Tokyo Waterworks' Earthquake Countermeasures: Towards Earthquake-resilient Water Services in Tokyo

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TOKYO WATERWORKS' EARTHQUAKE COUNTERMEASURES: CURRENT STATE AND CHALLENGES

In March 11, 2011, the Great East Japan Earthquake occurred, with a magnitude of 9 – the largest ever recorded in Japan. The big shakes and tsunamis due to the great earthquake inflicted enormous damage to the lifeline mainly in the Tohoku region. The water supplies to approximately 2.57 million houses were suspended, which led to the situation where water was unavailable even in shelters. Also, the quake caused damage that we have never experienced (e.g. leakage accidents due to ground liquefaction and turbid water associated with planned power outage) even in Tokyo – a place far distant from the epicenter. This shed light on the problem in securing water supply.

Meanwhile, in April 2012, the Tokyo Metropolitan Government (hereinafter, TMG) issued the Estimated Damage from a Tokyo Inland Earthquake and conducted a review of the situation where the worst possible damage can be caused in the future in a more realistic manner. As a result, we found that the damage will be larger than estimated before: the maximum seismic intensity 7 to be observed in certain places and the intensity 6 upper in broad areas, and the maximum tsunami height of TP 2.61 meters to be observed along the coast of Tokyo Port.

Under such a situation, in February 2015, Tokyo Waterworks formulated the Master Plan for Tokyo Water Supply Facility Development (hereinafter, Master Plan) in order to respond to various challenges such as the Tokyo Inland Earthquake, the urgency of which has been pointed out, thereby announcing the facility development policies including earthquake-resistance measures. Also, in March 2015, we reviewed the Tokyo Waterworks Earthquake Emergency Response Plan in order to more quickly and effectively recover the normal water supply and secure drinking water in case of earthquake damage.

Towards earthquake-resilient water services, it is important for us – a waterworks operator of the capital city Tokyo – to ensure the measures from both tangible and intangible perspectives.

TOKYO WATERWORKS' EFFORTS

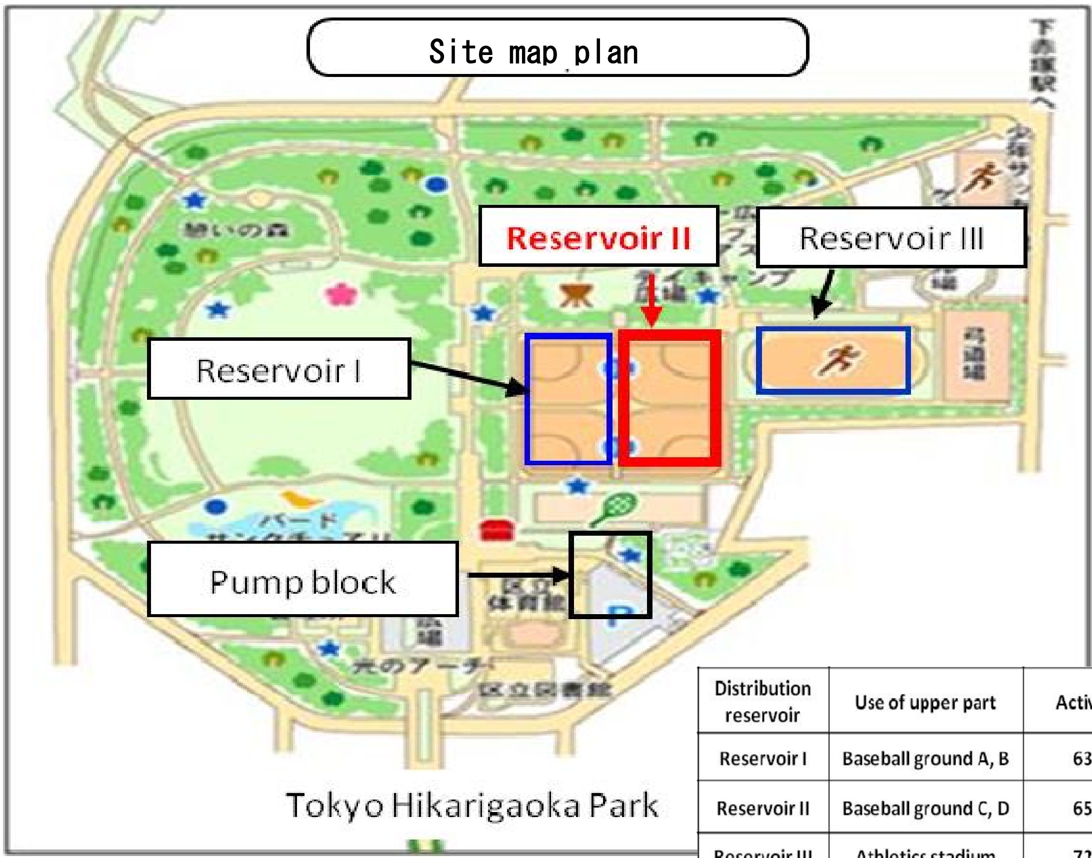
At the previous Japan-US-Taiwan Workshop on Water Supply System Seismic Practices (2013), We made a presentation titled "Tokyo Waterworks' Earthquake Countermeasures Based on the Tokyo Waterworks Management Plan 2013." This time, I will report mainly on the details of such earthquake countermeasures and introduce the countermeasures that have been taken since the previous presentation.

Promotion of earthquake countermeasures

Promotion of earthquake retrofitting at water purification plants and water supply stations

Many of the purification plants and water supply stations are becoming older because they were built around 1960, a half century ago. If a disaster (e.g. Tokyo Inland Earthquake) causes damage to those facilities in such a situation, their facility capacities will significantly decline due to damage caused by their lack of strength. We are, therefore, promoting earthquake resistance of facilities towards the development of such facilities with proper seismic capacity in a planned manner.

In terms of the promotion of earthquake resistance of purification plants, we are effectively carrying out earthquake retrofitting in light of the continuity from receiving wells to filter basins, internal connection pipes and wastewater treatment stations. Also, as for distribution reservoirs at water supply stations, we are prioritizing those without supporting functions, facilities related to water supplies to the capital's main organizations and emergency medical institutions, and facilities in areas with high liquefaction potential.
For example, the Nerima Water Supply Station that was built in 1980 is an important water distribution base in Tokyo, with three distribution reservoirs under the ground of the Tokyo Hikarigaoka Park, the total capacity of which is the largest in Tokyo (200,000 m^3). In preparation for disasters such as the expected Tokyo Inland Earthquake, the urgency of which has been pointed out, we have promoted earthquake retrofitting works in order since 2008, completed Reservoirs I and III, and are currently constructing Reservoir II.



Distribution reservoir	Use of upper part	Active storage
Reservoir I	Baseball ground A, B	63,000 m^3
Reservoir II	Baseball ground C, D	65,000 m^3
Reservoir III	Athletics stadium	72,000 m^3

Figure 1. Site plan of the Nerima Water Supply

The major earthquake retrofitting works carried out include shear reinforcement, concrete deck-slab reinforcement, installation of flexible expansion joints, and inner corrosion protection.

Shear reinforcement: improving the earthquake resistance by inserting reinforcing steel bars from the sides to increase the amount of reinforcing steel.

Figure 2. Sidewall boring

Concrete deck-slab reinforcement: improving the earthquake resistance of posts by casting concrete to the bases of posts

Figure 3. Concrete deck-slab reinforcement

Installation of flexible expansion joints: The joints compensate the displacement due to earthquakes, thereby reducing impacts on structures.

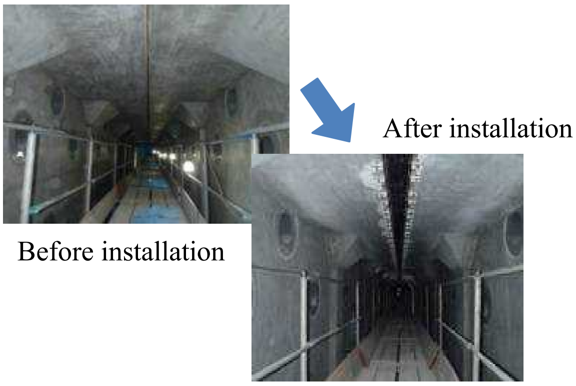


Figure 4. Concrete deck-slab reinforcement

Inner corrosion protection: removing deteriorated internal coating and repairing it with mortar.

Coating removal   Mortar corrosion protection

Figure 5. Inner corrosion protection

Before earthquake retrofitting   After earthquake retrofitting

Figure 6. Earthquake retrofitting work (Nerima Water Supply Station)

Promotion of earthquake-resistant water pipes

In response to the lessons learned from the fact that many water pipe joints were slipped off due to the Great East Japan Earthquake, the TMG decided to implement the “10-year project to promote earthquake-resistant joints” aiming to complete the replacement of existing joints on pipelines of 5,000 kilometers in length by earthquake-resistant joints with the slipping-off prevention function in 10 years. As of end-March 2014, the share of earthquake-resistant joints has reached 35 percent. We have further promoted the use of earthquake-resistant joints aiming to increase the replacement rate up to 59 percent by March 2025 as planned in the Master Plan.

In terms of the promotion of earthquake-resistant joints, we have given priority to supply routes to important facilities such as the capital's main organizations and emergency medical institutions. In response to the lessons learned from the damage caused by water outage at shelters at the time of the Great East Japan Earthquake, we have newly included shelters and main stations in the list of the priority facilities, thereby working on promoting earthquake-resistant joints at these facilities.

For information on the promotion of earthquake resistant water pipes, please also refer to the Earthquake countermeasures as an affiliated corporation of the TMG (TSS Tokyo Water Co., Ltd.).

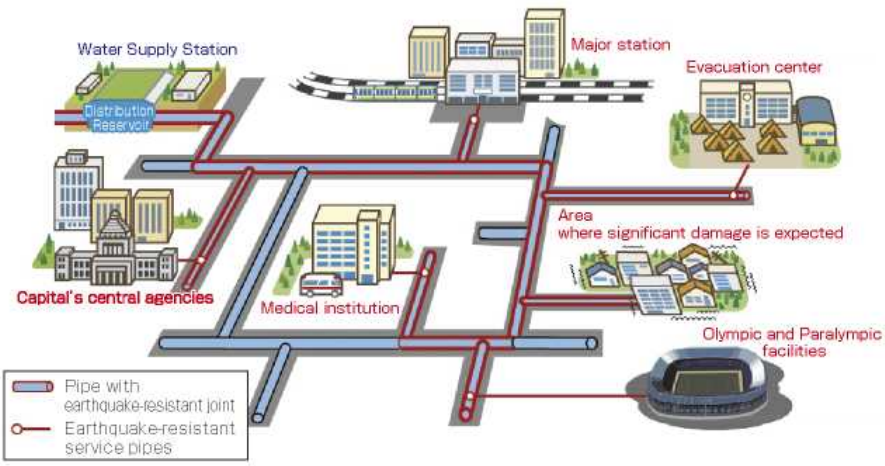


Figure7. Pipe jointing by earthquake-resistant joints in water supply pipes connected to major facilities

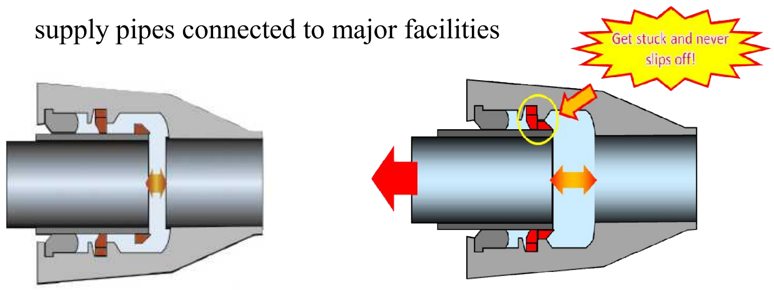


Figure 8. Structure of earthquake resistant pipe joint

Ensuring a stable water supply

Duplexing of conveyance facilities

The conveyance facilities are important facilities that convey raw water taken at water intake facilities to purification plants. The TMG takes 78% of water from the Tonegawa and Arakawa River systems and 19% from the Tamagawa River system.

In 1964, in order to enable mutual transmission of raw water between river systems as a measure against drought, Tokyo Waterworks developed the raw water connection pipeline between the Asaka Purification Plant that conveys raw water from the Tonegawa and Arakawa

River systems, and the Higasimurayama Purification Plant that conveys raw water from the Tamagawa River system. This is the only pipeline that enables mutual transmission between the Tonegawa and Arakawa River systems, and the Tamagawa River system.

At normal times, we work on securing a sufficient amount of water in the Tamagawa River system by transmitting raw water from the Tonegawa and Arakawa River systems that are relatively abundant in water to the Higashimurayama Purification Plant.

Also, at the time of drought or accident along the Tonegawa and Arakawa River systems, we ensure stable water supply by transmitting water from the Tamagawa River system to the Asaka Purification Plant.

The raw water connection pipeline is more than 50 years old and subject to concerns about the progress of aging and the seismic vulnerability; therefore, we conducted interior and exterior inspections and seismic diagnosis in 1999. As a result, we found four places that urgently require repairs due to problems in their seismic resistance, and carried out emergency repair works.

In this way, although the raw water connection pipeline is a crucial facility for Tokyo Waterworks, it has problems: lack of alternative pipelines, lack of option of long-term facility closure during water supply operations and vulnerability against the Tokyo Inland Earthquake that is of concern.

In order to resolve these problems, we decided to develop a new connection pipeline of raw water (hereinafter, Second connecting pipes of raw water) which have the backup functions .

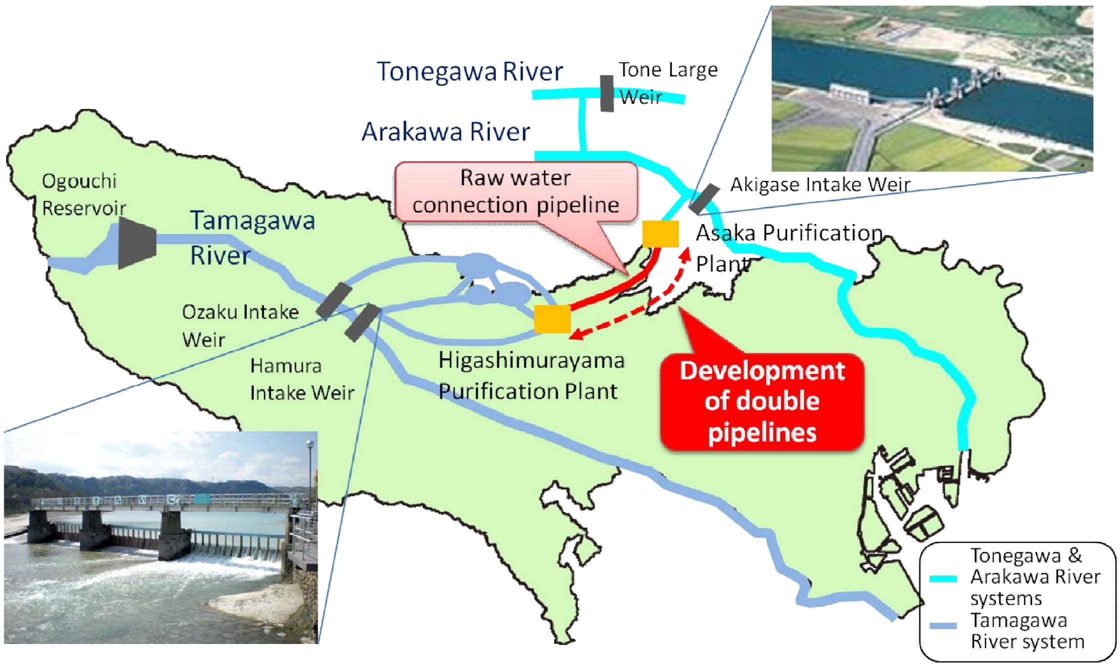


Figure 9. Duplexing of conveyance facilities

We lay Second connecting pipes of raw water on the same route as the conventional pipeline considering economic efficiency and workability. Whereas the conventional pipeline is laid under the earth covering of 3-meter depth, Second connecting pipes of raw water is to be laid around 30 meters below the ground by the shield tunneling method.

Projecting period and the scale of facilities
  Projecting period
    From 2010 to 2018
  The scale of facilities
    Pipe diameter: 2,000 mm
    Total extension: about 16 km

We adopted the slurry shield construction method in all the construction sites.

The construction sites are divided into five considering the shortening of the construction period. We build a 2,200-millimeter-diameter tunnel in each construction site by the shield tunneling method and lay earthquake-resistant pipes of 2,200 millimeter diameter inside it.

We are able to secure only four vertical shaft sites for the construction route and the distance between the sites is six to seven kilometers long. Thus, we adopt the underground jointing method that requires no arrival shafts between Sites II and III, and Sites IV and V.

As of October 2015, the tunnel constructions at Sites IV and V have been completed, and those at Sites I, II and III are under construction.

We are laying earthquake resistant pipes in order after the completion of the tunnels aiming to complete all the works in 2018.

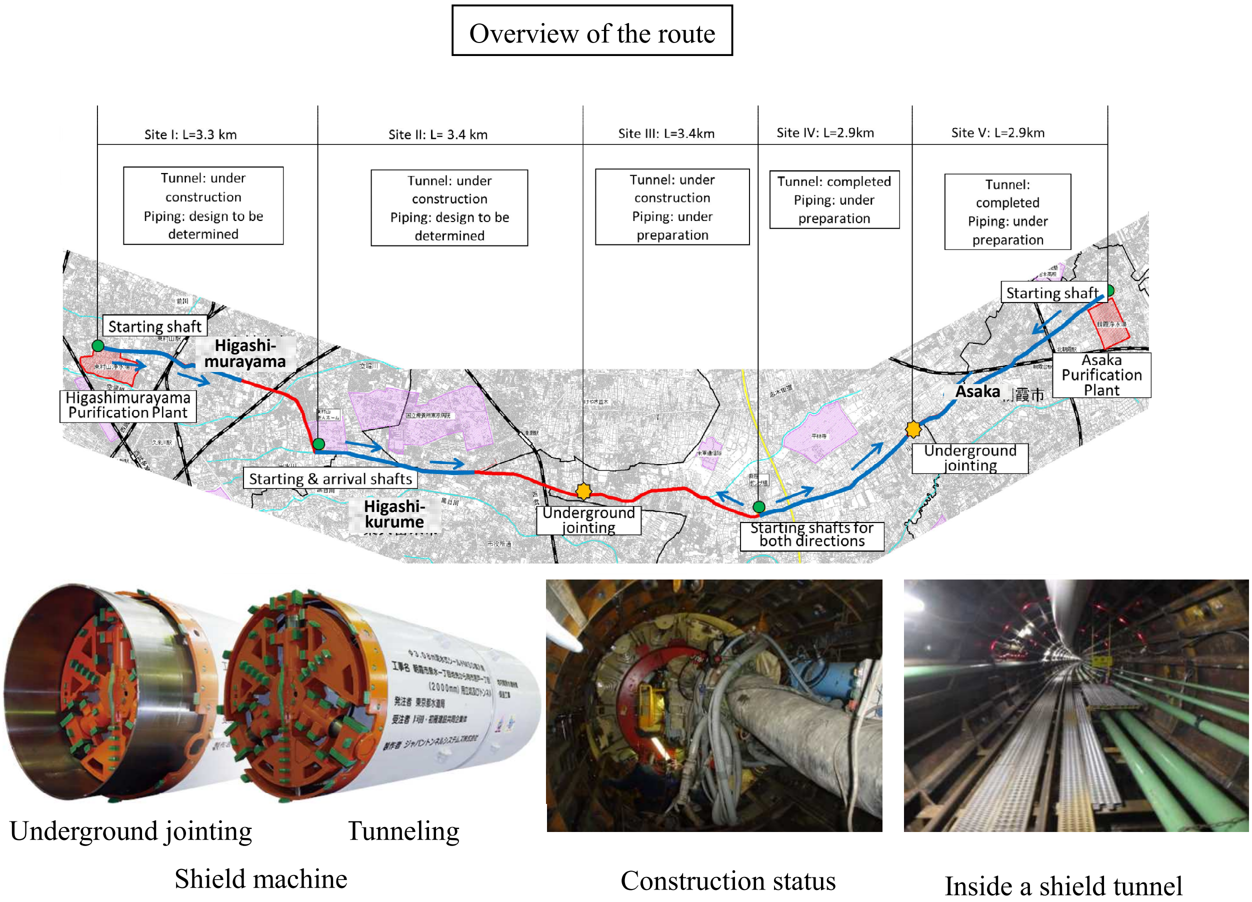


Figure 10. Overview of the second raw water connection pipeline

Establishment of emergency water supply system

Reorganization of emergency water supply bases

There are 203 emergency water supply bases in Tokyo (as of April 1, 2015). As for earthquake emergency water supply activities at purification plants and water supply stations, Tokyo Waterworks is responsible for unlocking the key to gates and setting up equipment, while municipalities are responsible for distributing water. In this regard, however, there used to be a problem that municipalities could not carry out emergency water supply activities until the arrival of Tokyo Waterworks' personnel who are familiar with how to enter into the base, where to store equipment, and how to start pumps.

Thus, we separated the area for emergency water supply activities and installed permanent hydrants (water taps) there within the facility site using dividing fences so that municipalities and local residents can promptly carry out emergency water supply activities without our staff. Also, we newly installed the emergency water supply pump unit within each site to supply water to these hydrants. This pump allows us to supply water just by opening the faucet without start-up operations and enables power supply from the non-utility power generator, which can work even in power outage in time of disaster. Thus, even those who have not mastered its operation can easily carry out emergency water supply activities.

In addition, we ensure the working of the security system by installing sensors on the dividing fence to prevent the general public from entering into the site of the purification plant or water supply station. We manage the entrance keys in accordance with agreements concluded with municipalities and local community associations.

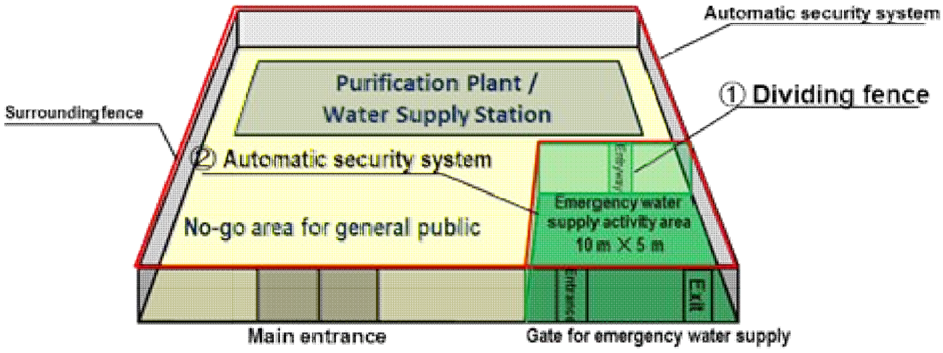


Figure 11. Area for emergency water supply activities

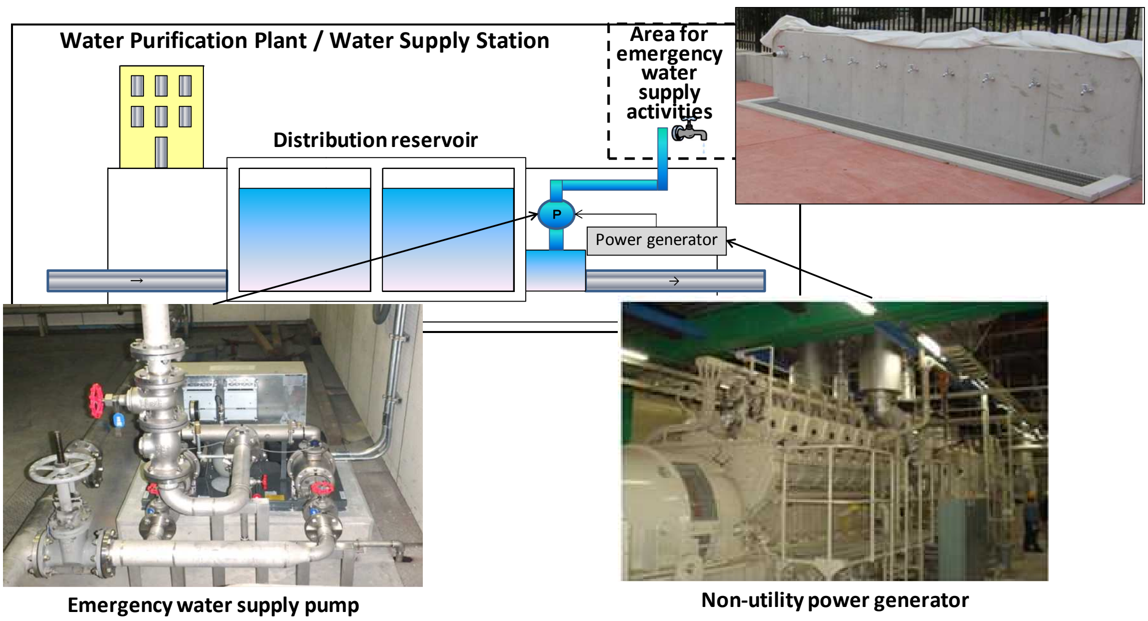


Figure 12. Illustration of the facility

Temporary hydrants

In order to provide rapid and smooth emergency water supply, the cooperation from local residents is essential. For the purpose of complementing emergency water supply bases, Tokyo Waterworks lends municipalities sets of equipment that are necessary for emergency water supply activities utilizing fire plugs around shelters.

The sets of equipment for temporary hydrants are composed of the following:

- Installation table for water supply pipes,
- Water supply pipes, and
- Hoses for water supply and faucets.

It is very easy to set up the hydrant that just requires us to connect pipes, and then turn over and fix pull rings. For emergency water supply using the temporary hydrant, water distribution pipes must be sound even if a service pipe is damaged; thus, securing the supply route to shelters as I mentioned earlier in the “10-year project to promote earthquake-resistant joints on water pipelines” is a crucial prerequisite.

Figure 13. Temporary hydrant

Joint trainings with local residents

Tokyo Waterworks has implemented joint trainings with municipalities and local residents at each emergency water supply base. We have provided not only trainings using normal hydrants (water taps) but also experimental programs of setting up temporary hydrants and of emergency water supply using fire plugs. In this way, we have promoted the improvement of disaster response capability by establishing the emergency water supply system in cooperation with local communities.

Below are images from the training held at the emergency water supply base in the Tama area in February 2015. On that day, the participants included staff members of Tokyo Waterworks (including affiliated corporations), City Hall staffs, local community associations, and local fire stations. We implemented the training for checking the performance of the normal hydrant, and the experience of setting up the temporary hydrant. We also train participants in measuring the residual chlorine concentration to confirm the compliance with the water quality standard (0.1 mg/L or more) before supplying water.

Figure 14. Information board of the emergency water supply base

Figure 15. Permanent hydrants

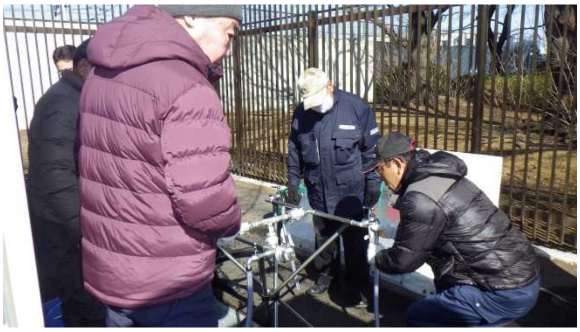


Figure 16. Experience of setting up temporary hydrants

Figure 17. Checking of water flow

Cooperation and collaboration with other cities and organizations

Agreements and memoranda of understandings

For appropriate implementation of emergency measures during disasters, we have made effort to establish the cooperative system with other cities and private businesses by concluding not only outsourcing contracts but also agreements or memoranda of understandings (MOUs) in advance, thereby ensuring post-earthquake emergency response activities. The followings are main agreements and MOUs that Tokyo Waterworks has concluded with other cities for the purpose of emergency water supply and recovery supports.

- MOU on Mutual Disaster Support between Waterworks Bureaus of 19 Cities (Tokyo, Sapporo, Sendai, Saitama, Kawasaki, Yokohama, Niigata, Shizuoka, Hamamatsu, Nagoya, Kyoto, Osaka, Sakai, Kobe, Okayama, Hiroshima, Kitakyushu, Fukuoka, and Kumamoto)
- Basic Agreement on the Establishment of the Asaka Connection Pipeline (Saitama Prefecture)
- Basic Agreement on the Establishment of the Connection Pipeline between Tokyo and Kawasaki City (Kawasaki City)

In addition to agreements with other cities, we have also concluded agreements or MOUs with private businesses (e.g. the Agreement on Disaster Emergency Services with TSS Tokyo Water Co., Ltd.) for the purposes of emergency response activities, and supply of materials for pipe recovery, vehicles and petroleum fuel.

Staging-area waterworks operators

In addition to agreements and MOUs, in September 2014, Tokyo Waterworks and the Ibaraki Prefectural Government Public Enterprise Bureau concluded the MOU on Activities as Staging-area Waterworks Operators, which is the first case in Japan.

The system of staging-area waterworks operators was instituted by the Japan Water Works Association because, in the aftermath of the Great East Japan Earthquake, support teams headed to affected areas could neither fully understand the disaster situation nor settle their activity bases as intended. Under this system, if the area of one waterworks operator is affected by a disaster, the other operator plays the function of a staging-area operator who provides a staging area as a parking or rest place for support teams who are dispatched to affected areas.

Trainings with other cities

Based on the agreements and MOUs, Tokyo Waterworks has regularly conducted joint trainings with other cities.

In the training with Ibaraki Prefecture held in January 2015, we conducted the information communication training of the process from making a request for the provision of a staging area to the Ibaraki Public Enterprise Bureau to the decision-making on a staging area, with the assumption that the Sendai City Waterworks Bureau that is our main support city is to dispatch its support team to Tokyo.

The training has been conducive to enhancing the effectiveness of the MOU by allowing better understanding of the procedure concerning the request to staging-area water operators.

Disaster emergency activities

Based on agreements with other cities and private trade associations, Tokyo Waterworks has conducted emergency supply of water and recovery of water facility in areas affected by disasters such as the Great East Japan Earthquake.

Table 1 below shows our major achievements:

Table 1. Major achievements based on agreements between Tokyo Waterworks, and other cities or private trade associations

Earthquake	Date of earthquake	Period of dispatch and the number of dispatched staff	
		Tokyo Waterworks	Private businesses

		(Emergency water supply support)	(Emergency recovery support)
Southern Hyogo Prefecture Earthquake (Great Hanshin-Awaji Earthquake)	Jan 17, 1995	254 Jan 21-Mar 31, 1995 (70 days)	598 Jan 23-Mar 31, 1995 (68 days)
Niigata Chuetsu Earthquake	Oct 23, 2004	24 Oct 24-Nov 15, 2004 (23 days)	12 Oct 30-Nov 15, 2004 (17 days)
Chuetsu Offshore Earthquake	Jul 16, 2007	34 Jul 18-31, 2007 (14 days)	42 Jul 19-31, 2007 (13 days)
Tohoku-Pacific Ocean Earthquake (Great East Japan Earthquake)	Mar 11, 2011	36 Mar 16-Apr 6, 2011 (22 days)	49 Mar 18-Apr 6, 2011 (20 days)

CONCLUSION

In 2012, the estimated damage from a Tokyo Inland Earthquake was reviewed in light of the Great East Japan Earthquake. As a result, the new estimate suggested more serious damage than the previous one. Tokyo Waterworks has also reviewed its conventional earthquake measures, thereby revising the Master Plan and the Earthquake Emergency Response Plan.
In the Master Plan, we newly added the goals in 10 years considering the achievements of the current facility development plan. In many cases, facility development takes a long period of time; thus, it is necessary to steadily implement the project by setting an order of priority on a limited budget.

In the Earthquake Emergency Response Plan, we changed our organizational structure in order to smoothly and flexibly carry out emergency response activities. Also, in 2014, we promoted cooperation with other cities, such as by concluding the MOU on activities by staging-area water operators with the Ibaraki Public Enterprise Bureau. The key to minimize damage is how to develop cooperative relations with other local governments, private businesses and all the citizens in Tokyo.

In this way, we have been making efforts to take earthquake disaster countermeasures from both tangible and intangible perspectives. We will continue to achieve the earthquake-resilient water services in Tokyo by further promoting various measures such as raising awareness related to self-help, co-help, and rescue and assistance by public bodies in times of disaster, along with the infrastructure development from a tangible perspective.

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