Comparison of Water Utility Earthquake Mitigation Practices

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Abstract

The U.S. and Japan lead the world in earthquake mitigation of water systems, but post earthquake performance objectives, system evaluation methods, and mitigation strategies to meet those objectives differ significantly.

Performance Objectives - In the U.S., there is no performance standard for post-earthquake system operation of water systems. Individual utilities have developed performance objectives based on their own needs. In general, these objectives address the desired level of system operation to provide water for fire suppression immediately following the event, and potable water within a prescribed number of days. The “event” is typically probabilistic/scenario based, and the desired probability of system performance is higher for earthquakes with a shorter recurrence interval. The Japan Water Works Association (JWWA) has established post-earthquake performance objectives for system restoration time to provide potable water a prescribed number of days following the event (i.e. restoration time). The restoration time, 30 days, is based on feedback from residents of Kobe following the 1995 Great Hanshin earthquake. The “event” appears to be deterministic/scenario based. Japanese performance objectives are silent on the issue of water for fire suppression.

System Evaluation Methods - In the U.S., there is no widely adopted standard or guideline for evaluation of earthquake vulnerability. Component evaluation is based on empirical data coupled with structural engineering methods. Systems are analyzed using proprietary methods developed by universities and implemented consulting firms, one of which is now incorporated into HAZUS. In Japan, the Japan Ductile Iron Pipe Association, working with the JWWA, with input from universities, has developed a system evaluation methodology that has been standardized by the JWWA. There are many similarities between the U.S. and Japan methodologies. Both are GIS-based, establish component damage states, and can perform Monte Carlo simulations of the system hydraulics. Both U.S. and Japanese evaluators have performed benefit-cost analyses.

Mitigation Strategies - Most U.S. utilities are upgrading key system components such as dams, transmission lines, treatment plants, pump stations, and tanks. There is minimal investment in replacement of vulnerable distribution pipelines, such as brittle pipe (cast iron) located in liquefiable soils. Many U.S. and Canadian utilities are making provision to provide water for fire suppression using dedicated seismic resistant fire suppression systems and/or pump and hose systems that can be quickly put into place following an event. The Japanese are also upgrading key system components, although there appears to be less attention paid to tanks. Their below-grade concrete tanks performed well in the 1995 Kobe earthquake. However, the Japanese appear to be undertaking significant wholesale distribution pipeline replacement programs. This difference results in a significantly higher per capita expenditure in mitigation by the Japanese.

In addition, the Japanese are very focused on providing emergency drinking water supplies in the first few hours following an event by developing a sophisticated system of emergency storage facilities throughout the system. In the U.S., provision of emergency water supplies is a lower priority, and is generally accomplished using portable tanks/tank trucks and/or bottled water.

Introduction

The U.S. and Japan lead the world in earthquake mitigation of water systems, but post earthquake performance objectives, system evaluation methods, and mitigation strategies to meet those objectives differ significantly. The Japan Water Works Association (JWWA) and the American Water Works Association Research Foundation (AWWARF) conducted a joint workshop on water system seismic mitigation practices in Tokyo in August of 2001. One of the key topics was system reliability. The workshop provided one of the first opportunities to learn about water system mitigation in Japanese cities, as presented by representatives of the cities, not academics. There are three preliminary conclusions:

- Japanese water utilities do not address fire suppression as a key post-earthquake performance objective.
- U.S. and Japanese system evaluation methodologies are similar, but have different results.
- The Japanese focus on system distribution pipeline replacement, a mitigation approach that is not commonly employed in the U.S.

Performance Objectives

Effective use of system modeling techniques requires the user to understand how well the system should function. In the U.S., various utilities have developed performance objectives for their own use. Ballantyne proposed performance objectives in documents prepared for the AWWA and NIST as shown in Table 1. These performance objectives have been used as a starting point by many utilities to develop their own.

Table 1

Water System Performance Objectives (Ballantyne et al, 1997, Ballantyne, 1994)

PERFORMANCE CATEGORY	ACCEPTABLE ADVERSE CONSEQUENCES	
	OBE (50% chance in 50 years)	DBE (10% chance in 50 years)
Life Safety	Minimal - Injury or loss of life are not acceptable consequences	Minimal - Injury or loss of life are not acceptable consequences
Fire Suppression	Minimal - With the exception of small isolated areas that are not densely populated, water for fire suppression should be available for entire service area.	Moderate - Water for fire suppression should be available for a minimum of 70% of the service area. All industrial areas and densely populated business and residential areas should have water available for fire suppression.
Public Health	Low - Water should be available for all but a few isolated areas. Boil water order acceptable for up to 48 hours.	Moderate - Service should be available for at least 50% of system. Boil water order, delivery by tanker truck, or bottled water acceptable for up to one week. Restoration to 100% service within one week.
System Restoration	Low - Water should be available for all but a few isolated areas.	Moderate - Service should be available for at least 50% of system. Restoration to 100% service within one week.
Property Damage	Low - Any damage should not affect facility functionality and should be repairable. Facilities not owned by the water utility should not be damaged by utility facility damage	Moderate - Complete loss of nonessential facilities acceptable if it is not cost-effective to upgrade them and other performance objectives are not violated. Critical facilities not owned by the water utility by utility facility damage.

East Bay Municipal Utility District has identified provision of water for fire suppression as one of their key performance objectives (Miller, 2001; Fuette, 2001). In San Francisco California, and Vancouver British Columbia water systems have been constructed dedicated to the use of fire suppression. (San Francisco will also use their system for distribution of reclaimed water.) In Vancouver, the system was designed and constructed by the Water Department for use by the Fire Department.

However, there is often only a loose working relationship between water departments and fire departments. If they are working under the same municipal organization, e.g. a city, the relationship is tighter and there is a greater likelihood that they will work together planning for providing water for fire suppression. Frank Blackburn, a former Fire Chief with the San Francisco Fire Department writes:

> *"Consistently providing adequate water supply for fire protection requires close liaison and cooperation between the fire and water departments. Unfortunately, these agencies are in most cases not part of the same governmental jurisdiction. As a result, understanding and awareness between the organizations can be lacking …. Coordination between the organizations can be complex and difficult to achieve…." (Ballantyne et al 1997)*

In the U.S., water mains are sized to provide water for fire suppression. The Insurance Services Office tests fire flow rates, and if they are inadequate, the water purveyor will often strengthen the grid. However, when there are significant earthquake vulnerabilities and large associated mitigation costs, water utilities with responsibility to provide "potable water" may have a difficult time raising adequate mitigation funding.

In Japan water departments do not appear to have, or take on the responsibility to provide water for fire suppression. The JWWA water system seismic design standard (JWWA, 1997) states:

> *"When an earthquake occurs, drinking water for residential areas cannot shut off, even for a single day. If water service to a residential area is shut off, an emergency water supply is necessary. Often, such emergency services cannot supply sufficient life supporting water. When this results, the everyday lives of residents become very incontinent. In addition, sanitary problems and difficulties restoring the city's activities are created. For these reasons, emergency restoration service must be completed as quickly as possible, preferably within one day or less."*

The Japanese have particular interest in providing emergency water supplies. In the aftermath of the Kobe earthquake, the Kobe water utility documented the response of their customers, and based on that response concluded that a 28-day outage following a large earthquake was acceptable. Part of their system had been without water for ten weeks. The JWWA used that conclusion to establish a guideline for all Japanese utilities that addressed for the desired quantity and distance to an emergency water supply in the days following an earthquake as shown in Table 2. By comparison, there is very little planning of this type in the U.S. The Japanese value the continuity of having a potable water supply.

Table 2
Emergency Water Supply Goals (Miyauchi, 2001)

Days after Earthquake (days)	Quantity Goal (liters/person/day)	Distance one can walk to obtain water (meters)
0-3	3	1,000
10	20	250
21	100	100
28	Normal	10

The JWWA water system seismic standard incorporates the following parameters to measure the "influence on people's lives" (Toshima, 2001):

P = Water supplied population (number of people)

P_w=Water supplied population after earthquake (number of persons)

T=Days required for restoring supply (number of days)

There is no discussion about the value of water for fire suppression. Kobe's emergency water system is designed to provide water for: "toilet, bathing, clothes washing, house cleaning, and so on." The author discussed this issue with a representative of the Kobe Water Department who indicated that they were in communication with the Kobe Fire Department to discuss water supply issues following earthquakes.

The observation that Japanese Water Departments do not having responsibility for water for fire suppression does not mean that other departments do not have that responsibility. The question really becomes what infrastructure system can best provide fire suppression water – the potable water system, or some other non-defined system?

To summarize, there is a significant difference between the Japanese and U.S. performance objectives. The Japanese focus on providing the capability to provide near continuous supply of water for domestic use while the U.S. focuses on providing water for fire suppression immediately following the event. Both address acceptable recovery times.

System Evaluation Methodologies

Water system seismic performance analysis techniques were developed in the late 1970's at Princeton University (Shinozuka and Takada, 1979). They were widely applied in the early

1990's when geographic information systems (GIS) became more available such as to the San Francisco Auxiliary Water Supply System, and municipal utility districts in East Bay, Marin (Theisen et al, 1995), and Contra Costa (Scawthorn, 1996). Pipeline damage data from the 1971 San Fernando Earthquake and many others through the 1994 Northridge Earthquake was used to develop the pipeline damage relationships used in the models,

Professor Takada, now at Kobe University, was key in transferring the technology to Japan from his original exposure in Princeton. The 1995 Kobe earthquake provided the incentive for the Japanese further develop and apply the methods. In 1997, Japanese researchers with the JWWA and a consulting firm had presented the general formulation of the approach using pipeline empirical damage information from the Kobe earthquake (Isoyama et al, 1998). At the US-Japan workshop, an engineer from Kubota Pipe Company (Toshima and Iwamoto, 2001) discussed the most recent development of the methodology working with the JWWA. Several large Japanese water utilities applied the methodology to their systems (Kamei (Tokyo), 2001; Miyauchi (Osaka), 2001).

The methodology now used in the U.S. and Japan is shown in Figure 1. This methodology is incorporated in HAZUS-99, an earthquake loss estimation tool developed with funding from the Federal Emergency Management Agency.

The conclusions drawn from the analysis seem to differ in the U.S. and Japan. The Japanese focus their efforts on pipeline damage. In presentations made about evaluations of the Tokyo and Osaka systems, there was no discussion about damage states of system tanks or pump stations. In the Kobe earthquake, these components performed relatively well. Most of their distribution tanks are below grade concrete which have performed well in most locations where subjected to earthquakes. In the U.S. we have many above grade steel and post-tensioned concrete tanks that are vulnerable to earthquakes when not built to recent seismic codes.

The evaluation of the San Diego system resulted in a system restoration curve such as that shown in Figure 2. A very similar relationship resulted from the evaluation of the Osaka water system as shown in Figure 3. Both plot customers served versus time.

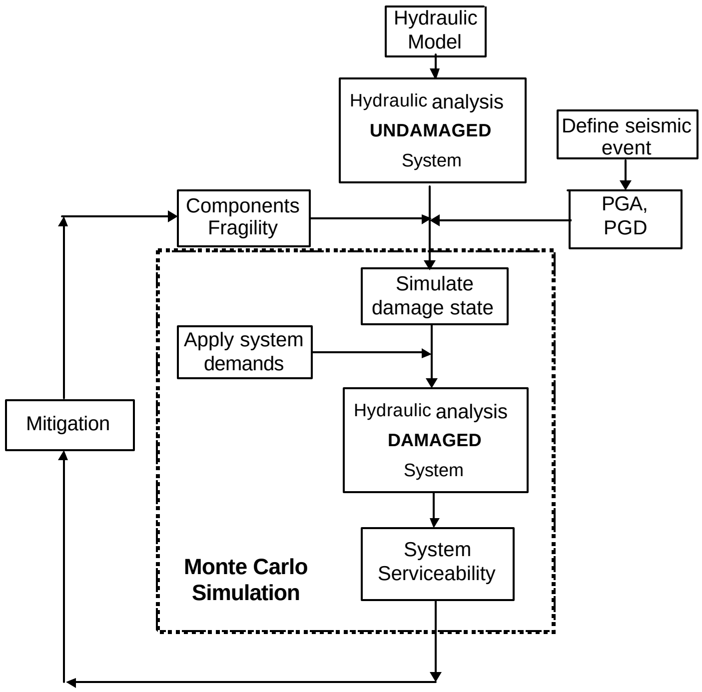

Figure 1
Water System Evaluation Methodology

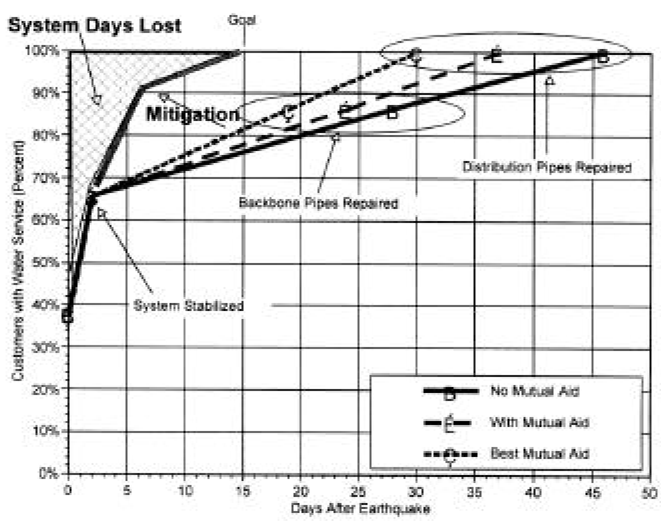

Figure 2
Restoration Relationship for San Diego California Water System
(Rose Canyon-Silver Strand M7.2 Earthquake) (Collins et al, 2001)

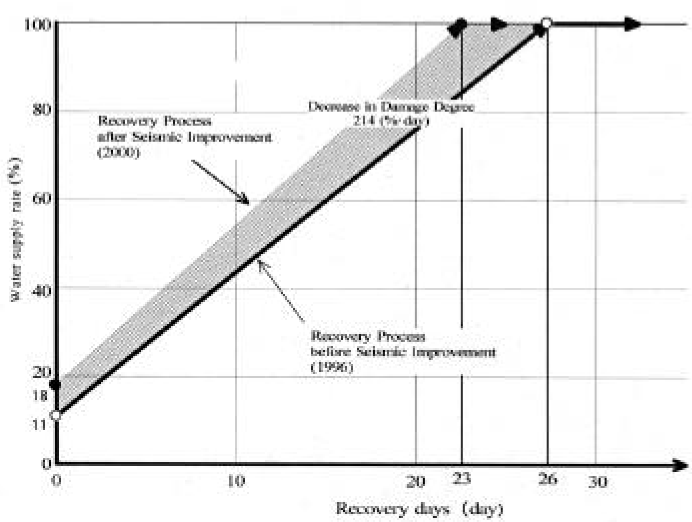

Figure 3
Restoration Relationship for the Osaka Japan Water System (Miyauchi et al, 2001)

Mitigation Strategies

The Japanese have great interest in pipeline replacement and in providing emergency water supplies for immediate post earthquake potable use. U.S. water utilities commonly develop comprehensive mitigation packages that match the mitigation investment with the level of system reliability. Representatives from water utilities in Tokyo, Osaka, and Kobe stepped through their analyses demonstrating how annual pipeline replacement would incrementally reduce the water system recovery time (Kamei 2001; Miyauchi 2001; Matsushita 2001). Osaka, for example, with 5,078 km of pipe, has a 10-year program to install/replace 710 km of pipe, about 1.4 percent a year. This exceeds the most aggressive U.S. pipe replacement programs.

It is inappropriate to conclude that the Japanese have focused entirely on pipeline replacement. Over the years, they have discussed seismic upgrades of many other system components ranging from water supply tunnels, bridges, and treatment facilities.

By comparison, mitigation programs for East Bay MUD (Miller 2001), San Diego (Collins, 2001), and Contra Costa (see Figure 5) (Scawthorn, 1996) developed comprehensive mitigation packages addressing many system components allowing the decision makers to select the level of service that meet their needs. Note that the project offering the greatest increase in reliability is the Backbone System enhancement giving them a rugged highly reliable conduit to move water for fire suppression through the service area.

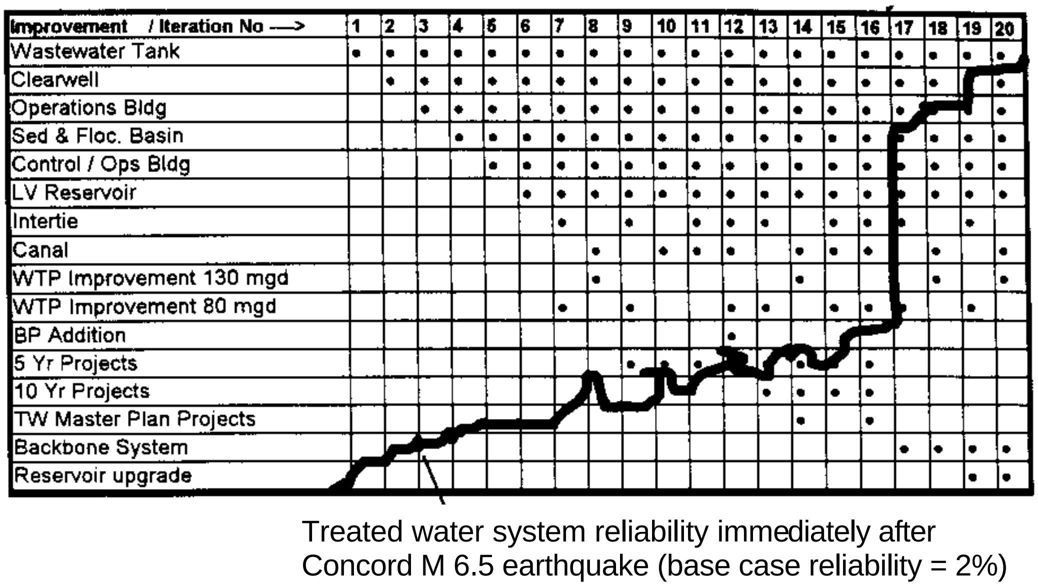

Figure 4
Iteration Alternatives for Contra Costa Water District
Cost-Benefit Analysis (Scawthorn, 1996)

Developing the capability to provide emergency water supplies within hours after the earthquake is an important Japanese mitigation strategy. Yokohama has an ongoing program to install circulation type underground storage tanks distributed throughout the service area (Hayashi, 2001)(Figure 5). They are each fitted with pipe manifold systems that can be set up by the local population.

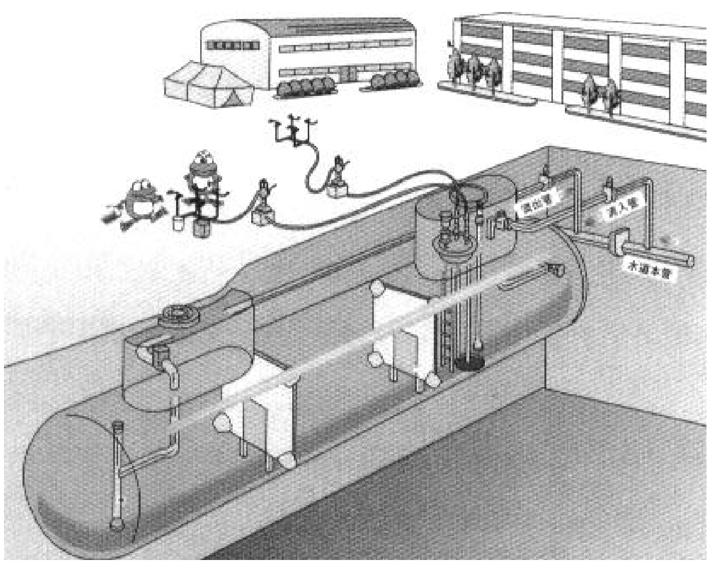

Figure 5

Circulation Type Underground Storage Tank (Hayashi, 2001)

Benefit Cost Analyses

Both Japanese and U.S. researchers have evaluated the benefit versus the cost of pipeline replacement. While the general concepts are the same, the approaches and results differ. Osaka, using the guidelines developed by the JWWA for benefit cost analysis of seismic mitigation programs, has calculated a benefit cost of 1.5 considering impacts on both business and domestic customers. The two largest cost reductions (benefits) are decrease in damage amount by water suspension, and decrease in the amount of leakage. The damage amount for one person is $70/day including water for cooking, cleaning, bathing, and toilet. Business losses were estimated to be $110/day per employee, noting that there is a separate industrial water supply that is not considered in the analysis. The decrease in leakage is for pre-earthquake conditions. That is, by replacing pipe, they have increased the accounted for water from 84.4% in 1996 to 85.8 % in 2000. This is valued at $130 million/year. They place a value on their water of about 2.5 times what this author pays in the U.S.

The Osaka analysis has used an earthquake recurrence interval of 50 years. In the U.S., the ground motions for earthquakes with this short a recurrence interval would be relatively small, and not very damaging. The approaches seem to be inconsistent.

By comparison, Dr. Stephanie Chang has recently conducted a life-cycle benefit-cost analysis of pipeline replacement in the Portland Oregon water system (Chang, 2001). She uses a percentage of the gross regional product, differentiated by business sector, to estimate the economic impact of loss of water supply. Her analysis showed that business interruption losses were on the order of 100 times direct costs. Her analysis did not take into account losses associated with fire-following the earthquake. She was unable to demonstrate that it was cost effective to replace brittle cast iron pipe in liquefiable soils.

Conclusions

The papers presented at the recent U.S.-Japan workshop on water system mitigation provided the first glimpse of Japanese water “system” evaluation methodologies and consequences of failure. In general, the methodologies appear to be similar to those used in the U.S., but the results are significantly different. This situation provides an opportunity for both U.S. and Japanese researchers to learn from our colleagues their thoughts and ideas, leading to improved analytical methods.

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