first leakage was confirmed over 12.2°. Consequently, the test result shows that there was no leakage until the joint deflection of 1.5 times larger than the maximum joint deflection angle (i.e., 8°).

(b) Large-scale fault rupture test: ERDIP (DN150, GX-type) under water pressure of 0.55 MPa was installed in a test sand box divided into two sections. The fault displacement was simulated by moving one side of the divided test box. Six joints were placed in the sand box. Both ends of the pipeline were fixed to the box. Normally, an actual chain structure pipeline is installed under less severe conditions than those under which this test was performed. Consequently, no leakage immediately occurred even though the test pipes exceeded the design performance limit of the joint by the fault rupture.

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Design Strategies of Transmission Trunks across Normal Fault-- A Case Study of Shanchiao Fault

Sheng-Shin Chu, Chin-Ling Huang and Kai-Ping Chang

ABSTRACT

According to the studies about active faults in metropolitan Taipei area, it has been indicated that Shanchiao Fault at the western rim of Taipei Basin is a highly active normal fault. Slip of the fault can cause deformation of shallower soil layers and lead to the destruction of infrastructures, residential building foundations and utility lines like transmission trunks near or across the influenced area.

Data on geological drilling and dating have been used to determine that a growth fault exists in the Shanchiao Fault. In an experiment, a sandbox model was built using noncohesive sandy soil to simulate the existence of a growth fault in the Shanchiao Fault and forecast the effect of the growth fault on shear-band development and ground differential deformation. The experimental results indicated that when a normal fault contains a growth fault at the offset of the base rock, the shear band develops upward beside the weak side of the shear band of the original-topped soil layer, and surfaces considerably faster than that of the single-topped layer. The offset ratio required is approximately one-third that of the single-cover soil layer.

The finite element method (FEM), finite difference method (FDM), and discrete element method (DEM) are usually used to analyze the fault deformation. However, when the normal fault is simulated, the new overlay was deposited after the fault slip; the finite element method (FEM) of the continuum is hard for normal fault analysis. In former study, a numerical simulation of the sandbox experiment was conducted using a discrete element method program, PFC2D, to simulate the upper-covering sand layer shear-band development pace and the scope of a growth normal fault slip. The simulation results indicated an outcome similar to that of the sandbox experiment.

According to the above test results, the Guandu(關渡) profile geometric simulation model established in this study, The PCF2D program was used to create a model for simulating SCF-8 and SCF-9 profiles and the shear-band propagation reached the particle surface in the final 1-m, 2-m, and 2.5-m slip of this growth normal fault numerical model. The simulation results can be applied to the design of construction projects near fault zones.

Keywords: Normal Fault; Shanchiao Fault; Discrete Element Method PFC2D; Transmission Trunks

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Performance Test of Steel Pipe for Crossing Fault in United States

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and Thomas D. O'Rourke.

ABSTRACT

This report describes the performance tests of Steel Pipe for crossing Fault (SPF), which is an "on fault earthquake-resistant countermeasure" pipe, conducted at Cornell University. In the test results, despite applying deformation of several times the design value, the pipe did not crack or leak and more than 80% of the pipe cross section where water can pass was secured in all the tests.

I. INTRODUCTION

There are about 2000 faults in Japan. Similarly, there are many huge active faults such as the San Andreas Fault on the West Coast of the United States. Particularly in California, large-scale earthquakes are expected in the future, and since many buried water pipelines cross faults, local water utility companies are studying fault countermeasures for underground waterworks pipelines.

Steel Pipe for crossing Fault (SPF) is a fault countermeasure for buried water pipelines. SPF is manufactured by processing steel pipes for waterworks into a special wavy shape (comparable to the wavy part of a bendable drinking straw) so that the fault displacement which occurs during an earthquake can be absorbed by concentrating the deformation on the wave-shaped section, rather than attempting to resist the deformation. We have conducted tests in Japan, including underground tests, and confirmed the performance of Steel Pipe for Crossing Faults.

This report will give an overview of Steel Pipe for Crossing Fault and describe the performance tests conducted at Cornell University.

II. OVERVIEW OF STEEL PIPE FOR CROSSING FAULT

Damage to Fault Crossing Pipeline

Figure 1 shows an example of damage to a buried steel pipeline (200A diameter steel pipe) crossing a fault in the Taiwan Earthquake of 1999. When a slip occurs at the fault plane, it is likely to be thought that the transverse pipeline undergoes shear deformation at the fault plane due to the shearing force of the ground.

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Mitigating Risk to Underwater Crossings to Improve Water Supply Reliability: Two Case Studies

Serge Terentieff, Denise Cicala, Xavier Irias, and Raffi Moughamian

ABSTRACT

Isolated segments of the East Bay Municipal Utility District's (EBMUD) raw water aqueducts and large diameter transmission pipelines are at risk of breaking as a result of seismically-induced liquefaction at underwater crossings, which may significantly limit potable water supply for EBMUD's 1.4 million customers in the San Francisco East Bay Area. This paper examines two case studies that highlight alternative approaches that can be used to mitigate risk of failure: the first considers potential levee failures in the Sacramento-San Joaquin Delta (Delta), as a result of a low-probability seismic event that could result in structural damage to EBMUD's raw water aqueducts at river crossings; the second considers failure of transmission pipes that supply potable water to Alameda Island, a city of about 80,000 residents that depends solely on underwater pipeline crossings for its water supply.

The first case study is Mokelumne Aqueduct No. 3, a major pipeline that crosses three rivers. While the probability of seismic damage is relatively low, as Aqueduct No. 3 was seismically retrofitted in 2003, the consequence is high because the pipeline is a major supplier to 1.4 million customers. To mitigate the risk of structural failure to Aqueduct No. 3, and to the other older and nonretrofitted Mokelumne Aqueduct Nos. 1 and 2, EBMUD installed cross connections among these three raw water aqueducts at both ends of the Delta to allow damaged sections to be bypassed. To further mitigate the risk to its raw water supply, EBMUD developed a repair plan and approach that identifies how raw water service could be restored within 6 months, utilizing a bypass scheme of floating in-place and sinking to the river bottom six 32-inch diameter high density polyurethane bypass pipes, and by connecting these pipes to Mokelumne Aqueduct No. 3 using manifolds on both sides of the river.

The second case study involves treated water pipelines supplying water to Alameda, an island with no water storage facilities. Four underwater pipeline crossings currently supply water to the island including some 16- to 24-inch diameter cast iron pipes installed between 1918 and 1946, located in potentially liquefiable soil with a high likelihood of failure. Results of a Crossings Master Plan study determined that failure of any one of the crossings could lead to a reduction in the level of service to Alameda Island, and recommended three new 24-inch diameter pipeline crossings and in-street pipelines connecting the new crossings to existing transmission pipelines.

This paper summarizes the process used to assess the vulnerability of underwater crossings for these two case studies and identifies mitigation strategies to improve water supply reliability considering both the likelihood and consequence of failure. This includes process used to evaluate underwater crossing alternatives, considering various alignment options and construction methods including micro-tunneling, horizontal directional drilling, and float-and-sink, as well as other criteria including cost, constructability, survivability, speed of repair, and environmental factors. The process used to select an alignment and construction method for the first Alameda crossings replacement is discussed, including design details to reduce potential for differential settlement.

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Verification and evaluation method for the seismic performance of potable water mains lined with cured-in-place pipe (CIPP)

Hiromasa Ishizeki and Masakatsu Miyajima

ABSTRACT

This paper presents earthquake damage surveys, experiments on seismic behavior, and a performance evaluation method using seismic calculation, for potable water mains lined with cured-in-place pipe (CIPP). CIPP is a trenchless technology that forms a new pipe within an existing pipeline for the purpose of renewal or corrosion prevention of aging pipes, and is used mostly in pipes with non-anti-seismic joints.

Japan has suffered significant damage to potable water pipelines caused by frequent seismic activities. It is reported that most of the resulting damage was water leakage caused by pullout of those joints that didn't have a separation preventing function, generally called non-anti-seismic joints.

For this research, an earthquake damage survey was first conducted on potable water mains in which PALTEM HL liners had been installed in the past. The survey showed that there were no damage reports for these pipelines. CIPPs were, therefore, judged to potentially contribute to the seismic improvement of pipelines with non-anti-seismic joints.

Next, physical experiments were conducted on pipe specimens lined with a fully-structural CIPP to verify seismic behavior. Even under loading conditions that reflected the past earthquakes with seismic intensities of 4 or above on the Japan Metrological Agency's (JMA) scaling, the CIPP protected host pipes from joint pullout, and the jointed pipelines exhibited behavior similar to a single, continuous pipe. The CIPP itself did not show any damage or leaks.

In addition, to establish a methodology to evaluate the seismic performance of CIPP that is installed inside existing pipes, a calculation model and its parameters were selected based on the seismic behavior observed and data obtained in the previous experiments. After that, the performance criteria required for CIPP were selected and material tests were conducted to determine the allowable stress using the fully structural CIPP.

This study has confirmed that CIPP improves seismic performance of old potable water pipelines and has enabled evaluation of seismic performance by seismic calculation in accordance with different site conditions.

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The Preliminary Study of the Impact of Liquefaction on Water Pipes

Jerry J. Chen and Y.C. Chou

ABSTRACT

Damages to the existing tap-water pipes have been found after earthquake. Some of these damages are derived from the soil liquefaction. Excess pore water pressure generated due to shear wave has been studied by way of the well-known numerical software PLAXIS in this article. The dissipation of pore pressure after soil liquefaction will cause ground subsidence. The loose sand can easier generate pore water pressure and cause a larger settlement. A greater liquefaction thickness will cause a larger ground settlement and will result in a more severe damage to DIP tap-water pipes. The numerical calculations reveal that the damage of tap-water pipe occurs mainly at the border between soil with and without liquefaction. Elongation and bending are the most common damage type happened in the existing tap-water pipes during earthquake. The installation of flexible joints has also mentioned to reduce the damage to the tap-water pipes. It is expected that the concept and calculation described in this paper would be helpful for the engineer in gaining the ability of analysis so that the more effective design can be developed for such problem in the future.

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Developing Business Continuity Management in Kobe City Waterworks Bureau

Akinori Sakata, Masahiro Wada, Tsutomu Mitsuishi and Nagahisa Hirayama

ABSTRACT

It is expected to keep supplying water even in an emergency, because water is indispensable for daily life and urban activities. Recently risks of natural disasters including earthquake, climate change, and terrorism and so on are increasing. Kobe City decided to develop Business Continuity Plan (BCP). Furthermore we found that it would be important to raise BCP and to establish management process, named as Business Continuity Management (BCM).

Generally most of Emergency Manuals based on individual “causes” of disasters. It would be difficult to deal with complex causes and an unexpected event if we think only one cause. Therefore we should aim to make the manual which is focused on the “result”.

Furthermore we think capacity development is very necessary. So the staffs should participate in developing BCP, which contains increasing awareness of impending crisis and developing ability for emergency response. We revised the existing manual through workshops in order to take advantage of the staffs’ know-how.

In addition we investigated all the contents thoroughly and integrate them into the BCP. The components of Kobe’s BCP is as follows, 1) Duty Table – Duties at the time of disaster. 2) Duty List – check list of duties listed in Duty Table. 3) Work Flow – flowchart of chronological order

We have developed our BCP with focusing on “the result” instead of “the cause”, to deal all kinds of disasters. From now we will keep revising BCP through table top exercises and will complete BCM, then we will be able to continue to supply water in emergency time.

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Cross-sector Infrastructure Planning for Water Purveyors and Critical Care Facilities

Anna T. Lau, Jose L. Rios, and Xavier J. Irias

ABSTRACT

Water supply interruptions from a major catastrophic event can severely compromise the operations of a medical facility during a time when the facility's services are most needed by society. For example, in a magnitude 7 earthquake, the East Bay Municipal Utility District (EBMUD) is expected to experience 4,000 to 6,000 main breaks, which could impact one or more of the sixteen hospitals in EBMUD's service area. To better assess and support emergency water supply planning for these critical customers, EBMUD launched a hospital outreach program to discuss its water system capabilities, limitations, and emergency preparedness measures. The twofold purpose of this program is to survey and better understand hospitals' emergency water supply readiness and expectations, and to facilitate coordinated planning efforts to enhance water supply resilience.

This paper summarizes findings from recent outreach efforts to six of the sixteen hospitals in EBMUD's service area that have recently completed seismic retrofits and upgrades to their facilities. While most hospitals have a general awareness of water supply disruptions resulting from emergencies, few were prepared for the severity and lengths of possible water service impacts, and some were overly optimistic about the quantity of water required to sustain operations. During recent seismic retrofits and hospital upgrades, the hospitals addressed critical infrastructure needs, but some did not incorporate adequate on-site storage for a 72-hour water outage or build sufficient redundancy to strengthen emergency water supply reliability. In fact, only two out of the six hospitals is currently in compliance with the California Office of Statewide Health Planning and Development (OSHPD) 2030 requirements for on-site storage.

EBMUD's outreach experience suggests that improvements in four areas – awareness of water infrastructure vulnerabilities, understanding of emergency water supply needs, implementation of on-site water storage or alternative water supply, and coordinated planning – could greatly enhance emergency planning for water purveyors and medical facilities, leading to better performance across both infrastructure sectors.

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U.S. Approach to Share Seismic Awareness, Hazard Assessment and Mitigation Practices with a Larger Universe of Water and Wastewater Utilities

David Goldbloom-Helzner and Craig A. Davis

ABSTRACT

More than 143 million Americans, almost half the population of the United States, live in areas that are vulnerable to earthquakes. The West Coast is particularly susceptible, but earthquakes can happen almost anywhere. For example, in the Central United States, the New Madrid Seismic Zone is a significant threat to eight states. For a community, water and wastewater utilities are critical lifelines and with tens of thousands of utilities located across the country, many are in earthquake hazard areas.

The U.S. Environmental Protection Agency (EPA) wants vulnerable utilities to be aware of this earthquake hazard and the potentially devastating impacts to public health and the environment. A number of large and some medium-sized water utilities have been at the forefront of research efforts and have already implemented earthquake mitigation measures. However, awareness of the threat is much more sporadic at most other utilities. Also, because of the catastrophic nature of earthquakes and the sometimes substantial costs for resilience, utilities may be discouraged to conduct hazard assessments and implement mitigation measures. So how can less informed small, medium, or even large water and wastewater utilities build resilience to earthquake hazards?

The EPA's Office of Water has a mission to help water and wastewater utilities prepare for, mitigate, respond to and recover from various hazards, including earthquakes. With the assistance of an Advisory Review Team composed of utilities, water associations, federal agencies and state mitigation officers, the EPA developed a suite of earthquake resilience products to share lessons learned to a larger universe of utilities. This suite of products includes:

- Earthquake Resilience Video.
- Earthquake Resilience Guide.
- Earthquake Interactive Maps.

The products were based on the latest research by water and earthquake experts. Additionally, the products were designed for water utilities that are located in earthquake-prone areas, but have not yet taken steps to understand their seismic hazards or taken steps to address them. The products also were designed to be easy-to-use and formatted so that best practices can be accessed with only a few clicks. The EPA has also developed an outreach strategy for communicating and sharing these products with utilities prone to earthquake hazards. The earthquake resilience products are available through the EPA's water utility resilience website [https://www.epa.gov/waterutilityresponse].

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'Disaster-resistant Waterworks Model, Connecting all to the Water of Life' and the countermeasures against natural disasters examples
Sharing the specific measures of cooperation with major cities and mutual help to community groups

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Wataru HOSODA[4], Yoshiaki KONNO[5], Kunihiko ONUMA[6]

ABSTRACT

On March 11, 2011, the Great East Japan Earthquake, the most powerful earthquake (Mw 9.0) ever recorded in the country struck.

Four years after the Great East Japan Earthquake, The Third United Nation World Conference on Disaster Risk Reduction (hereafter referred to as WCDRR) was held in Sendai City from March 14th to March 18th in 2015. Based on this knowledge, the Sendai City Waterworks Bureau held a Symposium for the WCDRR: Connecting all to the Water of Life with participants from the industry, government, academics and citizens. In light of the discussion, we proposed and sent out the message of the 'Disaster-Resilient Waterworks Model, Connecting all to the Water of Life' (hereafter referred to as "The Model"), which combines ①Self-Help by individual citizens, ②Mutual Help together with local communities, schools and businesses, ③Public Support from water suppliers, and ④Cooperation with entire stakeholders including plumbing constructors and the National Water Supply Utilities Network.

In this paper, we explain the correspondence between The Model which we proposed at the 3rd WCDRR and our current countermeasures against disasters. In addition, we will explain two of our measures, 'Mutual Help' and 'Cooperation' that are focused on emergency water supply. An example of the first measure, 'Mutual Help' is 'Emergency Water Taps' that enable citizens to set up a water supply station on their own after an event such as disaster. Based on the experiences of the Great East Japan Earthquake, we constructed an 'Emergency Water Tap' at each elementary school that is a designated refuge area since FY 2013. We explain that an outline of an 'Emergency Water Tap', educational campaign of an explanatory meeting for a local community residents and that progress. The second measure is 'Cooperation' with plumbing constructors and the National Water Supply Utilities Network. We have signed a memorandum of mutual support in a disaster with the Sapporo City Waterworks Bureau and the Tokyo Metropolitan Waterworks Bureau. We share information and hold joint disaster training with those cities. In addition, we also hold joint disaster training with other cities and The Japan Water Works Association and through this we have established various relationships.

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Validation Accompanying the Introduction of a New Form of Energy (Fuel Cell System)

Kazuki Masaki, Hiroshi Hatsumi

ABSTRACT

In FY2014 fuel cell facilities were installed in radio relay stations owned by the Yokohama Waterworks Bureau. While there are multiple examples of fuel cells being installed in Japan, this marked the first time fuel cells were introduced by the Yokohama Waterworks Bureau. For this reason, demonstration tests were carried out verifying the stability of power supply and confirming fuel consumption amounts. This paper will provide a report on the details and results of said demonstration tests.

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Main Shock and After Shock Impact to Water System Seismic Fragility of Embankment Dams, Tank Reservoirs, and Large Diameter Pipelines

Yogesh Prashar, P.E., G.E. Env SP.[1], Andrea Chen, P.E.[2], Roberts McMullin, P.E.[3], and Xavier Irias, P.E.[4]

ABSTRACT

The East Bay Municipal Utility District (EBMUD) is a major water utility providing drinking water to over 1.4 million people on the eastern side of the San Francisco Bay Area. The EBMUD water system comprises approximately 144 storage tanks, 132 pumping plants, 22 active dams, 7 water treatment plants, 6760 km of treated water distribution and transmission pipelines, and 270 miles of raw water aqueducts. The EBMUD service area encompasses over 331 square miles of varying topography. EBMUD has created a damage prediction model to aide in the rapid fragility assessment of all critical infrastructure, which can reduce recovery time.

The published document entitled “Water System Seismic Fragility of Embankment Dams, Tank Reservoirs, and Large Diameter Pipelines” (Prashar, et al. August 2012) provides the introductory framework to this paper. Estimating the level of ground shaking at any particular site is the critical input in developing the expected performance of any given structure. Forecasting aftershock levels at sites of critical facilities will assist in establishing the likelihood of further damage to our facilities and guide response and recovery decisions. The damage prediction models provide results for the water system components of EBMUD’s water system.

This paper discusses the development of the damage prediction models for EBMUD’s water system for embankment dam reservoirs, tank reservoirs, and large diameter pipelines; damage results related to the two Hayward Fault scenario earthquake and aftershock events; and the next steps for damage prediction to increase robustness in the water system. A revised approach to developing a more comprehensive EBMUD infrastructure risk model is presented. The probability of failure is revisited in this approach of considering the contribution of aftershocks in rapid modeling of infrastructure fragility.

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Review of an Equation to Estimate Seismic Damage to Water Mains in Light of the 2016 Kumamoto Earthquake

Yuko Tsuruda, Yuichi Ishikawa, Fumio Sasaki, and Masakatsu Miyajima

ABSTRACT

In 2011, the Japan Water Research Center established an equation to estimate (predict) the number of pipe failures in earthquakes. The equation estimates relative damage to mains per 250-meter grid cell of a service area. It was developed based on an analysis of major seismic disasters in the past. As the equation aims to facilitate an efficient seismic reinforcement of water supply facilities by water utilities, it needs to be reviewed and updated properly based on new knowledge and findings from relevant seismic disasters. Most recently, in April 2016, the Kumamoto Region of Japan was hit directly by two earthquakes of magnitude greater than Mw 6.0 that occurred consecutively over a three-day period. In the wake of the Kumamoto Earthquake, we reviewed the equation to see whether it needs an update to improve its accuracy for damage estimation.

The review result showed that overall, the correction factors of the equation and its reference damage rate have similar tendencies to the characteristics of the actual damages although the total number of estimated pipe damages in Kumamoto City was about 4.1 times larger than the number of the actual pipe damages, this can be partly explained from the fact that the equation is designed to estimate on the safe side. From these results, we decided that the equation is valid, requiring no immediate modifications to the correction factors and the reference damage rate. One concern remains, however, that the equation might have estimated a little too far on the safe side. Therefore, this aspect would need a further consideration.

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Seismic Evaluation and Retrofit of Existing Water Pipe Bridges in Taipei

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ABSTRACT

Taipei is the capital city of Taiwan and its population is more than 2.7 millions, so water supply system is especially important. Moreover, the four existing water pipe bridges managed by Taipei Water Department play a pivotal role in the water supply system. The four existing water pipe bridges were designed according to the old version of the seismic code. If the existing water pipe bridges are damaged during the earthquake and unable to supply the water. It will bring people's livelihood problem; enlarge secondary disasters and delay post-earthquake reconstruction. Therefore, this paper presents the seismic assessment of Yuanshan, Yongfu, Hsintien arch water pipe bridges and Jiantan cable-stayed water pipe bridge. The seismic performance criteria follow Draft of the Taiwan Bridge Performance-Based Seismic Design and Water Facilities Seismic Design Guide and Commentary to examine the seismic capacity of existing water pipe bridges and check whether the corresponding retrofits are necessary or not. The static nonlinear pushover analysis is carried out using SAP2000 to capture the overall seismic capacity of existing water pipe bridges, respectively. The nonlinear time history analysis is also carried out using SAP2000 to obtain the member force and displacement of superstructures for the existing water pipe bridges. According to the analysis results, Yuanshan, Hsintien and Jiantan water pipe bridges have enough seismic capacity to satisfy the seismic performance criteria but the seismic capacity of Yongfu water pipe bridge in longitudinal direction fails to meet the seismic performance criteria. The piers of Yongfu water pipe bridge had been retrofitted by steel jacket for insufficiency of ductility. The relative displacements between superstructure and the abutment are larger than the flexible capacity of pipe expansion joint for the Yongfu and Jiantan water pipe bridges, respectively. There are two retrofit options are considered. One is the replacement pipe expansion joint scheme, the other is the additional Outer flexible expansion joint scheme. The bearings of existing water pipe bridges fail to meet the seismic performance criteria, therefore there are two retrofit options are considered. One is the replacement bearings scheme, the other is the additional RC or steel anti-shock devices scheme.

Keyword: Existing Water Pipe Bridge, Seismic Evaluation, Seismic Retrofit, Static nonlinear pushover analysis, nonlinear time history analysis

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Damage Analysis of Air Valves of Drinking Water Pipeline in the 2016 Kumamoto Earthquake

Taichiro Inui, Mitsuyasu Tamase and Masakatsu Miyajima

ABSTRACT

This paper deals with the damage to air valves of drinking water pipelines in the 2016 Kumamoto earthquake. Not only damage to pipe body and joints but also valves were severely caused by the 2016 Kumamoto earthquake. Firstly, a questionnaire survey on the damage to air valves was conducted to waterworks bureaus in Kyushu region in order to clarify the causes of the damage. The results show that the damage to air valves was caused not only in areas near the epicenter but also in areas far from the epicenter. This suggests that the cause of the damage to air valves is not only strong seismic motion. Since many damages were occurred at floating valve body and float valve body of air valve, an abrupt increase of water pressure in air valves is seems to be one of causes of the damage to valve.

Next, a relation between the distribution of the peak ground velocity and the location of the damage to air valves are studied in Kumamoto City. The damages to air valves were occurred not only in the areas of large peak ground velocity but also in the areas of not so large peak ground velocity in Kumamoto City. About 50% of damage to valves in the areas of large peak ground velocity seems to be caused by abrupt increase of water pressure in air valve according to the damaged part of the air valve.

The result of this study shows that one of causes of damage to air valves is abrupt increase of water pressure and abrupt decrease of water flow just after the earthquake. The cause of the abnormal behavior of water supply system just after an earthquake must be clarified and countermeasure of valves should be developed in the near future.

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Seismic Evaluation and Retrofit of Existing Distribution Reservoirs in Taipei City

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ABSTRACT

This paper presents the main results of the seismic safety assessment for the Nangang distribution reservoir in Taipei city. The distribution reservoir is an underground rectangular RC tank with maximum storage of 5000 m^3. In a recent on-site inspection, it was found that some of the support columns suffered severe damage, where significant cracking occurs at the top of the columns accompanied by buckling of the reinforcing bars inside. It was inferred that the damage was due to the so called "short column effect" resulted from the connection of the guide walls to the columns in partial height. To further exploit the cause of the damage as well as to assess the impact of the damage to the distribution reservoir, a 3D finite element model was developed using analysis package SAP2000 and was then employed to conduct seismic analysis of the distribution reservoir. The inference that the damage was mainly due to the short column effect was confirmed by the analysis results. In addition, the earthquake-resistant capability of the distribution reservoir was assessed using a draft code for seismic design of tank structures newly prepared by NCREE. In this code, the Housner's approach (Housner, 1963) is adopted instead of the conventionally used simplified Westergaard formula for calculation of the hydrodynamic forces acting on the distribution reservoir. To realize the difference between the forces calculated using the two approaches, a comparative study was carried out for tanks of different sizes with varying water depths. It was indicated that the simplified Westergaard formula produces higher hydrodynamic force than the Housner's approach does when the ratio of the tank length to the water depth is relatively small. Therefore, for larger tanks in Taipei city designed during 1980s~1990s like the Nangang distribution reservoir, the hydrodynamic force calculated by using the simplified Westergaard formula in design was probably under-estimated, which may fail to meet the requirements of the new design code. Finally, some retrofit measures were proposed to prevent the distribution reservoir from further development of the damage.

Keywords: Water facilities, Seismic evaluation, Distribution reservoir

INTRODUCTION

Water distribution system is the vital part of a city's potable water supply system. It ensures that water is delivered to the citizens with proper quality, quantity and enough pressure. Once the water distribution system was not able to operate as required, the water supply service will be severely impaired. Moreover, if the distribution system was damaged during an earthquake, the secondary disaster such as fire or plaque in the city will be hard to

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Napa Water System Earthquake Response: like fine wine, the right blend of self-help and mutual aid

Joy Eldredge, Water General Manager

ABSTRACT

On August 24, 2014 at 3:20am the south Napa Earthquake struck 5 miles southwest of the City of Napa and 2 miles west of one of two major water treatment plants. The energy radiated north and affected the west side of the pressurized pipe network that makes up the transmission and distribution systems that carry potable water to over 84,000 residents throughout City of Napa and surrounding areas. The event, the largest earthquake in the San Francisco Bay Area since 1989, unveiled newly identified surface faults and wreaked havoc on water infrastructure.

The water system was impacted and the event instantly compromised a storage tank and caused the equivalent of more breaks than typically experienced over an entire year within the distribution system. It was apparent within hours, while the extent of damage was still being assessed, that mutual aid was required to protect public health, and effectively reinstate water service in a timely manner. CALWARN the established California Water and Wastewater Agency Response Network, offered to assist with the emergency response within one hour of the event.

The City of Napa coordinated with CALWARN, and water managers ordered 6 fully-functioning crews stocked with heavy equipment and materials. By the middle of day two, a production assembly line of pipe repair was established: digging, repairing, backfilling, trench plating, flushing, water quality analyzing, and paving each site. Local private contractors kept a steady supply of trucks for off-hauling spoils, delivering sand and aggregate bedding for backfill, setting up and closing down traffic control and barricades as needed. The operation quickly became an efficient operation of pipeline repair and site clean-up. Information and status of repairs was coordinated back to the Emergency Operations Center (EOC), status tracked and information pushed out to the public and media. Before the end of day two, an additional two crews were ordered and inserted into the leak repair assembly process. This paper is written to provide a brief description and background of the City of Napa's water system, describe the event and thought process during the uncertainty of the immediate aftermath, and share the successes of the response as well as the lessons learned to improve preparedness and execution for when the next one hits.

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Application of Road Excavation Management System for Seismic Disaster Preparedness

Chun-Cheng Chen and Tin-Lai Lee

ABSTRACT

Tainan City has 37 administrative districts and an area of 2,192 km^2, including 750,000 manhole, 49 pipeline authorities and total underground pipeline length of 36,000 km. To effectively integrate, manage the pipelines and prevent disasters from happening, Tainan City Government not only has installed public utility database and road excavation management system, but also has actively developed earthquake disaster prevention evaluation system and other surplus applicative functions. In response to the digital trend, the system has been transform from computer system management into mobile management and various mobile device application functions. It wielded actual effects on the February 6th earthquake of 2016, in which it provided disaster relief information within a short period of time so that underground pipeline problems can be handled precisely to prevent secondary disasters and enhance efficiency greatly.

Keywords: public utility database, mobility management, disaster prevention, earthquake.

1. Introduction

Tainan city with a size of about 2,192 m^{2}and has a population of 1.88 million. There is a total of 49 pipeline management agencies that maintain about 750,000 utility manholes and over 30,600 kilometers of pipelines that include a number of hazardous pipeline systems for high voltage electricity, natural gas, and oil within the city's jurisdiction. Maps and data for these utility pipelines were mostly independently established and maintained by the respective agencies. However, the power and responsibility of supervision and management of these pipelines were distributed amongst various agencies instead of being integrated under a single standard due to the requirements of Taiwan's laws and regulations, leading to tough management issues during integration, supervision, and disaster prevention.

Tainan city is also a high-risk compound disaster area and local residents have dealt with threats stemming from multiple natural and man-made disasters for a very long time. Utility pipelines also face similar threats from these disasters as well. A most recent example would be the February 6th, 2016 magnitude 6.3 earthquake (hereinafter referred to as the "0206 Earthquake"), which had a maximum intensity rating of VII. The damages resulted in power outages for over 170,000 households and water outages for over 400,000 households in the city, and showed that damages to utility pipelines would be unavoidable during earthquakes.

According to the survey of the Central Geological Bureau indicated that there were 6 active faults in Tainan, 3 of first-type fault and 3 of second-type, giving the city the highest number and density of faults for any county and city in Taiwan. We can foresee a very high earthquake hazard potential. Realizing that, Tainan City Government takes actions to manage public utilities pipelines with the concept for disaster prevention and began to study how to make public utilities pipeline information available for disaster relief applications. There are four topics for public utility database management system (Figure 1):

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Concept of Waterworks in Disaster Relief based on the 2016 Kumamoto Earthquake

Yosuke Uno, Hiroto Sano, Haruko Kakita

ABSTRACT

In the occurrence of the 2016 Kumamoto Earthquake , Osaka Municipal Waterworks Bureau had sent the cumulative total of 42 staff to the affected area in five cycles for one month in which the 1st batch was sent on 16th April, the day of receiving request from Relief Headquarter, until the final 5th batch returned Osaka on 14th May to implement three supporting activities, emergency water supply, emergency restoration and back up support. We reported our performance of supporting activities during the dispatch period and the background of completion of those activities. Based on the experience of the 2016 Kumamoto Earthquake, Osaka Municipal Waterworks Bureau has drawn up the guideline, serving as a road map of supporting activities in case that a large-scale disaster occurs at other cities. This guideline has intended to implement prompt and effective supporting activities when large-scale disaster occurs somewhere in Japan in the future. At the end of this report, we introduce the construction of accepting support plan from waterworks entities of other cities when disaster hits Osaka along with Business Continuity Plan of Osaka Municipal Waterworks Bureau (BCP) that we're currently revising.

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Seismic Scenario Simulation of Water Supply Systems

Chin-Hsun Yeh, Gee-Yu Liu and Hsiang-Yuan Hung

ABSTRACT

Lack of water for a long time after disastrous earthquakes may cause severe inconvenience to the daily lives of people in the affected areas, not to mention fire-fighting, medical-care, sanitation, and so on. To reduce losses and disruption time, water companies and authorities may develop a seismic scenario simulation technology to assess various kinds of probable outcomes due to large earthquakes, such as the distribution of ground motion intensity, the extent of ground failures, the damage-state of facilities, the number of repairs in pipelines, the amount of water shortages, the number of households without water, the expected repair-time and losses of facilities and pipelines, and so on. Countermeasures could be proposed and executed accordingly before earthquakes to enhance the preparedness or emergency response in an appropriate and timely manner. In this paper, a seismic scenario simulation technology developed by NCREE (the National Center for Research on Earthquake Engineering, Taiwan) was introduced. The ground motion intensity and the ground failure extent due to fault rupture or soil liquefaction were considered in the seismic hazard analysis model. The damage and loss assessment models of water facilities and pipelines have been proposed and integrated into the scenario simulation. The water outage in terms of reduction in daily supply and the number of households without water soon after the scenario earthquake were also output base on damage and loss-of-function assessment of facilities and pipelines. The coefficients of analysis models used in the scenario simulation technology were calibrated by the observations from the 1999 Chi-Chi earthquake; and they have been verified by the 2016 Meinong earthquake.

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An Investigation of the Seismic Performance of Portland Water Bureau's Water System in an M 9.0 Earthquake

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ABSTRACT

The Oregon Resilience Plan (ORP) was developed in 2013 by the State of Oregon to reduce risk and improve recovery during and following a Magnitude (M) 9.0 earthquake and tsunami. The Portland Water Bureau (PWB) hired InfraTerra, Inc. to help them prepare a Water System Seismic Study (WSSS) of the PWB water system. PWB and InfraTerra determined the seismic performance of PWB's water system in an M 9.0 earthquake and developed mitigation actions to meet the target states of recovery (TSoR) provided in the ORP. The study findings highlighted the need to invest in mitigation projects and water system improvements. The study also identified resources needed for post-earthquake repair and areas where additional planning and policy change were needed.

INTRODUCTION

Background

The Oregon Resilience Plan (ORP) was developed by the Oregon Seismic Safety Policy Advisory Commission (OSSPAC) upon passage of House Resolution 3 by the Oregon House of Representatives. The purpose of the ORP is to reduce risk and improve recovery during and following a Magnitude (M) 9.0 Cascadia Subduction Zone earthquake and tsunami. The ORP addressed a number of concerns by developing Task Groups that looked at Business and Workforce Continuity, Critical and Essential Buildings, Transportation, Energy, Information and Communications, and Water and Wastewater. The ORP was finalized in 2013.

In 2016, the Portland Water Bureau (PWB) hired InfraTerra, Inc. to help prepare a Water System Seismic Study (WSSS) of the PWB water system. The performance goals developed by the OSSPAC Water and Wastewater Task Group of the ORP formed the basis for the WSSS. A key recommendation of the Task Group was to identify and strengthen a backbone water system that can provide water for critical needs following a M9 Cascadia Subduction Zone (CSZ) earthquake while damage to the remainder of the system is being repaired within a period of 6 months to a year. Table I shows ORP's target states of recovery (TSoR) for its water system.

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Formation of Information Transfer Methods for Envisaged Disasters

Kazunori Iwamoto, Fujio Nagasawa, Hiroyuki Maeda

ABSTRACT

After the occurrence of the Great East Japan Earthquake on March 11th 2011, an unprecedented confusion occurred around the Tohoku region, because of the stoppage of communication infrastructure due to the interruption of network lines, power cuts, etc. In the City of Yokohama, too, it became difficult to transmit information due to connection restrictions of general and mobile phones. Because of this, Yokohama Waterworks Bureau had difficulty assembling staff, grasping the extent damage of its facilities, and sharing information amongst branch offices.

We consider that in order to carry out recovery activities of water supply swiftly in all the areas of the City of Yokohama at the time of similar disasters in the future, ensuring reliability of means of information communication across the headquarters of Yokohama Waterworks Bureau and its branch offices is important. Therefore, we have constructed a means of information communication to be used in the Waterworks Bureau with a consideration of economic factor about which we report here.

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Application of a Mesh-based Earthquake Impact Assessment Tool for Water Supply System on Policy Support

Bing-Ru Wu and Siao-Syun Ke

ABSTRACT

A mesh-based earthquake impact assessment tool for water supply system, is developed in the Taiwan Earthquake Impact Information Platform (TERIA) with the collaboration of NCDR and academic institutions. The quantitative impact analysis in various levels of excitations, consisting of extreme and operational scenarios, can be applied to find the weak items and distribution for disaster preparedness. Two examples illustrate the application of impact analysis on disaster preparedness and policy support: (1) Scenario simulation for the National Earthquake Drill; (2) Impact analysis for policy suggestion on disaster management. The quantitative impact analysis in various levels of scenarios is helpful to disaster prevention planning.

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Study report of priority evaluation of earthquake resistance on water supply facilities focused on the restoration process of water supply

Akihisa Ishida, Kimiyasu Ohtake, Mikita Amano and Keisuke Baba
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1. INTRODUCTION

The priority evaluation of earthquake resistance is determined by the earthquake performance, the role as water supply base of an emergency, the presence of water supply to hospitals and shelters, and a degree of difficulty of recovering.

On the other hand, it is common to be shown the effect of earthquake resistance as using the indices of an earthquake resistance rate of water distribution stations, water purification plants and water pipes. These indices are effective to manage the progress of earthquake resistance on water facilities for water supply utilities, but it is difficult to understand the effect of earthquake resistance for water users. It is important for water users to know when we can be supplied water and water facilities get recovered, so it is considered that it would be more understandable for water users to put “the number of recovering days” and “suppliable water amount” into the indices of an effect earthquake resistance.

Therefore, we carried out a priority evaluation as indices of an effect of earthquake resistance focused on the restoration process of water supply with the aim of clarifying the effect of earthquake resistance from water user’s point of view.

2. STUDY CONDITIONS

Evaluation Method

The estimation method is shown in Figure 1.

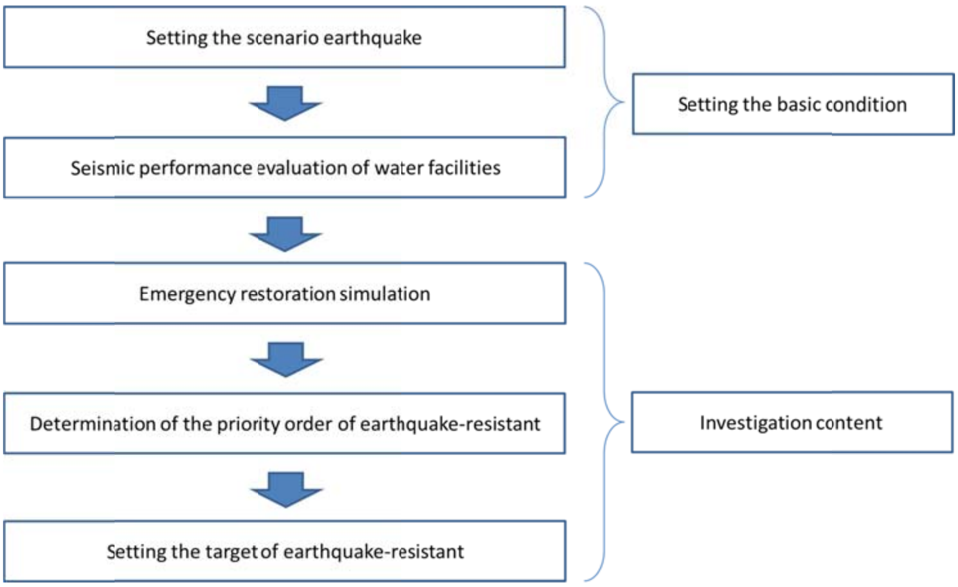

Figure 1 Evaluation method of the investigation

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The Prioritized Pipeline Maps for Emergency Restoration

Keita Katae, Haruka Utada

ABSTRACT

In previous earthquake disasters, the water supply facilities suffered serious damage. It required considerable time for them to be restored, which impacted citizens of the area greatly. The 2016 Kumamoto Earthquake also caused a lot of water pipeline damage especially on service pipes and harmed the water supply. Water utilities from all over Japan, including the Yokohama Waterworks Bureau, helped emergency restoration of the water supply in the disaster area. The damage restoration efforts must share their experiences, which will allow effective measures to be taken in order to prepare for earthquakes in the future.

Meanwhile, in Yokohama, we have been replacing aged pipes with earthquake-resistant pipes, establishing emergency water supply stations, encouraging stocking of drinking water, and implementing citizen-participation in emergency water supply drills as earthquake measures.

Moreover, we have learned much through the assistance efforts in Kumamoto. As such, we have created prioritized pipeline maps for emergency restoration in case of earthquake disaster in Yokohama. When receiving external assistance/relief from other water utilities, the maps will serve as effective explanation material. Furthermore, we will consider the idea of emergency restoration of the water supply and sewage facilities in cooperation with offices that manage sewage works in Yokohama City.

In this paper, we report on the contents of the maps, the way of thinking, and future prospects.

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Emergency Activity during a Disaster by the Public–Private Cooperation in Nagoya City

Minoru Sakaguchi

ABSTRACT

A water supplier is required to supply safe water after a large earthquake. Nagoya City is predicted to suffer extensive damage in the upcoming Nankai Trough Earthquake. Therefore, we are promoting ways to develop seismic resistance of water facilities.

However, facing a severe financial situation due to decreasing water supply revenues, it will take a long time to make all water facilities earthquake resistant. Furthermore, in case of serious damages due to a large earthquake, there remains concern regarding whether the personnel necessary for disaster response can be secured quickly. Therefore, to construct a rapid post-disaster response system, we have been promoting the expansion of a cooperative system with Meisuikyo, an organization consist of Nagoya City designated company for water supply equipment work, during a disaster.

We report on this public and private partnership system, which we have been promoting between the city authorities and Meisuikyo, that operates during a disaster.

We concluded an agreement on emergency water supply in 2000 with Meisuikyo. In 2012, considering the situation during the Great East Japan Earthquake that occurred in March 2011, we revised the agreement and included emergency water supply, emergency restoration, and emergency waterproofing in it. Thus, we have prepared the foundation for a cooperation system that can be implemented during a disaster. Moreover, in 2016, we entrusted temporary water faucets, which are equipment for opening emergency water supply facilities, to Meisuikyo, who is working closely with local communities on a daily basis, and requested them to open 105 of 207 emergency water supply facilities after the earthquake occurred. We have thus established a system that can rapidly develop emergency water supply activities. Furthermore, we incorporate cooperative drills with Meisuikyo in our disaster reduction drills, which we conduct annually, and are trying to maintain and strengthen the collaboration structure between them.

From now on, we will continue to build the earthquake resistance of water facilities with limited personnel and financial resources. Furthermore, to implement emergency activities more effectively, we will strengthen our cooperation with various collaborators such as Meisuikyo and develop a town that can respond strongly during a disaster.

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Seismic Preparedness and Emergency Response of Water Systems — Visions and Experiences

Lap-Loi Chung, Chin-Hsun Yeh, Lee-Hui Huang, and Kuo-Liang Wang

ABSTRACT

In this paper, tasks related to the seismic preparedness and emergency response of water systems in Taiwan were presented and discussed. The first task is to identify the water facilities and pipelines at risk. The inventory database containing geographical information and seismic attributes of water facilities and pipelines have been collected and checked their correctness. Various kinds of seismic hazard maps, such as the hazard map of earthquake ground-motion intensity, the hazard map of known active faults around Taiwan, the hazard map of soil liquefaction due to earthquakes, etc., have been studied and created. The second task is to propose a feasible and efficient disaster reduction plan which is based on scenario simulations of a catastrophe. To evaluate the seismic performance of water systems after major earthquakes, a seismic scenario simulation technology which is integrated with geographic information system (GIS) should be developed. Based on the scenario simulations of disastrous earthquake events, the damages of water facilities and pipelines, the amount of water shortages, the number of households without water, the expected disruption time, and so on can be evaluated quantitatively. Furthermore, the needs and the capacities of various kinds of resources, such as the man-power, material and equipment to repair water facilities and pipelines, the amount of emergency water supply for firefighting, medical-care and livelihood, and so on, can be reviewed. The third task is to develop an early seismic loss estimation system, which may provide valuable information with precision soon after earthquake occurrences and may assist the initialization and decision-making in emergency stage. Soon after disastrous earthquakes, emergency response sectors should be notified the earthquake occurrence as soon as possible. Moreover, summary of the probable disasters and their distribution, either from reports or predicted estimates, may assist in making proper decisions to reduce casualties, losses and secondary disasters.

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Crisis Management by Waterworks Emergency Service Unit ; Quick Response and Prompt Securement of Water Supply in the Event of Disasters

Wataru Kiga

ABSTRACT

Bureau of Waterworks, Tokyo Metropolitan Government (BWTMG) is responsible for the mission of stably supplying safe, clean and high-quality water 24 hours a day as a core lifeline supporting the civic life and the urban activities in Tokyo Metropolitan. Especially water supply to the administrative organizations of the country that are the key to restoration in emergency situations and disaster base hospitals that protect the lives of citizens is indispensable. As a facility to support this function, Waterworks Emergency Service Unit was built. The main task of the unit is to secure water supply routes to the central agencies of the capital such as government agencies and disaster base hospitals, and others, within three days from the occurrence of a disaster such as a large-scale earthquake. Even in Tokyo during the Great East Japan Earthquake, main roads became heavy traffic congestion due to the difficulties of returning home, and others, resulting in a long and considerable time to check and confirm the water supply route. Based on this lesson learned, we constructed a system that can monitor water supply pressure so that the unit's headquarters can grasp the situation intensively. This system will be introduced for the first time in Japan as a water supply utility.

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The Effectiveness of the Dispatch of Support Staff to Small Waterworks

Takuya KUDO[1], Yoshihito HIGUCHI[2]

ABSTRACT

After the Great East Japan Earthquake of 2011, technical support for damaged waterworks was focused on the major waterworks while the small waterworks did not receive sufficient support. The Niigata City Waterworks Bureau was asked to support such small waterworks and it dispatched one pipeline engineer to the town of Shichigahama (population 20,000) for four months.

The water distribution system of Shichigahama and the main supply pipe of the Enterprise Bureau in the Miyagi district were seriously damaged by the earthquake. The water supply system had to be shut down and was repaired within a month with the exception of the components in the lowlands that were damaged by the tsunami. In the reconstruction plan, the town of Shichigahama decided to relocate people living in tsunami-damaged communities to hilly regions, which do not face the danger of tsunamis. Thus, essential utilities, including a water supply, are urgently required in these new residential areas.

The dispatched staff engaged in the following work:

1. Supporting normal routine work
2. Carrying out tasks related to disaster-recovery
3. Managing the model project in Shichigahama

In particular, the preparation of the documents to apply for government subsidies was time-consuming. Furthermore, the waterworks reconstruction plan had to be repeatedly changed in response to the town's changing urban plan.

The dispatch of the engineer enabled Shichigahama to participate in a model project by the Ministry of Health, Labour and Welfare. With financial and technical support, the town of Shichigahama prepared an efficient waterworks reconstruction plan. The dispatched engineer brought valuable experience to the city of Niigata: before the dispatch, none of the staff in Niigata City Waterworks Bureau had experience in the design of a pipeline reconstruction plan but the knowledge gained through this experience will help prepare Niigata for future earthquakes and tsunamis. Further, during the project, the engineer took on a range of responsibilities and gained knowledge and skills through the experience.

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Determining Water Distribution System Pipe Replacement Given Random Defects
– *Case Study of San Francisco's Auxiliary Water Supply System*

Charles Scawthorn[1], David Myerson[2], Douglas York[3], Eugene Ling[3]

ABSTRACT

For a water distribution system (WDS) subjected to random leaks or breaks, key questions exist as to which pipe in the network should be the first pipe to be mitigated, which pipe the second, and so on – in other words, what is the ranking, importance or priority of the network's pipes? To address this problem, a new algorithm termed **P**ipe **I**mportance and **P**riority **E**valuation (**PIPE** algorithm) for evaluating the importance or priority of pipes in a hydraulic network given random defects such as leaks or breaks has been developed and validated.

The essence of the PIPE algorithm is determining each pipe's Average Deficit Contribution (ADC), defined as the average contribution of each pipe to each demand point's deficit (deficit is the difference between required and furnished flow at a demand point). The pipe with highest *ADC* is the pipe that contributes most to the demand's deficit, 2nd ranked pipe contributes next most etc. If the highest ranked pipe is mitigated, deficit is reduced the most and so on. *ADC*'s can be individually calculated for multiple demand points, or for any combination such as the total of all. A key aspect in implementing the PIPE algorithm is the determination of pipe weights via generalized linear modeling, which is discussed in some detail.

The PIPE algorithm was validated by a series of case studies of a gridded network with multiple demand points and then applied to San Francisco's seismic environment and a scenario earthquake – essentially a repeat of the 1906 event. Permanent ground displacements and shaking hazard were determined with special emphasis placed on capturing the randomness of shaking effects using recent work on efficient selection of hazard maps for simulation. Recent work on pipe breaks due to shaking, and due to permanent ground displacement were employed to model defects, which were then applied as random defects conditioned on hazard in Monte Carlo simulations (in some cases, more than 100,000 trials) of the AWSS, in which each trial included a demand-driven hydraulic analysis of the damaged system, using EPANET. We believe this use of EPANET in large demand-driven hydraulic Monte Carlo analyses is the first such analysis. Application of the PIPE algorithm resulted in a ranking of all 6,000 pipes in the AWSS, based on each pipe's contribution to average demand point flow deficits.

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[2] San Francisco Public Utilities Commission

[3] San Francisco Public Works

Seismic Screening of Large Water Pipelines for TWC's Seismic Improvement Program

Gee-Yu Liu, Chin-Hsun Yeh, and Lee-Hui Huang

ABSTRACT

Mitigation of water supply systems against earthquake hazard is a crucial task in Taiwan. An investigation was therefore conducted to develop/utilize the seismic hazard maps of ground shaking, soil liquefaction, active fault rupture, and landslide related to the cause of damages in water pipelines. The inventory of large water pipes of Taiwan Water Corporation (TWC) with a diameter of 800mm or greater has been collected and calibrated. It consists of 2,229.3 km of pipes of various sizes and pipe materials (types of joints). The seismic risk of these pipes as a function of both hazard severity and pipe vulnerability has been determined and sorted. Their importance has also been classified according to the daily volume of conveyed water and the existence of redundancy or not. Finally, the most critical pipes were identified for TWC to implement seismic improvement program in the near future.

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Mitigation of Potential Impacts of Seismic Events on a Regional Water Distribution System

Gordon Johnson*, Ricardo R. Hernandez**

ABSTRACT

The Metropolitan Water District of Southern California owns and operates a conveyance and distribution system that consists of approximately 1,770 km (1,100 miles) of large capacity aqueducts, pipelines, and tunnels to distribute untreated and treated water throughout Southern California. This system crosses a number of active faults and is susceptible to fault rupture, ground failure, and shaking damage. Construction of this conveyance and distribution system was completed in phases from the 1930's through the 2000's, and included few special provisions for seismic events. Since the system was completed, overall knowledge of the geology and seismicity within Southern California has greatly increased, while significant advancements have occurred in earthquake engineering and design. Based on this increased knowledge, Metropolitan has established an ongoing seismic resilience program to periodically reassess the seismic risk to its infrastructure, and to address key vulnerabilities. Over the past two decades, Metropolitan has focused primarily on addressing the susceptibility of above-ground structures, aqueducts, and tunnels. Presently, Metropolitan is developing a standardized approach for addressing seismic issues during the rehabilitation of existing large diameter pipelines, and for the construction of new pipelines. This paper presents Metropolitan's strategy for assessing seismic issues for existing pipelines, and provides two examples of this standard being applied to fault zone crossings: 1) the Second Lower Feeder crossing of the Newport-Inglewood Fault, and 2) the Casa Loma Siphon crossing of the Casa Loma Fault.

INTRODUCTION

The Metropolitan Water District of Southern California is a consortium of 26 cities and local water agencies that provides drinking water to 19 million people over a 13,470 square kilometer (5,200 square mile) service area along the Southern California coastal plain. On average, Metropolitan delivers 6.4 million cubic meters (1.7 billion gallons) of water per day to its customers. Metropolitan owns and operates five water treatment plants, nine pumping plants, 16 hydroelectric plants, 20 dams and reservoirs, over 1,335 km (830 miles) of large diameter pipelines and tunnels up to 6.25 m (20.5 feet) in diameter, and the 390 km (242 mile) Colorado River Aqueduct (CRA).

Figure 1: Southern California Imported Water Supply Aqueducts

TWC's Thoughts on Implementing Seismic Improvement to Large Water Pipelines

Tsung-Jen Chiu, Feng-Ming Lu, Sheng-I Tseng, Glaus Ou, and Gee-Yu Liu

ABSTRACT

Taiwan Water Corporation (TWC) is the largest water utility in Taiwan. It consists of 12 branches which operates 144 systems with a total capacity of 11.42 million CMD. It provides water supply to 6.87 million customers or 17.98 million people (2016). It has long been serving the people in Taiwan. Many of its pipelines and facilities were built in early years without any seismic design. They are very vulnerable to earthquake hazards. One of the most important task now in front of TWC is to improve its large water pipelines seismically. In order to help all branches and headquarter of TWC to work together on this matter, some shared criteria and procedures should be specifies first. To be precise, TWC needs to

- Specify the seismic objective (including seismic demand and performance level) for pipelines of various importance,
- Specify the procedure that each branch of TWC shall follow to carry out project dealing with the pipeline enhancement and prepare the report accordingly,
- Specify the procedure that decision makers in TWC headquarter shall approve or not the submitted report of a pipeline seismic enhancement project.

In this paper, some of TWC's thoughts on these topics have been introduced.

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Water System Pipeline Damage
Seattle Public Utilities Case Study

William F. Heubach[1]

ABSTRACT

Seattle Public Utilities (SPU) provides water to approximately 1.4 million people in the central Puget Sound area. In addition to providing direct service to approximately 700,000 residents, SPU wholesales water to 20 cities and water districts near Seattle.

SPU is completing an update of a 1990 seismic vulnerability assessment that was performed by Cygna Energy Services [1]. This assessment update accounts for changes in the understanding of the seismic hazards that threaten the Puget Sound region. The 2017 update emphasizes pipeline performance and overall system response.

The 2017 findings show that although some important "vertical" facilities such as reservoirs and pump stations are vulnerable, the most significant effect on water system response will be pipeline damage. Damage to transmission and distribution system pipeline damage is expected to severely disrupt system operation and delay system restoration. In order to mitigate the effects of this pipeline damage, SPU's mitigation strategy is to employ both short-term measures to manage the current vulnerability of the SPU water system and longer-term measures to reduce the vulnerability of the SPU water system. The five basic elements of SPU's mitigation approach are

Short Term

- Implement Isolation and Control Measures to Mitigate the Effects of Pipeline Damage on System-Wide Water Pressure
- Improve Earthquake Emergency Preparedness and Response Planning to Reduce Recovery Time

Long Term

- Construct an Earthquake-Resistant Transmission Pipeline That Will Supply Minimal Water Demand to SPU's Direct Service Area
- Use earthquake-resistant pipe in permanent ground displacement susceptible areas and for pipelines that are essential for fire-fighting or that serve critical facilities
- Seismically Upgrade Critical Reservoirs, Tanks, Pump Stations and Support Facilities

This paper summarizes the findings of SPU's seismic vulnerability study update and SPU's mitigation approach.

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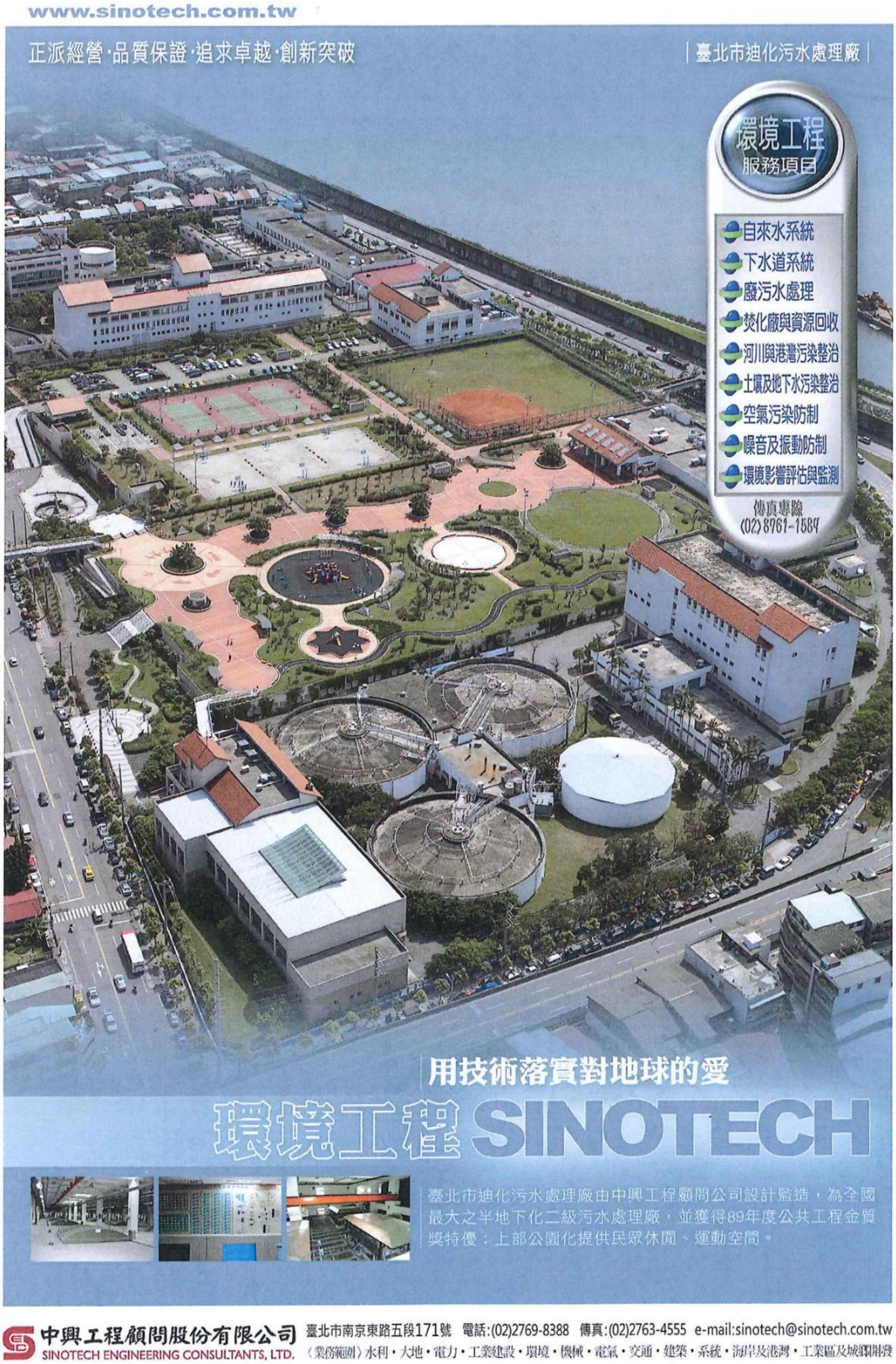
4. Sponsors

A. Sinotech Engineering Consultants, LTD



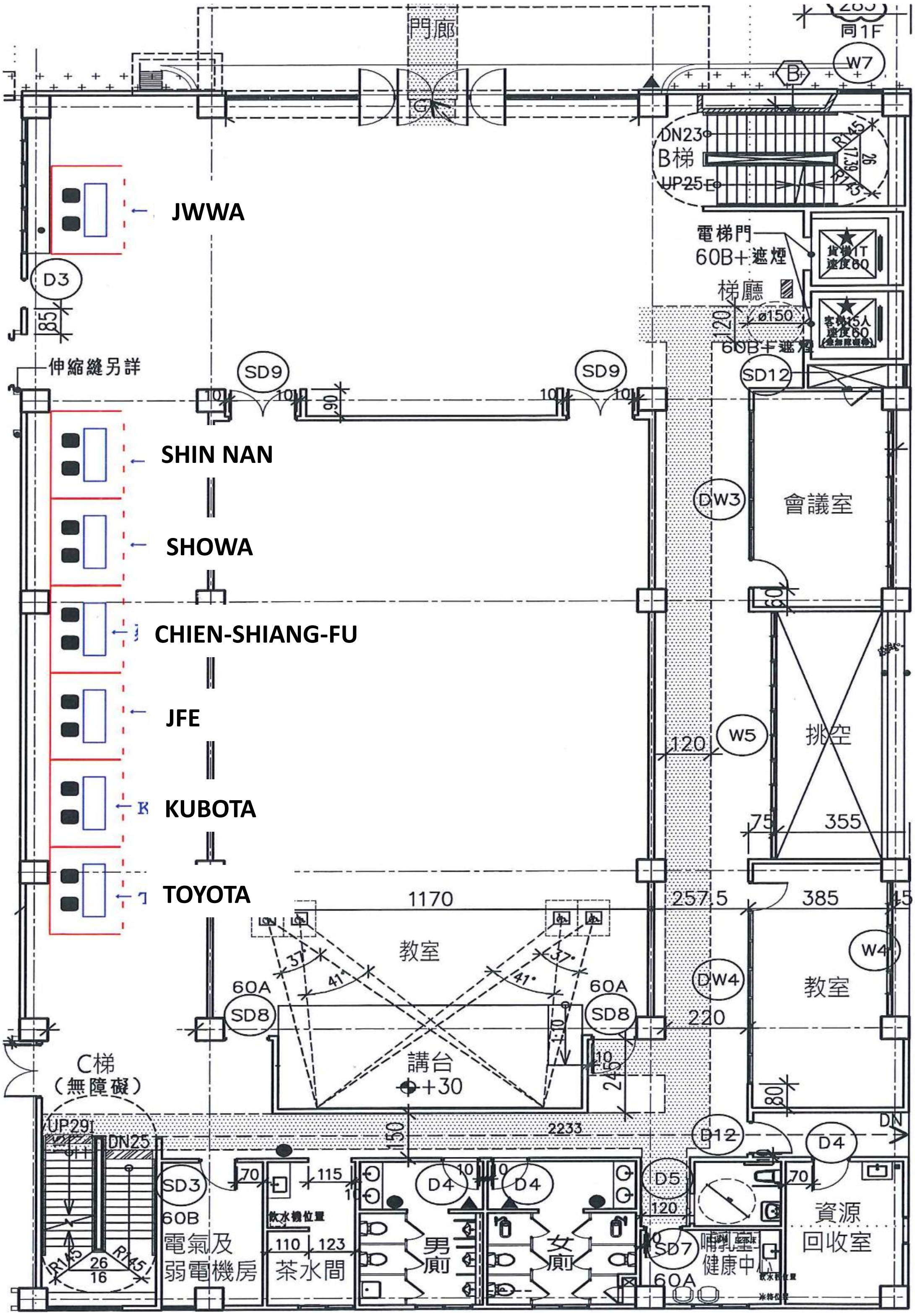
B. CECI Engineering Consultants, Inc., Taiwan

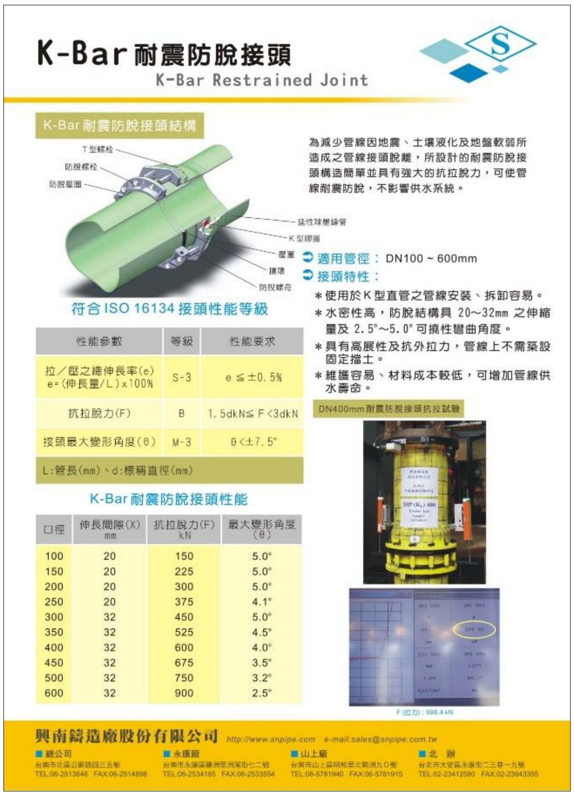
C. MWH Americas INC., Taiwan Branch

5. Commercial Exhibitions

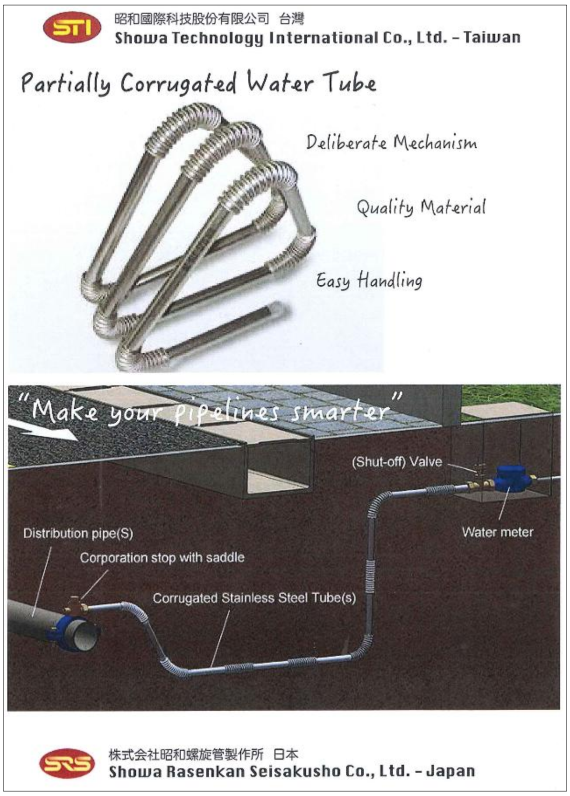
	Name of Corporation	Main Products
1	興南鑄造廠股份有限公司 Shin Nan Casting Factory Co.,Ltd	K-bar Restraint Joint DIP
2	昭和國際科技股份有限公司(台灣) Showa Technology International Co., Ltd (Taiwan)	Corrugated Stainless Steel Tubes
3	建翔富實業股份有限公司 Chien-Shiang-Fu Global Trading Corporation	Repair Equipment
4	日本鋼管 JFE Engineering Corporation	Steel Pipe and Fittings
5	久保田株式會社 Kubota Corporation	DIP and Fittings
6	台灣豐田通商 Toyota Tsusho Corporation 中興電工機械股份有限公司 Chung-Hsin Electric & Machinery Mfg. Corporation	Full Cell System

Exhibition Layout





Shin Nan Casting Factory Co., Ltd



Showa Technology International

Chien-Shiang-Fu Global Trading Co.

Toyota Tsusho Corporation

6. Venue and restaurant for conference banquet

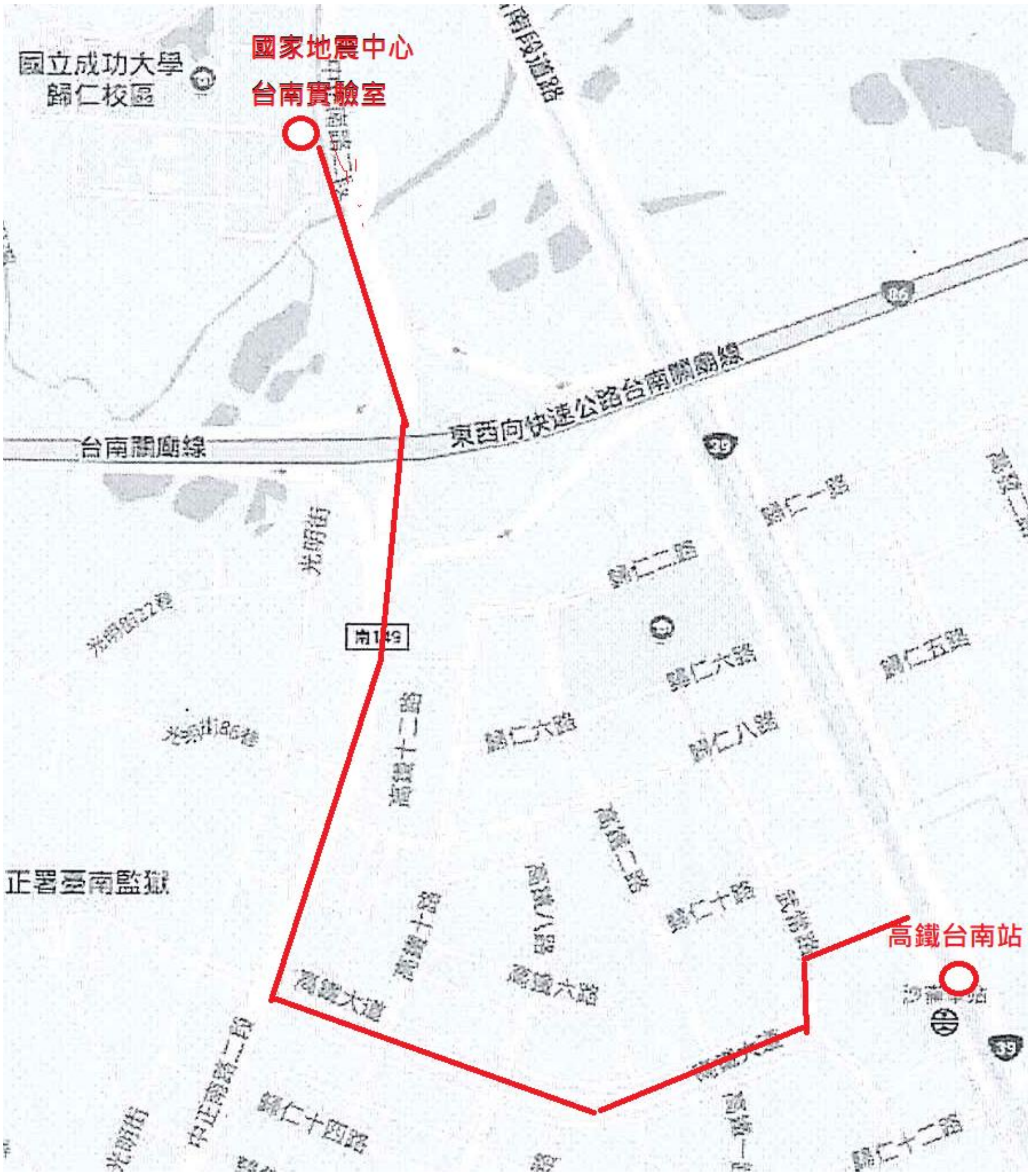
A. Conference venue

Tainan Laboratory, National Center for Research on Earthquake Engineering

(國家地震工程研究中心臺南實驗室)

2001 Sec. 1, Chung-Cheng South Rd., Gueiren District, Tainan City

(台南市歸仁區中正南路一段 2001 號)



B. **Restaurant for conference banquet:**

Dashi Seafood, National Cheng Kung University Branch

(大使雨荷舞水餐廳)

118, Shengli Road, Tainan City

(台南市勝利路 118 號)