Effort of Reinforcing Earthquake-Resistant Joint of Water Distribution Pipes in Tokyo Waterworks

Author: Eiji Oomori
Director for Engineering Section, Asaka Purification Administration Office
1-3-1,Miyato, Asaka City, Saitama Pref., Japan
E-mail omori-eiji@waterworks.metro.tokyo.jp

Abstract

Japan is one of the most earthquake-prone countries in the world. For this reason, the Bureau of Waterworks, Tokyo Metropolitan Government (BWTMG) has almost replaced old cast-iron pipes with the ductile cast-iron pipes made of durable materials. However, large-scale earthquakes in Japan frequently cause a slip of joints for ductile cast-iron pipes. Due to this fact, BWTMG has adopted earthquake-resistant joint pipes with slip preventional function since FY1998, reinforcing pipes with earthquake-resistant joints. In this paper, we report the approach and concept of reinforcing pipes with earthquake-resistant joints promoted by BWTMG.

Keywords

Earthquake-resistant-joint pipes, slip preventional function, seismic reinforcement of supply routes to important facilities, reinforcing earthquake-resistant joint ratio

1. Introduction

In 1898 water utilities in Tokyo started to provide water as modern water service. Since then, water service has expanded with the growth of Japanese economy, supporting the city life of inhabitants and urban activities of Tokyo capital. In particular, water supply demand rapidly increased in the 1960s because of more concentrated industries and population in the metropolitan area along with high economic growth, more diversified lifestyles, and more constructed large buildings. This led to a number of facilities and pipelines built and improved rapidly. After that, water service has been expanded and repeatedly renewed, resulting in serving water to about 13 million users and treating 6.68 million m^3/day at facilities. Also, the total length of water pipes BWTMG extends to about 27,000 km or equivalent to about two thirds of the equator of the earth.

Water service is now an essential utility infrastructure for public activities, whose stable supply is indispensable for the safety and security of people living in Tokyo. It is our responsibility to ensure water supplies during normal times and to the extent possible during an earthquake disaster as well. For this reason, the facilities and pipelines must be appropriately maintained and managed. We must make greater efforts for efficiently maintaining and systematically renewing water distribution pipes because of their extension in length. Also, as Japan is an earthquake-prone country, it is necessary to replace the existing pipelines with those durable during large-scale earthquakes as well.

This paper reports on how BWTMG promotes the development of pipelines with earthquake resistance and its basic strategies.

2. Imminence of the Epicentral Earthquake in Tokyo Capital

The Japanese archipelago is in a place where the four plates of the Pacific plate, the Philippine Sea plate, the North American plate, and the Eurasia plate collide with each other among tens of plates covering the earth. For this reason, multiple plates add complicated forces around Japan, making it as one of the places experiencing the most frequent earthquakes in the world. In fact, Japan has experienced many gigantic earthquakes in the past, including the Great East Japan Earthquake on March 11, 2011(which registered the magnitude of 9.0). Therefore, earthquake relief measures are considered one of the most important priorities.

With the probability of 70%, the Japanese government presumes that a magnitude-7 earthquake will hit the metropolitan area including Tokyo within the next 30 years. Also, a survey conducted by the Metropolitan government assumes that more than 30% of the area will experience water suspension due to the earthquake centered directly under the capital. Particularly, in eastern area of Tokyo, where the ground is weak and vibrates strongly, the ratio of water outage is estimated to record about 80%.

This also presents a pressing issue for the Tokyo Metropolitan Government. BWTMG has a responsibility to ensure water service provision as continuously as possible even in the event of a disaster.

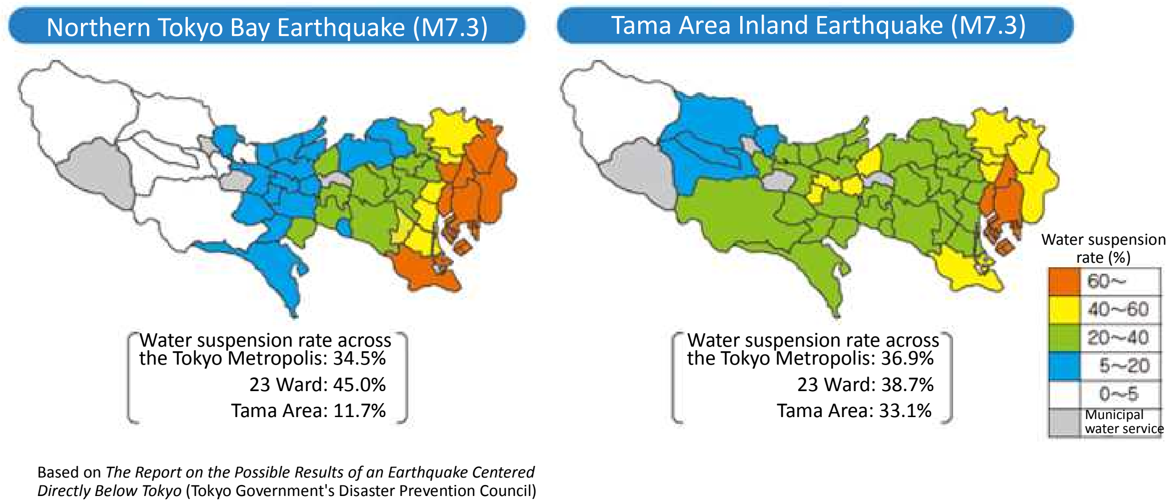

Figure 1 Water Suspension Rates Assumed after a Tokyo Epicentral Earthquake

3. Characteristics of BWTMG Pipelines

In many cases, ductile cast-iron pipes and steel pipes with high strength are commonly used for the main pipelines, because Japan is an earthquake-prone country. BWTMG also uses ductile cast-iron pipes and steel pipes for the material of water pipes, of which ductile cast-iron pipes account for 98%.

BWTMG is replacing old pipelines with little strength as planned to ensure a necessary amount of clean tap water delivered under an appropriate pressure. BWTMG has started to adopt ductile cast-iron pipes since around the 1960s, and now has already almost completed the replacement of cast-iron pipes with the ductile cast-iron pipes.

Ductile cast-iron pipes have a spherical shape of precipitated graphite in the cast iron structure, which ensures excellent toughness and high strength due to the continuity of the steel basement. These pipes are characterized by their high earthquake resistance at the time of an earthquake.

BWTMG had used cast-iron pipes in a flake graphite shape and with little strength before the 1960s; however, the cast iron pipe was weak in strength, causing leakage due to cracks. Also, it caused turbidity because there was no lining inside. Also, from the 1960s to early 1970s ductile cast-iron pipes were adopted, but heterogeneous pipes using cast iron pipes were also used.

Thus, in 2002 BWTMG launched a project aimed at replacing old pipelines such as cast-iron pipes and the 1960s-installed ductile cast-iron pipes, and has worked to eliminate them. As a result, the project to switch to high-strength ductile cast-iron pipes durable against earthquakes was almost completed by 2008.

	Cast-iron pipe	Ductile cast-iron pipe
Material	Flake-shaped graphite	Spherical shaped graphite
Property	As bare metal continuity is not provided due to the shape of graphite, cracks tend to occur.	As bare metal continuity is provided due to the shape of graphite, it is durable and hard to crack.
Strength (tensile strength)	High-grade cast iron: 245 N/mm^2 or more Cast iron: 122 N/mm^2 or more	420 N/mm^2 or more

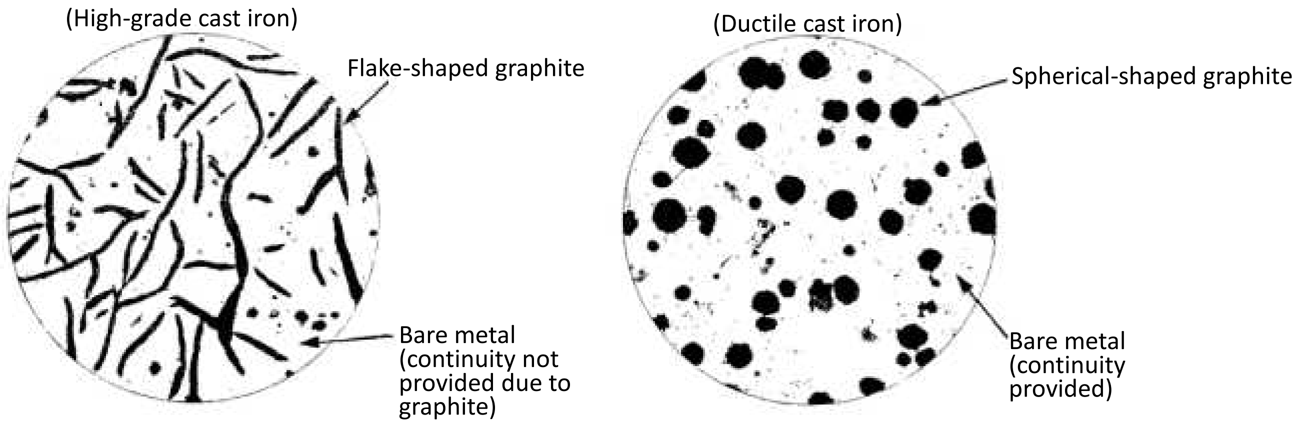

Figure 2 Comparison between Cast Iron and Ductile Cast-iron Pipes

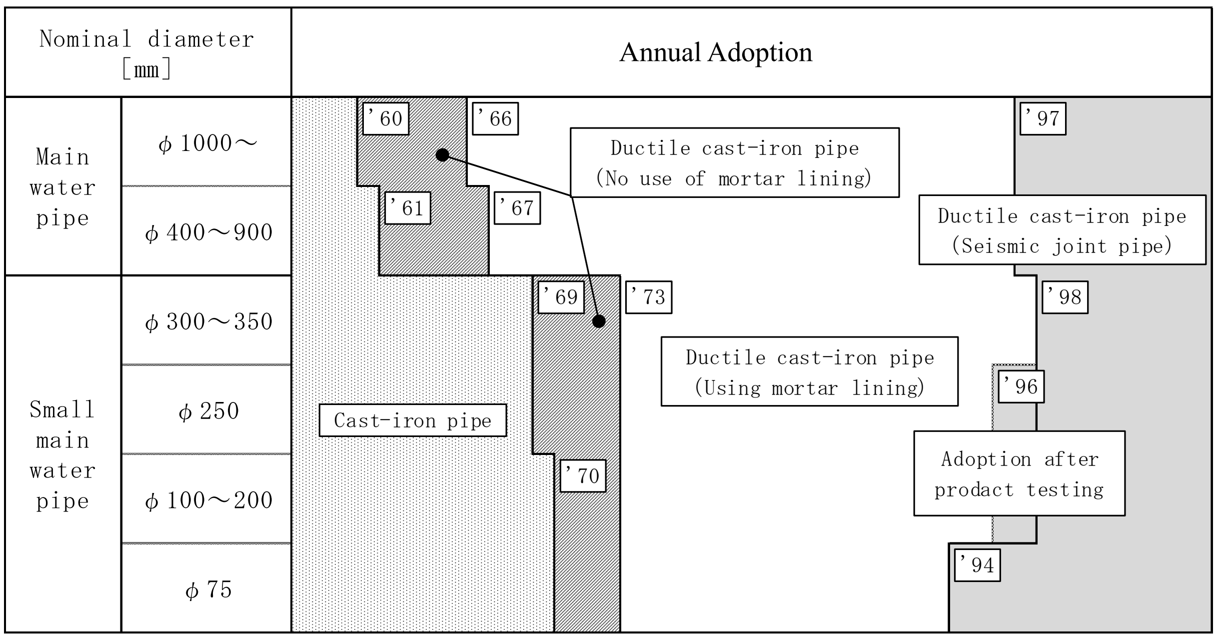

Table 1 Adoption process of waterpipes in BWTMG

4. Adoption of earthquake-resistant joint pipes with excellent seismic performance

Although ductile-cast iron pipes have high tolerance against earthquakes, numerous pull-out accidents in joint parts have occurred in large-scale earthquakes such as the Great Hanshin-Awaji Earthquake that registered the magnitude of 7.3(1995) and the Great East Japan Earthquake(2011). In fact, the Great Hanshin-Awaji Earthquake damaged 304 pipes themselves, and 960 joint parts, of which 936 cases were caused by pull-out accidents, accounting for 97.5% of the joint damages. To prevent such pull-out accidents, existing pipes were improved and earthquake-resistant joint pipes were born.

The most important feature of earthquake-resistant joint pipes is the pull-out prevention function in joint parts, where the lock ring set firmly on the pipe hits the projection provided at the insertion opening. Disengagement prevention force at the joint part is equivalent to 3D kN (D: pipe nominal diameter). After the Great East Japan Earthquake, damages were found in 0.06 places per kilometer in ductile cast-iron pipes without the pull-out prevention function and 0.22 places per kilometer in hard vinyl chloride pipes. On the other hand, damages did not occur in earthquake-resistant joint pipes, which proves their superiority.

While imminence of an earthquake under Tokyo Metropolitan area has been pointed out, BWTMG recognizes earthquake disaster countermeasures as one of the most important tasks. Furthermore, it launched pilot construction of earthquake resistant joint pipes with slip preventional function since 1996 and entirely adopted them since FY1998, based on the lessons learned from the Hanshin-Awaji Earthquake disaster in 1995, where numerous slipping-off accidents occurred. The following years also saw an improvement in the joint parts, including a new earthquake-resistant joint with excellent workability and long life which has been adopted for a pipe with an opening diameter of 250 mm since 2014.

In fact, in the Great East Japan Earthquake, damages were found in 22 pipelines in Tokyo, of which 19 were caused due to pull-out accidents in joint parts. None of them were earthquake resistant joints. Based on the fact that damages on earthquake-resistant joints after an earthquake have not been reported in Japan, it is demonstrated that the adoption of earthquake-resistant joints was a correct decision.

Photo 1 Damage on a Water Pipe in the Great East Japan Earthquake

Damaged parts	Number of cases	Component ratio [%]
Damage of pipe	304	17.3
Damage of joint parts	960	54.6
Falling out	936	(53.3)
Others	24	(1.3)
Accessory equipment	493	28.1
Total	1,757	100.0

Table 2 Damage situation of Han-shin Awaji Earthquake disaster
(Source : "Overview of water pipelines damage of Han-shin Awaji Earthquake disaster" edited by Japan Waterworks Association (Public Interest Incorporated Association))

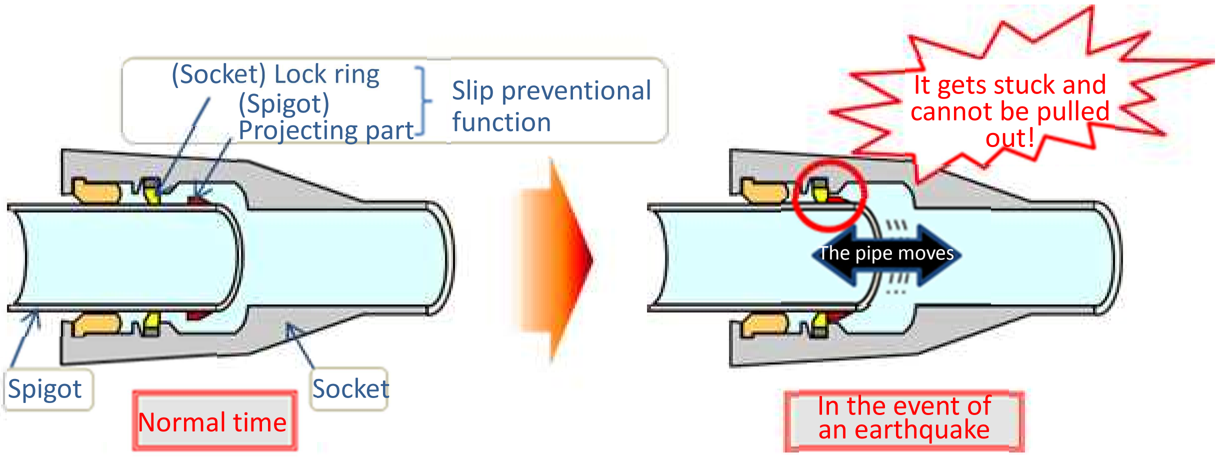

Figure 3 Function of Earthquake-resistance Joint (Image)

Figure 4 Structure of Earthquake-resistant Joint (NS Joint)

5. Promoting effective earthquake-resistant joints

The Great East Japan Earthquake caused many water failure cases in Tohoku district, close to the epicenter, where water pipes were pulled out at the joints. As a result, many people were forced to live in inconvenient living conditions without enough water of domestic use, including for toilets and baths. This fact again highlights the importance of supplying water continuously at the time of disaster. Also, people who were unable to return home gathered at major stations due to paralyzed transportation system in the metropolitan area, which demonstrates the importance to secure water to those facilities.

Based on these facts, it is necessary to promptly reinforce earthquake-resistant joints of water distribution pipes to secure water supply at the time of disaster. On the other hand, as the total length of water pipes in Metropolitan area is approx. 27,000km, it would require substantial time and cost of completing all of the reinforcement.

Therefore, we prioritize facilities and water supply routes to them in reinforcing the earthquake-resistant joints in order to mitigate the damage of water failure and realize the effect of the project quickly.

1) How to prioritize facilities

Tokyo, the capital of Japan, has the central functions of politics, administration, and economy with the dense population and buildings. The "Tokyo Metropolitan Earthquake Disaster Reduction Strategy" published by the government, points out that, water utility operators shall take a role in multiplexing and reinforcing quake-resistant facilities that serve water to the capital's central agencies, enhancing quake-resistant supply lines to critical facilities involving human lives (e.g., emergency medical institutions), and multiplexing and decentralization of water supply services.

For this reason, 365 facilities were designated as priority facilities, including administrative organizations such as the national government, banks, emergency medical institutions saving a life in disaster situations, with a plan for quake-proof reinforcement by the year 2019.

Although since 2013 the government has reviewed the area with a high possibility of liquefaction damage, an extensively wider area was affected in the wake of the Great East Japan Earthquake. Therefore, priority is given to areas where large liquefaction damage is expected to cause, in order to mitigate the damage of water failure and reinforce earthquake-resistant joints.

Furthermore, during the Great East Japan Earthquake, major railway stations were full of people who were unable to return home to stay, and evacuation centers for rescue operations also suffered from water failure. Thus, our priority list of facilities for reinforcing earthquake-resistant joints included major railway stations and schools which become as evacuation center. In particular, we plan to prioritize major railway stations exceeding 200 thousand passengers a day, which is the criteria of critical traffic node, and junior high schools which are scattered in a wide area with high capacity among evacuation centers. We also plan to complete the reinforcement for the Olympic and Paralympic Games Tokyo 2020 by FY2019.

Henceforth, with Olympic and Paralympic Games Tokyo 2020 in the scope, we plan to reinforce major stadiums and arenas for the Olympic and Paralympic Games Tokyo 2020 by FY2019 with an aim to ensure more stable water supply service.

2) Establishing supply routes to priority facilities

BWTMG defines that a main water pipe has a diameter of 400 mm or more that forms the structure of water service, whereas a small water pipe has a diameter of 350 mm or less that is used for water service to a district. Also, each pipe is not used for a single system of water service but forms a network collectively. In particular, small water pipes form a dense network in a district. For this reason, we analyzed the supply of tap water to facilities that should be prioritized using pipe network analysis and other methods. The result demonstrated that, even if the main water pipe is damaged, by using the network of main water pipes water pressure for small water pipes will be assured and tap water service to priority facilities will be available.

Therefore, we defined the small water pipes that supply water to priority facilities as the "supply route," focusing and targeting on the replacement.

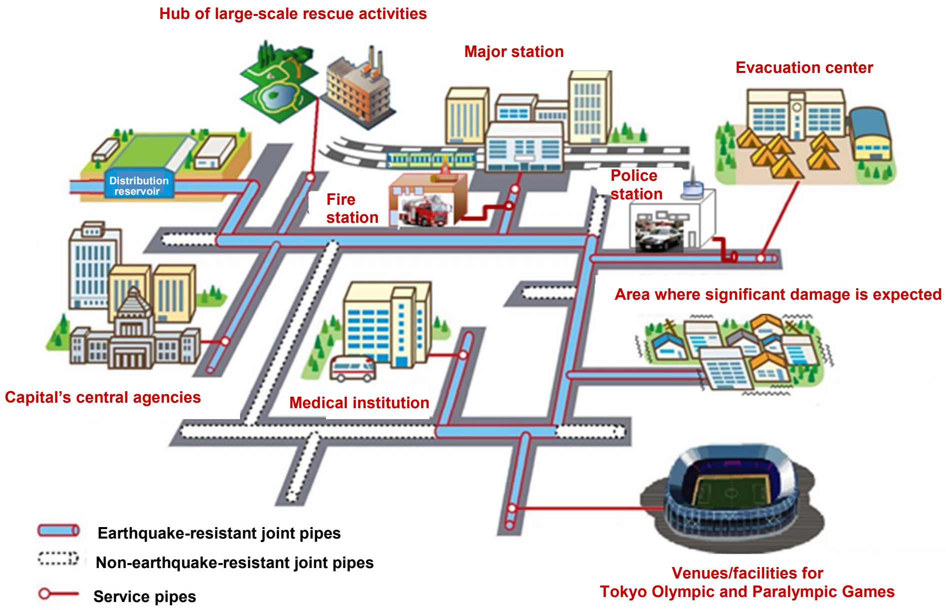

Figure 5 Reinforcing the supply route to important facilities with earthquake-resistant joints (image)

6. Conclusion

Water pipes in Metropolitan area stretch in a finely meshed pattern, extending as long as 27,000km. It is important to advance the work systematically and effectively to replace the extended water distribution pipes which are spread in Tokyo Metropolitan nets.

We have a plan to increase the ratio of earthquake-resistant joints up to 61% in 2025 by steadily reinforcing earthquake-resistant joints. These efforts will shorten restoration period at the time of disaster (assumption) from 30 days to 16 days and to dramatically improve the reliability of water supply for important facilities such as Capital's central agencies and evacuation centers.

Replacement to earthquake-resistant joint pipes is the solution to all cities which have the large of risk earthquakes. Moreover, reinforcement with earthquake-resistant joints does not only contribute a lot to water supply during the earthquake disaster, but also to prevention of secondary damage and creation of hygiene environment after an earthquake disaster; it is the measure which should be actively advanced in the area where numerous people are expected to gather.

BWTMG continues the reinforcement of pipe joints against earthquakes steadily, in order to support the city function in case of disaster.