Proceedings of the International Symposium on Engineering Lessons Learned from
the 2011 Great East Japan Earthquake, March 1-4, 2012, Tokyo, Japan

# EMERGENCY-RESPONSE CAPACITY OF LIFELINES AFTER WIDE-AREA EARTHQUAKE DISASTERS

Yasuko KUWATA[1] and Yoji OHNISHI[2]

[1] Associate Professor, Department of Civil Engineering, Kobe University,
Kobe, Japan, kuwata@kobe-u.ac.jp
[2] Graduate Student, Department of Civil Engineering, Kobe University,
Kobe, Japan, 114t111t@stu.kobe-u.ac.jp

**ABSTRACT**: When the Tohoku earthquake occurred on March 11, 2011, lifeline services were cut to millions of households in East Japan. Lessons learned from the 1995 Kobe earthquake resulted in improvements in disaster-assistance frameworks that have been implemented in earthquakes since then. This study focuses on the nation-wide emergency-response capacity to repair damage and provide alternative lifeline services to stricken areas. We conclude that it is difficult to achieve the goal established after the Kobe earthquake in the case of wide-area earthquake disasters.

**Key Words**: wide-area earthquake disaster, emergency-response capacity, lifeline, nation-wide disaster-assistance dispatch

## INTRODUCTION

The Tohoku earthquake, which occurred in the Pacific Ocean at 14:46 (local time) on March 11, 2011, was a giant earthquake in the Japanese earthquake catalog, causing strong and prolonged shaking throughout East Japan. This catastrophe was accompanied by a large-scale tsunami. The outage of lifeline services caused by this earthquake and the following earthquakes in Niigata and Nagano Prefectures affected about 8.9 million households in 18 prefectures among 4 electric power companies, about 2.25 million households in 19 prefectures for water supply, and about 460,000 households in 8 prefectures for piped-gas supply. These numbers of affected households were larger than those ever experienced in Japan.

Even though quick restoration of a lifeline system after an earthquake is expected for saving human life and maintaining daily existence, it is hampered by complex elements such as internal restoration work and inter-related problems with other lifeline systems. Alternative lifeline service such as generator, emergency water delivery by trucks, and voice mail system plays the role of normal lifeline service during an outage period. Emergency-response of lifeline system is therefore required quick system restoration as well as temporary service providing the alternatives. In particular, if an inter-plate earthquake as severe as the Tohoku earthquake provokes a wide-area destructive disaster, lifeline authorities and companies in stricken areas may not be able to respond sufficiently and may need national assistance. A disaster-assistance system at the national level involves the establishment of headquarters, an information-gathering system, a command structure, an arrangement between the

assisting and the assisted lifeline companies, and a dispatch of disaster-restoration resources (personnel, machines, equipments and goods).

National disaster assistance of the lifeline authorities in Japan began with the Kobe earthquake of January 17, 1995. This earthquake hit the modern urban area of Hanshin and caused severe malfunction of lifeline systems. In the Hyogo Prefecture regional disaster-prevention plan at the time, mainly typhoon and flood measures were assessed and prepared for, under consideration of the disaster history in that area. Earthquake measures were little described. Despite the severity of the earthquake, for instance, about 70% of the staff from the affected water-supply authorities promptly came to their offices on the day of the earthquake, and disaster-assistance teams from other cities arrived with water trucks to provide emergency water delivery. At its peak, disaster-assistance activity included 432 water trucks and 804 personnel from 83 cities, 20 private groups, and Self Defense Forces by one week after the earthquake. Thus, the Kobe earthquake challenged authorities to reconsider the Japanese earthquake disaster countermeasures used at the time.

This study focuses on emergency-response capacity of lifeline authorities during a wide-area earthquake disaster. The emergency-response capacity can be explained by the system of organization, ability, experience and resource to respond demands caused by an event. With regard to the wide-area earthquake, the disaster assistance outside the stricken area becomes a key of result. After reviewing the emergency-response demand from the extent of lifeline damage and restoration time during the Tohoku earthquake, comparing to those in the Kobe earthquake, the most critical lifeline is selected and analyzed on its emergency-response capacity.

## LIFELINE DAMAGE AND RESTORATION

The outages of lifeline services and emergency response in the lifeline communities during the Tohoku earthquake are reviewed on the electric power supply, water supply and piped gas supply. These numbers are compared with those in the Kobe earthquake.

### Electric power supply

There was a power outage to 4.66 million households in the supplied area of the Tohoku Electric Power (Tohoko-EPCO), which are about 70% of total customers. The number of affected households decreased up to 0.99 million (80% restored) by 3 days after the earthquake remaining the coastal area and the Miyagi Prefecture, and to 0.26 million (94% restored) by 8 days after the earthquake. Until 8 days after the earthquake, the power supply was resumed except the tsunami-suffered area. In the supplied area of the Tokyo Electric Power (TEPCO), the power supply was cut to 4.05 million households. The number decreased up to 0.6 million (85% restored) by 1 day after the earthquake. The restoration was completed by 7 days after the earthquake. Fig.1 shows the number of households without power supply in the 6 affected prefectures. The restoration process in the affected prefectures except the Miyagi Prefecture is similar to that in the Kobe earthquake.

With regard to damage to facilities in the Tohoku Electric Power, three of thermal power plants located on the Pacific Coast were severely damaged and required a long time for restoration. The damage to substation was at 75 locations. While there were the large number of damage in the distribution facilities such as electric pole, cable and post, their damage rates were less than or equal to those in the Kobe earthquake. For the restoration in 100 days after the earthquake, the total number of the personnel composed of staff and members from construction companies and the other electric power companies were about 21,000 for substation, about 42,000 for transmission line and 214,000 for distribution line. Out of these numbers, the disaster assistance from the other power companies was on the repair of distribution line and accounted 4,176 man-days until April 1. Fig.2 shows the number of personnel for restoration works between the Tohoku earthquake and the Kobe earthquake. The number of households for power outages during this earthquake was 8.9 million that is 3.4 times of 2.6 million in the Kobe earthquake. Although the restoration in Miyagi Prefecture required a week for restoration, the personnel for restoration works are in total double of those in the Kobe earthquake.

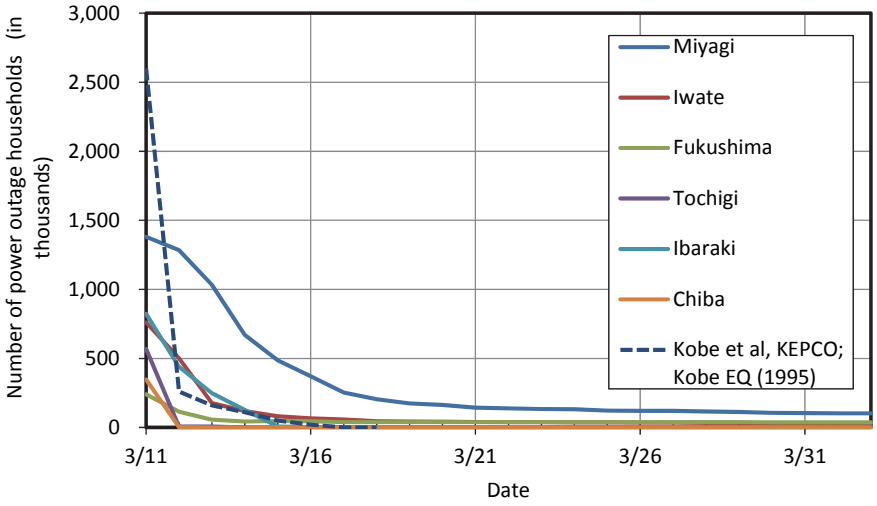



Fig.1 Number of households affected by water-supply outages in the days after the Tohoku earthquake in 6 affected prefectures (Miyagi, Iwate and Fukushima Prefectures are in charge of the Tohoku-EPCO, and the rests are TEPCO). Date of the Kobe earthquake is adjusted from the day of earthquake.

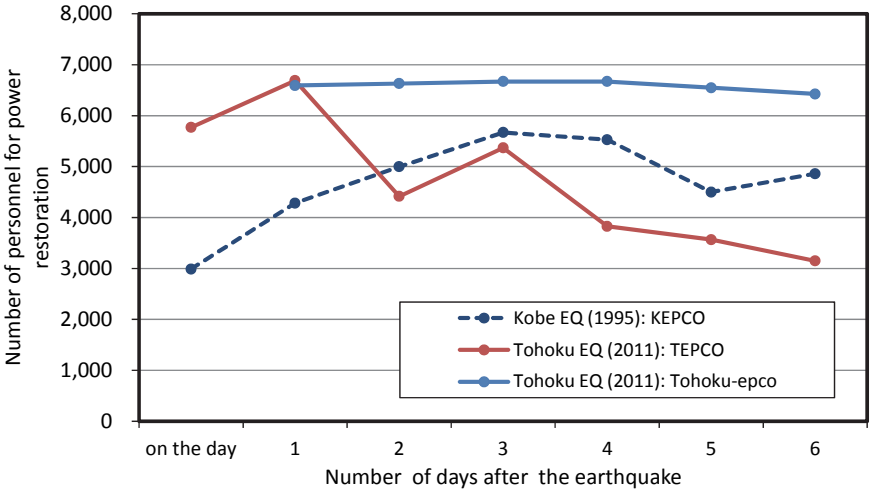



Fig.2 Number of personnel for power restoration works of substation, transmission line and distribution line including the staff and members from construction companies and the other electric power companies following the Tohoku earthquake and the Kobe earthquake

**Water supply**

The water supply was cut to about 2.25 million households at its peak. Fig. 3 shows the number of households affected by water-supply outages in affected prefectures in the days following the earthquake. These numbers are based on a report by the Ministry of Health, Labor, and Welfare (2011). In those cases where the water-supply outage for a local authority was reported qualitatively as “complete outage” or “partial outage,” the number of households used to indicate the extent of water-supply outage is indicated as all or half of the total households, respectively, in the local authority. The total number of households affected by water-supply outage in the Tohoku earthquake was twice that of the Kobe earthquake. The number decreased from 2.25 million to 1.2 million, 0.6 million, and 0.31 million by the 1st, 2nd, and 3rd week, respectively, after the earthquake. Although water-supply restoration was hardly evident in the first 3 days after the earthquake, it proceeded promptly, except for restoration in Miyagi Prefecture, where it was completed up to 90% by two weeks after the earthquake. In the Miyagi Prefecture, the two regional water-supply systems, Sennan-Senen and Osaki, had damage to large transmission pipelines, and it took 2–3 weeks for repair.

Moreover, restoration speed stagnated when the water-supply outage rate was about 10%. Several areas could not obtain water for a long time because of regional evacuation that followed radioactivity leakage at the Fukushima nuclear power plant, tsunami damage, and liquefaction damage. Comparing with Kobe City in the Kobe earthquake, the total households of one city almost corresponds to one prefecture, the Miyagi. The restoration demand in the Tohoku earthquake was the double of that in the Kobe earthquake.

Just after the earthquake, the Japan Water Works Association (JWWA) gathered information on the stricken areas and requested water truck dispatches from each representative of unaffected JWWA regional branches; it then requested dispatches from each water-supply authority. On the basis of the number of water trucks ready to go, dispatch destinations were directed to all water-supply authorities on March 12. Disaster-assistance teams were also dispatched, and emergency water delivery began in the affected areas on March 13. By March 14, the emphasis in emergency activity policy was changed from "parallel work of emergency water delivery, pipe damage investigation, and disaster repair planning" to "intensive work only on emergency water delivery," according to how extensive the damaged areas were. Fig.4 shows the number of water-supply authorities dispatched and the number of dispatched and secured water trucks in the days following the earthquake, as reported by the Ministry of Health, Labor, and Welfare (2011). A "secured" water truck means one that was ready to

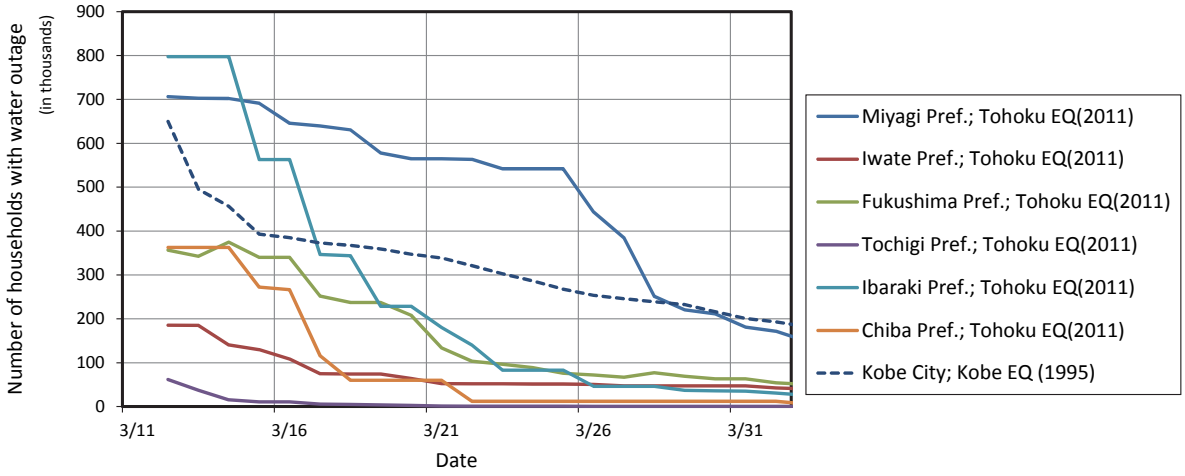



Fig.3 Number of households affected by water-supply outages in the days after the Tohoku earthquake in 6 affected prefectures. Date of the Kobe earthquake is adjusted from the day of earthquake.

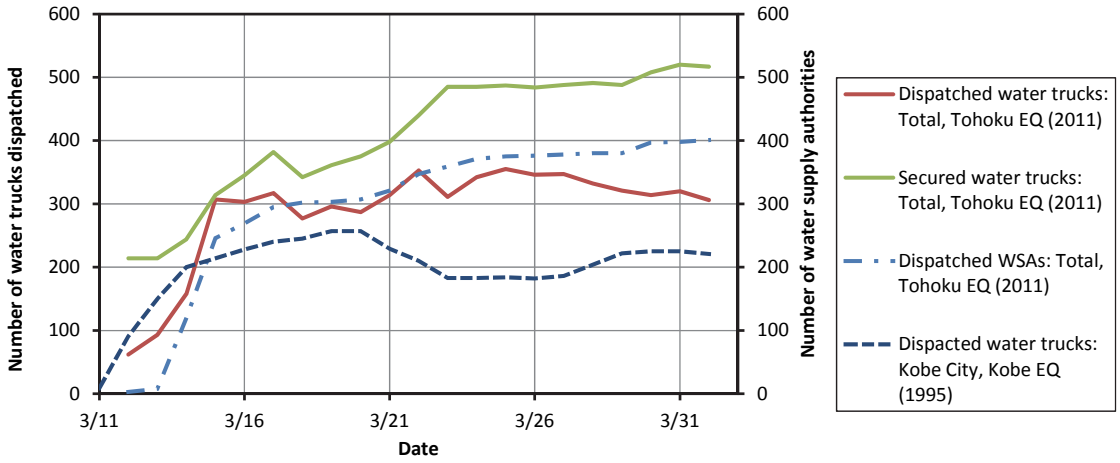



Fig.4 Number of water trucks and water-supply authorities (WSAs) dispatched to the stricken areas. Date of the Kobe earthquake is adjusted from the day of earthquake.

go at JWWA request, and a “dispatched” water truck means one that was actually sent to a stricken area. The number of dispatched water trucks increased up to 300 vehicles after the policy change on March 14 and stayed at that level between March 15 and the beginning of April. At its highest, the number of dispatched water trucks was 355 vehicles on March 22. The number of water truck dispatched in the Tohoku earthquake is not so much different from that in the Kobe earthquake, if vicinities of the Kobe City are regarded too.

**Gas supply**

The gas-supply was cut to 16 piped-gas supply companies and about 460,000 households. The Japan Gas Association (JGA) sent an advance team to Sendai in the morning of March 12 and began dispatching disaster repair teams from March 14 based on the guideline of disaster assistance. Under the JGA headquarter of disaster-assistance in Tokyo, three main teams were organized; Sendai repair team, Sanriku (coastal area of Iwate Prefecture) support team, and Fukushima repair team. Since majority of the affected households were in Sendai City with 359,000 households (78% of all affected households), several sub-repair teams were composed of the teams dispatched from nationwide large gas companies. The most in the stricken area are in rural area and generally use the gas from propane-gas cylinder. The disaster-assistance personnel sent in the JGA framework were 4,200 at its peak from 51 companies. While it took a few weeks for securing the plant function after the tsunami damage in Sendai and Ishinomaki Cities, the pipeline repair rate was fast so that the extent of pipeline damage was minor in comparison of those in the past earthquakes in Kobe and Niigata and the original role of the repair team was allotted to the teams of pipe repair and valve opening.

Fig. 5 shows the number of households affected by gas-supply outages in affected prefectures in the days following the earthquake. The number of affected households was about 857,000 in the Kobe earthquake. The number of households affected by the gas-supply outage was about the half of that in the Kobe earthquake. After the Kobe earthquake, the large number of personnel as about 9,700 came to repair the damage. The number of disaster-assistance personnel dispatched was about the half as well. The disaster assistance can be considered to have been enough in this earthquake because emergency-response demand was fewer, except the tsunami damage to facilities.

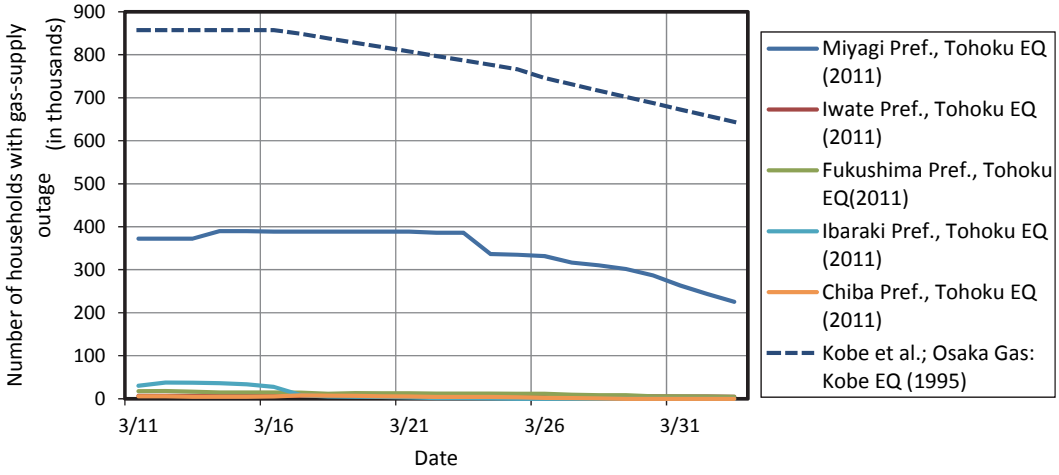



Fig.5 Number of households affected by gas-supply outages in the days after the Tohoku earthquake in 5 affected prefectures. Date of the Kobe earthquake is adjusted from the day of earthquake.

**Summary of reviews**

In terms of the number of households affected by the lifeline interruption and restoration resources following the Tohoku earthquake, the demand of disaster assistance for gas supply authorities was fewer than that in the Kobe earthquake. That for electricity and water supply authorities, however, was

so challenging. For the electricity, the total personnel of restoration works in the TEPCO and Tohoku-EPCO were two times more than those in the Kobe earthquake. By the way, the dispatched water trucks were almost the same. During the Kobe earthquake, the total number of personnel dispatched from other cities for emergency water delivery was same as that for repair work. Considering the disaster assistance on the repair works from the other cities, the disaster assistance of water supply authorities seems tough. Followings are focused on the emergency response for providing water supply.

## EMERGENCY RESPONSE FOR PROVIDING WATER SUPPLY

### Disaster assistance framework of water supply

In 1996, the JWWA reviewed its system for disaster assistance on the basis of lessons learned from the 1995 earthquake and summarized its findings in the "Report on responses in emergencies such as earthquakes." Four main improvements were suggested in this report: (1) assistance should exceed the regional branch framework; (2) advanced team should be dispatched; (3) response to JWWA nonmembers such as private and small-scale water supply authorities should be provided; (4) disaster responses should be organized at the designated headquarters. In addition, the report suggested that emergency activity be improved by clarification of roles and it suggested the implementation of training and drills for emergency action. The report also provided guidelines on the basis of case studies of emergency activity.

The targeted amount of water to be delivered after an earthquake emergency, according to the number of days after an earthquake, was also revised in January 1997. The goal of securing 3 liters per person per day for the first 7 days, which was part of the emergency water delivery plan before the Kobe earthquake, was maintained. In the water-supply goal, 3 liters of water per person per day, identified until 3 days after the earthquake, is assumed to be the minimum requirement for human life; 20 liters until 10th day, for simple cooking; and 100 liters until 21th day, for bathing and washing once every three days. This goal is given as an example only, and the target amount is determined by each water-supply authority according to its level of preparedness and the condition of its earthquake-proof facilities and emergency water-supply stations. The 3 liter amount is regarded as the amount of water to be supplied by emergency water delivery, and the other amounts are expected to be provided by piped water.

The revised national and regional disaster-assistance systems and the revised goals for the amount of water to be delivered during an emergency, on the basis of the lessons learned from the Kobe earthquake disaster, ensured clear roles for representatives of prefectures and regional branches and the quick establishment of disaster-assistance headquarters after the 2004 Niigata Chuestu, the 2007 Noto, and the 2008 Niigata Chuestu-oki earthquakes in Japan. However, the wide-area earthquake disaster caused by the Tohoku earthquake far exceeded the capacity of these disaster-assistance systems. It is important to clarify the requirements for emergency disaster response to an earthquake of the magnitude of the Tohoku earthquake and to verify the emergency-response capacity for providing water supply in a wide-area earthquake disaster in preparation for the Tonankai-Nankai interplate earthquake, which is expected to be the next threat of giant earthquakes along the south coast of Japan.

### Dispatch operation

The JWWA disaster-assistance operations were based on guidelines for responses to emergencies like earthquakes. Detailed emergency response was the combined effort of affected prefecture and assisting regional branches. Fig.6 is a schematic of the relationships in the disaster-assistance system. Iwate, Miyagi, and Fukushima Prefectures were supported by several JWWA regional branches. Chiba and Ibaraki Prefectures were supported by their own Kanto regional branch. Kansai and Chugoku-shikoku regional branches took charge of disaster assistance for Iwate Prefecture, and Chubu and Hokkaido regional branches took charge for Miyagi Prefecture. Kanto and Kyushu regional

branches took charge for Fukushima Prefecture by arrangement with the JWWA after the earthquake. Although the mutual assistance agreement before the earthquake had been concluded with Sendai, Miyagi Prefecture, and Kobe City, the planned disaster-assistance system between Sendai and Kobe changed. The disaster-assistance plan for the regional branch and the affected prefecture combination is also different from that for public administrative work. Because of the extent of the disaster, the representatives of water-supply authorities from the Tohoku regional branch and prefecture, who were expected to manage disaster assistance, could not respond. Until Sendai City, representative of the Tohoku regional branch, finished its restoration early in April, the JWWA represented it on its behalf, as shown in Fig. 6.

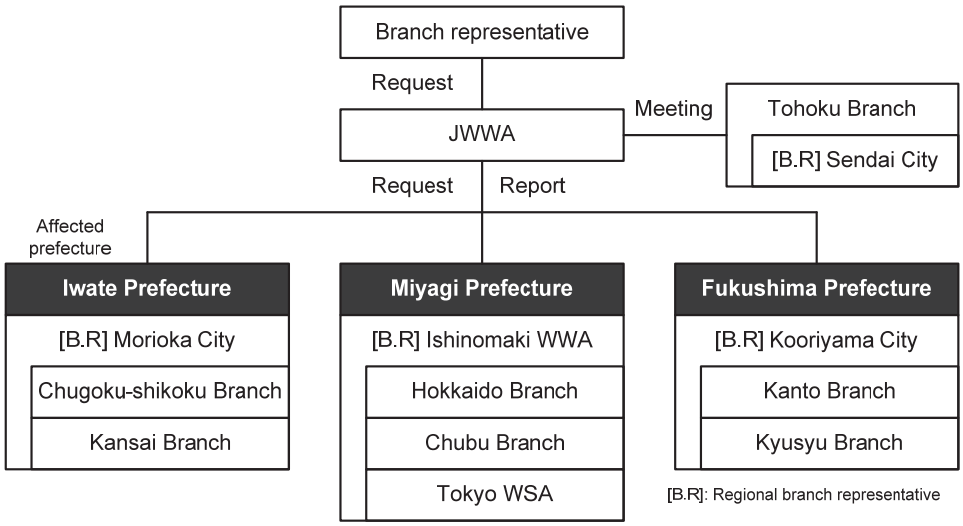
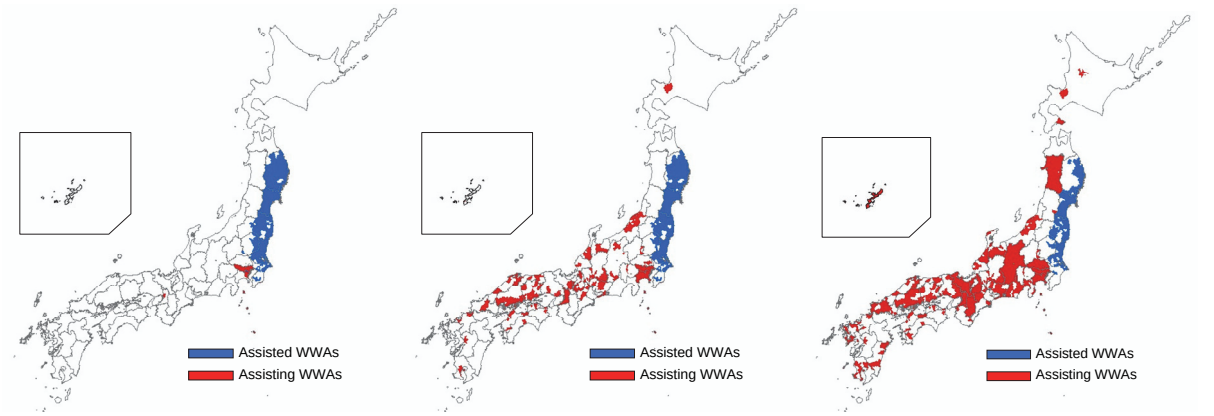



Fig. 6 Schematic of the disaster-assistance system followed during the Tohoku earthquake

Disaster-assistance teams were dispatched from all over the country. Fig. 4 shows the distribution of dispatched water-supply authorities 1 day, 3 days, and 1 week after the earthquake. Assisted water-supply authorities shown in Fig.7 refer to the ones with water-supply outages at the time. Initial dispatch action by megacities such as Tokyo, Yokohama, and Osaka was quite early. Sapporo, Niigata, and Nagoya followed 2 days later. Water trucks were sent from 118 water-supply authorities 3 days later, and 300 water-supply authorities were sent 1 week later. As can be seen, assisting water-supply authorities were not only from the vicinity of the stricken area but also from throughout the country, including the islands of Hokkaido, Shikoku, Kyushu, and Okinawa.




(a) (b) (c)

Fig. 7 Assisting and assisted water-supply authorities. (a) 1 day after earthquake (March 12), (b) 3 days after earthquake (March 14), (c) 1 week after earthquake (March 18)

The number of water trucks at an affected prefecture did not show the same relationship to the number of dispatched water trucks, which increased just after the earthquake and settled to a definite value in 1 week. Fig.8 shows the number of received water trucks in 6 main affected prefectures. During the time period shown in Fig.8, further water-supply outages were intermittently caused by rolling blackouts in the metropolitan area from March 15 to March 21. Moreover, gasoline shortages not only in the metropolitan area but also in the stricken areas hampered restoration work. These lifeline interdependencies presented tough issues for emergency water delivery and restoration. Disaster headquarters for the JWWA met to discuss restoration work on March 20 and March 26. The number of water trucks dispatched by the JWWA increased during the first 3 days, as mentioned above. Those in Miyagi Prefecture increased after the first JWWA meeting and after the resumption of gasoline transportation to the Tohoku region. Those in Fukushima Prefecture, however, decreased after March 17, even though the number of households affected by water-supply outages was higher than in Iwate Prefecture. It is thought that the dispatching water-supply authorities refrained from sending water trucks because of the explosions and fire at the Fukushima nuclear power plant on March 15 and March 16. The dispatching water authority did not have enough information on the situation at the power plant, and under such uncertainty, it was hard to make decisions for ensuring dispatched staff safety. While this study deals only with emergency water delivery, water-quality management at water-treatment plants during radioactive leaks from the nuclear plant also challenged the emergency-response capacity of the water-supply community.

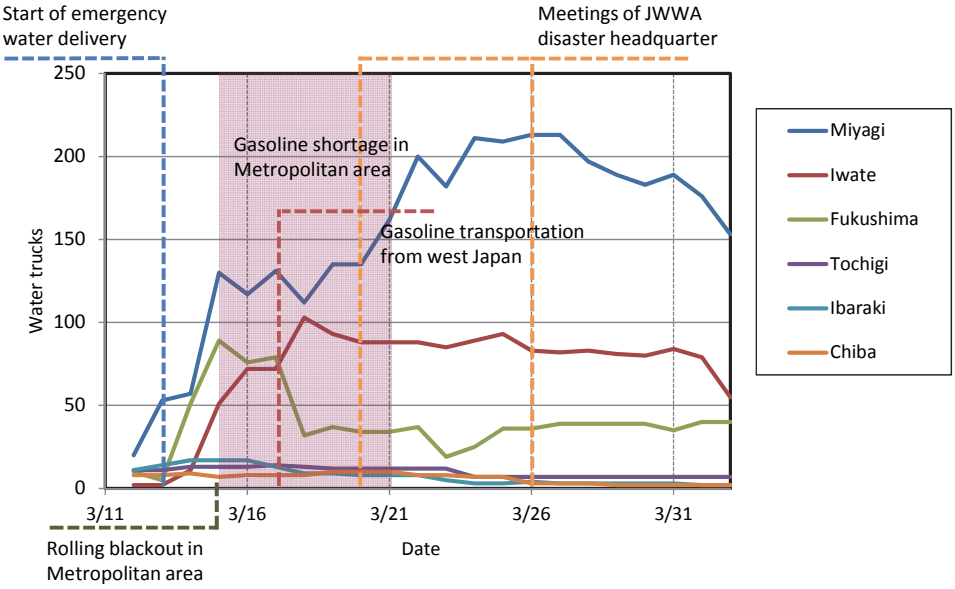



Fig.8 Number of water trucks dispatched to affected prefectures

**Capacity for water truck dispatch by assisting water-supply authorities**

Water-supply authorities in Japan exist in many sizes, ranging from those in small villages to those in megacities with populations in the millions. Not all water-supply authorities can send water trucks to stricken areas in a wide-area earthquake disaster. It is important to understand the dispatch realities for water-supply authorities of different sizes in an earthquake of this scale and to understand the capacity of emergency restoration resources such as water trucks and assistance personnel for wide-area earthquake disasters in the future.

Fig.9 shows the number of water-supply authorities that had water trucks and those that dispatched water trucks in the Tohoku earthquake, classified by water-supply population size. Regional water-supply authorities and affected water-supply authorities are not included. The rate for dispatched water trucks shown in Fig.9 is the ratio of dispatched water-supply authorities to those having water

trucks. The larger the water-supply authority, the easier it was for it to dispatch water trucks. This was especially true for water-supply authorities that had customers of 500,000 people or more; they dispatched 100 % of their water trucks. Staff size and number of water trucks also relate to dispatch requirements, determining whether an assisting water-supply authority can maintain routine work after dispatching water trucks for assistance. Statistics on staff size and number of water trucks as they relate to the size of water-supply authorities are shown in Fig. 7. Water-supply authorities with customers of 300,000 people or more have staff of 150 people or more and one or more water trucks. The number of water trucks per authority increased as the water-supplied population increases, but the increase was not as high among water-supply authorities supplying 100,000–700,000 people. For these water-supply authorities, the number of water trucks is not a criterion for deciding whether to dispatch them. In other words, staff size controlled the decision to dispatch water trucks. It is thought that some water-supply authorities might refrain from dispatching water trucks out of concern that they might not be able to respond to needs in their own area if a disaster occurred while water trucks were being dispatched to other stricken areas.

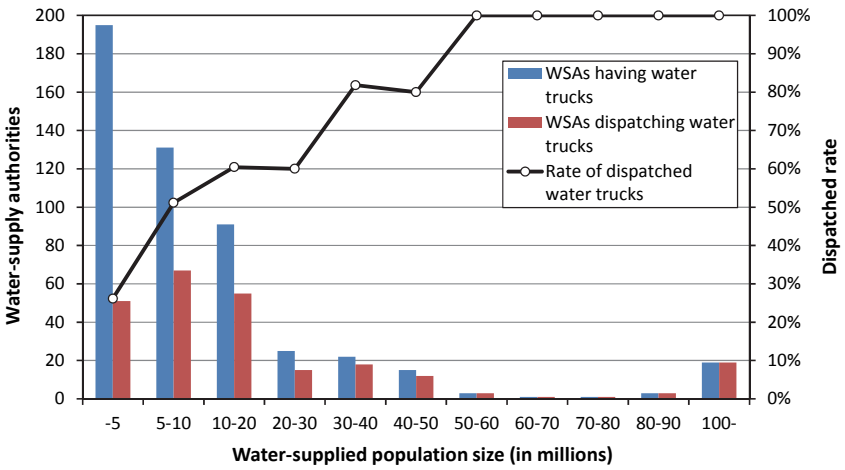



Fig. 9 Number of water-supply authorities dispatched to affected prefectures on the basis of water-supplied population size (in millions)

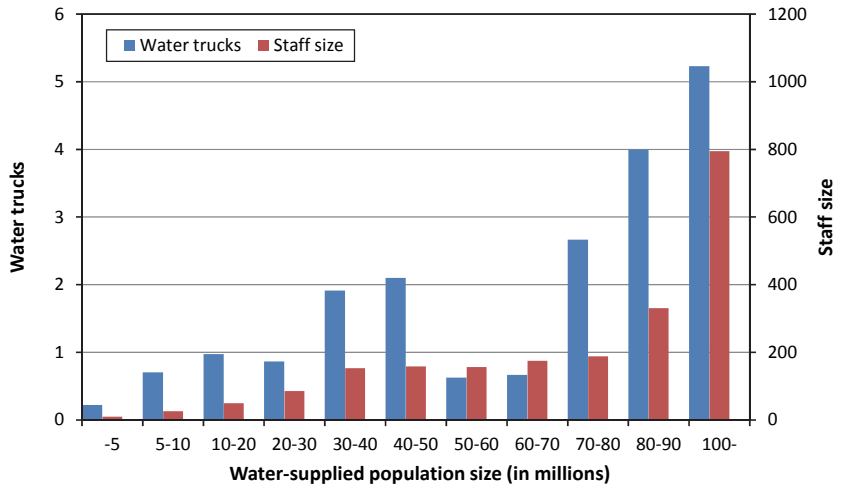



Fig. 10 Number of water trucks and staff size of water-supply authorities on the basis of water-supplied population size (in millions) (based on JWWA(2007))

Among Japanese water-supply authorities in cities, which are defined administratively as municipalities with populations of 500,000 or more, those having water trucks are 380 authorities. This number means that almost all the water trucks in Japan were dispatched for assistance in the Tohoku earthquake. Since the Kobe earthquake, a number of municipalities have consolidated, and the number of water trucks in the entire country has tended to decrease with consolidation. Over the last 17 years, the ability to offer disaster assistance by dispatching water trucks has clearly decreased.

To improve dispatch ability during wide-area earthquake disasters, the quality of disaster assistance should be changed. For instance, clear channels of communication, organization of water trucks that can be sent promptly to several stricken areas, and dispatch of staff with disaster-assistance experience should be developed. With regard to available staff, it is important that personnel sent to affected areas should be a combination of experienced senior staff and inexperienced younger staff, who will be trained for future technological succession.

**Capacity for emergency water delivery**

The Ministry of Health, Labor, and Welfare provides the guidelines for the amount of the emergency water delivered every day after an earthquake. We attempted to calculate the amount of delivered water at each prefecture. The amount of the delivered water per person, $Q$, is calculated as follows:

$$Q = \frac{Cn}{hd}, \tag{1}$$

where $Q$ is the amount of delivered water (in liters per person per day), $C$ is the capacity of a water truck (assumed at 3,000 liters per vehicle), $n$ is number of water trucks used (both dispatched and owned trucks), $h$ is the number of households without water supply, and $d$ is the number of family members per household (assumed at 2.34, based on the national census).

The capacity of water trucks used in Japan is generally 2 or 4 $m^3$. This study assumes that a water truck is used once a day because it takes 1–2 hours to fill a truck, 2 hours to deliver water to a supply site, and 2–3 hours for a round-trip between the distribution reservoir and supply site.

Fig.11 shows the amount of emergency delivered water in affected prefectures. The target goal of 3 liters per person per day was achieved shortly after the earthquake in Tochigi Prefecture, and it was achieved in 2 weeks in Chiba Prefecture. These prefectures had comparatively few households with water-supply outages and, compared with other affected prefectures, could restore water supply soon after the earthquake. In Tochigi Prefecture, the number of households without water was 1/10th of the number in Chiba Prefecture and 1/250th of that in Miyagi Prefecture. Moreover, the number of water-authority trucks in Chiba Prefecture were two or more times the number in other prefectures because of its large population. We conclude that the number of water trucks available in Japan is not sufficient to achieve the goal of 3 liters per person per day when a disaster on the scale of the Tohoku earthquake occurs, under the consideration that all available trucks in the country had been sent in response to this event and were not sufficient to meet the goal.

By the way, the current JWWA disaster-assistance framework worked well in the recent earthquakes in Niigata and Noto, causing the water-supply outage to 40,000 households or less. The goal of delivered amount was also satisfied in these earthquakes. If the scale of earthquake disaster is 40,000 households in terms of the number of affected households, there is no matter to change the framework.

To improve the emergency-response capacity of the water supply during wide-area earthquake disasters in the future, pipeline damage should be reduced by developing earthquake-proof water-supply facilities and by implementing frameworks for quick and flexible disaster response at the national level. With regard to earthquake proofing, if pipeline damage was minor, and restoration was completed earlier, discussions on long-term emergency water delivery would not be needed at all. With regard to disaster-response plans, even for the Kobe earthquake, disaster assistance for recovery as well as emergency water delivery was national. Disaster assistance in the Tohoku earthquake was

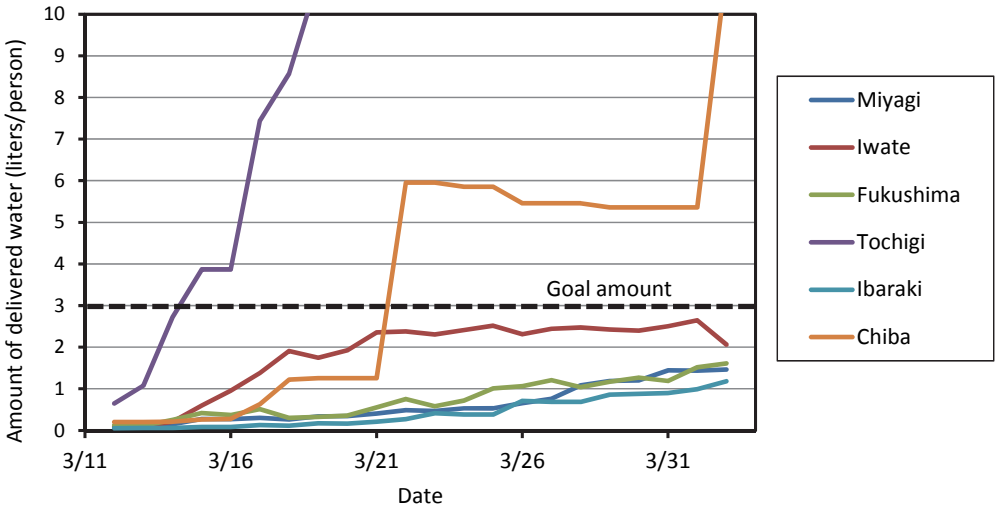



Fig.11 The amount of emergency delivered water in affected prefectures in the days following the Tohoku earthquake

mainly accomplished by emergency water delivery, while pipelines were repaired by local construction companies. It is necessary to develop a national assistance system for disaster recovery that includes not only traders related to the water-supply authorities but also water-service businesses.

Moreover, although this study only analyzed assistance provided by the JWWA, regional, and branch water-supply authorities that were reported by the Ministry of Health, Labor, and Welfare, emergency water delivery was also provided by Self Defense Forces as well as other organizations and groups. Water boats from the Maritime Self-Defense Force, Japan Coast Guard, and private companies provided disaster assistance at 11 places along the coast in the Kobe earthquake. The advantage to this kind of assistance is that it can be carried out smoothly regardless of the traffic jams after an earthquake. Because the total number of water trucks in the entire country has decreased, it is necessary to cooperate with organizations that can provide emergency water delivery to stricken areas.

Finally, it is difficult to estimate the extent of damage shortly after an earthquake, especially in a wide-area earthquake disaster, when communication and transportation systems are damaged and out of service. In the 2008 Niigata Chuetsu-oki earthquake, the numbers of assistance personnel and water trucks were increased a week after the earthquake once authorities realized that liquefaction damage was serious. A disaster-assistance organization should be flexible enough to build up assistance at the level of prefecture, as well as at the level of regional chapter, when the disaster damage information is updated in real time. It is necessary for JWWA readership at the national level to arrange cooperation between affected prefectures/cities and assisting prefectures. Furthermore, the assisting prefectures also need sufficient response capacity to manage details and practical water delivery service with water-supply authorities and to effectively play a subsystem role for regional disaster assistance.

## CONCLUSIONS

This study reviewed earthquake damage and emergency response of lifeline systems during the Tohoku earthquake and examined the emergency-response capacity to provide water supply during the wide-area earthquake disaster. The following conclusions of this study are summarized here.

- In terms of the number of households affected by the lifeline interruption and restoration resources following the Tohoku earthquake, the demand of disaster assistance for water supply authorities was the highest among the other lifeline and was higher than the Kobe earthquake.
- About 350 water trucks were sent to the affected area in the Tohoku earthquake. The water-supply

authorities with the best ability to prepare water trucks and that had enough human resources to send assistance personnel were those large enough to provide water service for populations of 500,000 or more. This number of water trucks is the limit for water trucks that could be available during a regional earthquake disaster in Japan.

- The emergency water delivery goal of 3 liters per person per day is difficult to achieve in wide-area disasters because the number of water trucks available to be sent to stricken areas is limited.
- At the national level, the assistance system for disaster recovery should be organized, and the system for providing emergency water delivery should be developed; both systems should be flexible enough to change according to the damage situation.
- Water-supply authorities should cooperate with other organizations that can provide emergency water delivery.

## REFERENCES


Editorial Committee for the Report on the Hanshin-Awaji Earthquake Disaster. (1997). "*Report on the Hanshin-Awaji Earthquake Disaster, Damage and Restoration of Lifeline Systems*", Maruzen (in Japanese).

Japan Gas Association. (2011). "*Extent of gas-supply outages (report Nos.1-61)*" (http://www.gas.or.jp/tohoku/press/index.htm)

Japan Water Works Association. (1997). "*Statistics of Water Works*", Tokyo (in Japanese).

Japan Water Works Association. (1996). "Report on responses in emergencies such as earthquake", Tokyo (in Japanese).

Kobe City Water Bureau. (1996). "*Hanshin-Awaji Earthquake Disaster. Report on Water Supply Recovery*", pp. 43-45 (in Japanese).

Ministry of Health, Labor, and Welfare, Japan. (2011). "*Damage and response in the Great East Japan Earthquake Disaster (report Nos. 1-49)*", (in Japanese). (http://www.mhlw.go.jp/stf/houdou/2r98520000014j15.html)

Ministry of Internal Affairs and Communications, Japan. (2011). "*National Census*".

Tohoku Electric Power Company. (2011). "On emergency response during off the Pacific Coast of Tohoku earthquake", Committee material of METI (in Japanese).

Tokyo Electric Power Company. (2011). "Summary on restoration on electric facilities and power supply", Committee material of METI (in Japanese).