Prevention of Leakage in Tokyo

2016

東京都水道局
Bureau of Waterworks, Tokyo Metropolitan Government
Contents

1 Outline of leakage prevention ................................................................. 1
   (1) Present situation ................................................................. 1
   (2) Necessity of leakage prevention ............................................... 2

2 Countermeasure of leakage prevention .................................................... 4
   (1) System of leakage prevention measures .................................... 4
      A Planned replacement of water pipes and improvement of materials for pipes ........ 4
           (A) Distribution pipe replacement (aged pipes, early ductile iron pipes, etc.) ......... 5
           (B) Integration of service pipes under the private road and replacement with submains .... 6
           (C) Reinforcement of seismic resistance of large-diameter service pipes ................. 7
           (D) Reinforcement of seismic resistance of service pipes in shelters and other facilities .... 7
           (E) Material improvement work of service pipes (Service pipe replacement) ............. 8
      B Early detection and repair work for leakage .................................... 10
           (A) Planned work ............................................................. 10
           a Patrol work (Circulating checking) ...................................... 11
           b Leakage volume measurement work ...................................... 11
           c Leakage investigation and measurement work ............................. 11
           (B) Mobile work ............................................................. 12
      C Secure high level of leakage prevention technologies ......................... 13
           (A) Efforts at Training and Technical Development Center ............................. 13
           (B) Accreditation of Tokyo waterworks technology experts and super plumbers ........ 14
   (2) Leakage prevention construction system .......................................... 14

3 The method of leakage investigation ....................................................... 15
   (1) Minimum night flow measurement method ...................................... 15
   (2) Acoustic leakage sound detection method ...................................... 16
   (3) Correlative leakage detection method ........................................... 18
   (4) Time integral type leakage detector ............................................. 19
   (5) Transmission-type leakage detector .............................................. 19
   (6) Other methods ................................................................. 20
4 Problems and the future of leakage prevention ........................................... 21

5 References ........................................................................................................ 22
Reference -1........................................................................................................ 23
  Distribution volume analysis in FY 2015
Reference -2........................................................................................................ 24
  Trends in total distribution volume, leakage volume and rate from FY 1996 to 2015
Reference -3........................................................................................................ 25
  Specifications of leakage cases in FY 2015
Reference -4........................................................................................................ 26
  Trends in number of each kind of repair works from FY 1996 to 2015
Reference -5........................................................................................................ 27
  Trends in percentages of ductile cast iron pipes in distribution pipes,
  stainless steel pipes in service pipes, leakage repair cases, leakage rate from FY 1996 to 2015
Reference -6........................................................................................................ 28
  Technology and equipment related to leakage prevention that were co-developed
  by the Tokyo Metropolitan Government Waterworks and private companies
Reference -7........................................................................................................ 29
  Organization of leakage prevention
Reference -8 ........................................................................................................ 30
  Glossary of Terms used in “Prevention of Leakage in Tokyo”
1 Outline of leakage prevention

(1) Present situation

The rivers flowing in this area, namely Tone, Ara, Tama river systems are the main source of water used in the Tokyo Metropolitan area.

We collect raw water from these rivers, process purification at water plants such as sedimentation, filtration and disinfection, convey into underground water pipes with pressure, then supply as tap water to customers. In addition, some water purification plants introduced advanced water purification systems though ozonation and biological activated carbon absorption treatment. After purification treatment, we supply purified (tap water) to customers through underground water pipes with pressure. This is the “leakage of water”.

In FY1996 – two decades ago – the annual leakage was 150 million m³ and the leakage rate 8.9%. Leakage decreased to 50 million m³ in FY2015. And leakage rate accounted for 3.2% against the annual distribution amount of 1,530 billion m³ (Fig.1, Reference-1 and 2).

Most leakages occur due to cracks and corrosion caused by aged deterioration of service pipes that are owned by our customers and distribution pipes. The total cases of leakage repair work in FY 2015 recorded around 8,315, and around 97% of which were at service pipes, and the remaining around 3% were at distribution pipes (Reference-3).

Leakage is classified into two types by its form; “surface leakage” flows out on the ground and “underground leakage” leaks out underground without appearing on the surface.

Basically, leakages occurring above the ground are dealt with by mobile work -repair it within the day- and those occurring underground by planned work -systematically conduct leakage surveys and repair-. The Figure 2 shows the ratio of mobile work to planned one.

There were 7,881 repairs by mobile work and 434 by planned one in the fiscal year 2015(Reference-4).

Underground leakage is invisible and thus practically unnoticeable; therefore, in many cases water has been leaking for a long period of time. Therefore, unless we identify and repair leakage systematically, valuable water will continue to leak and large accidents many occur by sagging road.

Although leakages are repaired as soon as they are found, On the other hand, the new leakage increases gradually in accordance with time. This is referred to as the “repetition phenomenon” of leakage (Fig. 3). As it is important to develop leakage prevention measures by taking this repetition phenomenon into consideration, we try to collect various data on leakage as many as possible in order to get an understanding of the repetition phenomenon.

![Fig.1 Annual distribution volume and leakage volume in FY 2015](image1)

![Fig.2 Comparison between Mobile work and Planned work (Cases)](image2)
(2) Necessity of leakage prevention

Tokyo currently possesses water resources that supply a volume of 6.3 million m³ per day. Some of the resources have problems: e.g. Sagami River from which water is diverted to Tokyo through yearly agreements with Kanagawa Prefecture and Kawasaki City, which may affect the water situation in Kanagawa Prefecture in terms of stability of water intake.

Furthermore, in the Tone River system which is Tokyo’s main water resource, the degree of safety against drought is low currently, as the amount of water which can be stably supplied from dams and other facilities has been decreased compared to the initial plan due to the rainfall conditions in recent years.

In light of the situation, Tokyo as the capital of Japan needs to continue promoting efficient use of water and leakage prevention measures as ever while making efforts to secure stable water resources, so that it can secure water supply even at the time of severe water shortage.

The distribution pipes consist of the distribution mains with a bore diameter of from 400 to 2,700 mm and distribution submains with a bore diameter of from 50 to 350 mm that branch out from the mains and directly connect to the service pipes. Water distribution pipes installed within Tokyo totals up to about 27,000 kilometers long as of FY2015, which is equivalent to two-thirds the length of the earth’s circumference.

Water pipes embedded underground are constantly subject to a danger of leakage, and when leakage occurs, these pipes pose risks of factors like secondary disasters including poor water flow, sagging road, inundation and so on.

Measures against leakage enable us to prevent secondary disasters such as sagging road as well as leakages which are equivalent to the amount of water to be obtained by developing a new water resource such as dam.

We at Tokyo Waterworks have actively taken measures against leakage as part of our major policies
Fig. 4-1  Scene of leakage

Fig. 4-2  Corrosion and leakage of iron pipes
2 Countermeasure of leakage prevention

(1) System of leakage prevention measures
The leakage control measures that we take in Tokyo are classified as follows.

- Planned replacement of water pipes and improvement of materials for pipes
  - Planned replacement and improvement of the quality of pipe materials can reduce the remaining leakage amount as well as forestall leakage and prevent “repetition phenomenon” of leakage. Thus, such projects are important and effective to implement leakage prevention works.
  - Followings are the major solutions.

A Planned replacement of water pipes and improvement of materials for pipes
  - Planned replacement and improvement of the quality of pipe materials can reduce the remaining leakage amount as well as forestall leakage and prevent “repetition phenomenon” of leakage. Thus, such projects are important and effective to implement leakage prevention works.
  - Followings are the major solutions.
(A) Distribution pipe replacement (aged pipes, early ductile iron pipes, etc.)

As part of earthquake disaster countermeasures, we have been replacing the following distribution pipes with those with earthquake-resistant joints.

a. Aged pipes (cast iron pipes without inner lining and aged steel pipes installed many years ago).
b. Early ductile iron pipes (pipes used for pipelines consisting of a mixture of straight pipes made of ductile cast iron and special fittings made of high-grade cast iron without inner lining).
c. Externally-uncoated pipes installed in highly-corrosive soft ground in areas such as the eastern part of the 23 wards.
d. Pipes without earthquake-resistant joints laid in areas where severe water outage is anticipated at the time of disaster.

In particular, the priority in such replacement works is placed on water supply routes to important facilities including the Capital’s central agencies, emergency medical institutions, shelters and main stations.

Fig.6 Micrograph of cast iron

High-grade cast iron
Ductile cast iron

Fig.7 Earthquake-resistant joints…Structure that does not cause joint detachment during the earthquake
(Left: Normal Time , Right: Earthquake Time )
(B) Integration of service pipes under the private road and replacement with submains

Beneath private roads are congested with many service pipes, causing leakage due to aging and corrosions. In this regard, we have been making efforts to prevent leakages and improve earthquake resistance of service pipes under private roads through the consolidation of the system of those pipes by installing submains and replacing the existing pipes with stainless-steel ones.

In addition, by installing a drain having the same function as a fire hydrant at the end of submain water pipes, etc., it can be utilized for emergency water supply at the time of earthquake disaster and for initial fire extinguishing at the time of fire.

\[\text{a Since FY 1994} \quad \text{private roads where more than three service pipes were installed}\]
\[\text{b Since FY 2007} \quad \text{private roads where more than three service pipes were installed or the ones which have more than 15 water meters}\]
\[\text{c Since FY 2009} \quad \text{private roads which have more than 15 water meters or the ones which have more than 10 water meters}\]
\[\text{d Since FY 2012} \quad \text{private roads with three or more water meters.}\]

We have been also trying to further improve earthquake resistance of service pipes under private roads by replacing PVC pipes under private roads with two or less water meters with stainless steel pipes since FY2012.

![Fig.8 Integration of service pipes under the private road and replacement with submains](image-url)
(C) Reinforcement of seismic resistance of large-diameter service pipes

To react on aged deterioration on large-diameter service pipes with the diameter of 75 mm or more, we have been working on earthquake resistant reinforcement by replacing them with earthquake resistant joint pipes since FY1998 in addition to planned (routine) replacement of distribution pipes and leakage repair works of service pipes. Since FY2007, we have expanded the scope of pipes for the systematic enhancement of earthquake resistance to large-diameter service pipes, from branching part of service pipes to (in principle) the first stop cock, which remain unreinforced against earthquake on the routes where replacement of distribution pipes had completed before FY1998.

The project was completed in FY2014.

(D) Reinforcement of seismic resistance of service pipes in shelters and other facilities

At the time of earthquake disaster, it is necessary to ensure supply of water to shelters where many people gather as their temporary living places and main stations where many people having difficulty in returning home, etc. gather. Therefore, in order to secure water supply to the shelters, we have been working on earthquake resistance enhancement on service pipes of facilities designated as shelters, and not only the part between the branching part of service pipes to water meters are subject for the enhancement work.
(E) Material improvement work of service pipes (Service pipes replacement)

Most of leakage cases occur in regard to old and corroded pipes (Reference-3), and they account for about 97% of the total leakage repair cases.

Consequently, in order to reduce leakages, it is extremely effective to prevent them that occur to service pipes. In Tokyo, we used to use lead for service pipes which is easy to constructing. But, lead has been a major cause of leakages due to its low intensity and corrosion-prone characteristics.

Therefore, since FY 1980 we have abandoned the use of lead pipes for service pipes to be newly installed under public roads, and adopted stainless steel pipes that have superior strength and corrosion resistance.

And then, since FY 1982, as a project of Tokyo Waterworks aiming for leakage reduction, we have replaced the following service pipes with stainless ones:

a Since FY1982: execution of replacement work of lead service pipes branched from a route of which the aged distribution pipes and frequently leaking distribution pipes were to be replaced with ductile cast iron pipes

b Since FY1983: execution of replacement work of lead service pipes branched from submain distribution pipes which have already been ductile cast iron pipes within the areas with much leakage amount selected by planning activities

c Since FY1984: execution of replacement work of lead service pipes branched from submain distribution pipes at every opportunity of construction work related to submain distribution pipes

d Since FY 1985: execution of replacement work of heavily corroded lead service pipes at the occasions of repairing leakages

In 1992, the stricter water quality standards for lead were introduced (water quality standard values 0.05mg/l), together with the long-term target for 2002 (water quality standard values 0.01mg/l).

Therefore, use of lead service pipes was banned except for repairing leakages in 1992. In 1995, we have entirely banned the use of lead pipes. In 1998, we adopted corrugated stainless steel ones that have excellent workability and earthquake resistance and also expanded the scope of material improvement which used to be from branching part of service pipes from submain distribution pipe to the first stop cock within the residential land to water meters within residential land. In addition, when a part of service pipes are lead service pipes, we have replaced them with PVC pipes in addition to replacing them with stainless steel pipes.

In 2000, we formulated an elimination plan of lead service pipes laid to water meters installed within residential land, and we were able to nearly complete the replacement of lead service pipes under private roads or leading to water meters within residential land by FY 2006.

In addition, there are a few lead pipes remaining unreplaced under the replacement project until now under private roads and within residential land. We have checked the remaining lead pipes again in the course of the planned activities in and after 2007 and replaced them every time discovered.
Fig. 9  Leakage on lead pipes

Fig. 10  Corrugated stainless steel
Early detection and repair work for leakage

Water leaked from underground pipes will eventually flow out to the ground. In order to minimize the damage caused by leakage, it is important to detect leakage early and repair it at an early stage. Therefore, Tokyo Waterworks implements planned and mobile operations as leakage prevention works, and is taking measures to prevent leakage day and night.

And, in order to make good use of limited water resources, Bureau of Waterworks repairs leakages in service pipes installed up to water meters within residential areas without charge except in special circumstances.

(A) Planned work

In planned work, submain pipes buried in the form of a net are divided into blocks by a certain length, and research is conducted for each block in a planned manner. The research includes patrol work, leakage volume measurement work and leakage investigation and measurement work.

In 23 wards, we have been working on planned operations since FY1913. Planned leakage survey is conducted mainly by staff members of Tokyo Waterworks and the majority of repair works of discovered leakage are undertaken by contractors of construction contracts.

Also, leakage survey in Tama area (26 cities/towns) had been conducted by each respective city/town. However, nowadays, as waterworks was integrated under the management of Tokyo Metropolitan Government, patrol survey (circulating checking) and leakage volume measurement works are conducted by Tokyo Suido Services Co., Ltd., one of the administrative organizations, and the majority repair works of discovered leakage are undertaken by contractors of construction contracts.
a  Patrol work (Circulating checking)

In the patrol works are individual investigation work that determines leakage with leakage sound detection bar (Fig.16) attached to water meter on every home, acoustic investigation work that is conducted during the night when there is less traffic to identify point of leakage with electronic leakage detector (Fig.17) from the road surface etc.

To determine the blocks to patrol, we take previous work history, leakage occurrence in the previous year, and residual number of lead service pipes into consideration.

In addition to that, we consign administrative bodies (TSS Tokyo Water Co., Ltd.) to conduct such individual investigation with time integral type leakage detector (Fig.21) replacing leakage sound detection bar on some blocks since FY2003.

b  Leakage volume measurement work

To estimate total leakage volume within Tokyo municipal and understand the leakage trend, we conduct leakage volume measurement works. In order to identify the more accurate amount of leakage an urban area which is active around the clock, we need to measure the leakage volume during the night hours when almost no one uses water. (3(1) Minimum night flow measurement method) As a result of the theoretical analysis based on the modeling of the water usage state and the result of the dynamic simulation taking the number of households and pipe network characteristics into consideration, since the number of taps that can be measured is limited to 300 to 400, we measure the minimum flow (leakage amount) at night by narrowing down the scope number of target taps within one block. By estimating leakage volume within a certain block, we are able to make total assumption of leakage volume within municipal Tokyo. Together with leakage investigation and measurement work that has been put into practice since FY 2010, we will put such works to improve our leakage prevention plan.

For the leakage volume measurement work, we consign administrative bodies (TSS Tokyo Water Co., Ltd.) since FY2005 for some blocks.

c  Leakage investigation and measurement work

To minimize water outage during the earthquake disaster and fast react on to recover the facilities, it is important to ensure the water flow from main pipes to submain pipes and it is essential to ensure the function of exhaust valves of main pipes. On that basis, it is necessary to avoid using quake-damaged pipelines (distribution submains) to secure operable water-supply routes as early as possible and then to expand areas to which water can be supplied.

This leakage investigation and measurement work is a practical series of works that conduct functional measurement of water valves required to secure water route after securing the safety of exhaust valve on distribution main, assuming the channel where leakage volume are high as damaged points, then recover/expand the service area sequentially. We conduct investigation on the whole water flow area based on the volume of leakage, and then operate repair works on leakage points one by one when found.

Such data will also be partially facilitated to leakage volume measurement work.
Mobile work

A work for repairing an aboveground leakage found by report of a customer, by patrol of staff or by other means is called mobile work.

In 23 wards, staff members and contractors are on call 24 hours a day to respond to leakage at branch offices (6 branch offices: 14 offices) that are field management offices of Tokyo Waterworks.

In Tama area (26 cities/towns), staff members of 4 management offices that are field management offices of Tokyo Waterworks, Tokyo Suido Services Co., Ltd. and our contractors are on call 24 hours a day, in which we operate our services, are ready 24 hours a day to respond to leakage.

C Secure high level of leakage prevention technologies

With background that we need to “maintain low rate of leakage” and “mass retirement of veteran workers”, our important efforts include trainings for transferring techniques related to leakage, engineering development, and human resource development, for the purpose of efficient and secure measures for leakage prevention.

(A) Efforts at Training and Technical Development Center

At the Training and Technical Development Center established in 2005, training division and development division work together to ensure the succession of technologies, enhance the capabilities of the staff members and to respond appropriately to diverse needs so that we can continue to provide a steady supply of safe and better-tasting water to customers into the future.

Its pipeline experiment facility has facilities for experiments and verification in order to resolve problems mainly concerning pipelines, which are equipped with the environment that is similar to the actual one.

These facilities are utilized for trainings for staff of neighboring and overseas waterworks companies as well as those of the Bureau of Waterworks.

In addition, for the list of items of leakage prevention related equipment that were co-developed by the Bureau of Waterworks and private companies, please see Reference-6.
Fig.13  Technical training for leakage prevention work

(B)  Accreditation of Tokyo waterworks technology experts and super plumbers

In various fields not limited to leakage prevention, many veteran staff with technology backed up with experience approach to the time of retirement, which is a big issue in terms of succession of technology. Therefore we founded “Tokyo Water Workers Technology Experts Program”, in which veteran workers provide training junior fellows as leaders, and offer instruction courses on leakage prevention technologies at Training and Technical Development Center.

Furthermore we enhance inheritance of leakage prevention technologies by visualizing implicit knowledge that has been cultivated/built and uploaded to shared network, enabling browse as-needed basis.

In addition, especially excellent plumbers are accredited as “super plumbers” among the contractors of distribution pipe construction in order to maintain and succession technology, as well as to enhance the level of the entire plumbing technology and motivation.

(2)  Leakage prevention construction system

Bureau of Waterworks adopt computerized system for tally records of repair work on leakage (cause and detail of actual repair work) and calculate paid amount for such works.

Current systems process the followings.

a  Reception of leakage prevention measures.

b  Calculation of construction cost for leakage repair, material improvements, etc.

c  Summarization of the records of leakage causes and contents of the work done.

The data obtained through electronic processing are effectively used for budget-making of the next fiscal year and drawing out long-term plans, selection of planned work blocks, and calculation of leakage volume, etc., contributing largely to the execution of effective preventive measures against leakage.
3 The method of leakage investigation

Currently we have mainly two types leakage investigations; based on maintenance status of pipelines and past history of leakage, select pipelines necessary to be investigated and conduct leakage investigation (minimum night flow measurement method). Another method is to determine the leakage by the sound and identify the location (acoustic leakage sound detection method, correlative leakage detection method, and method using the time integral type leakage detector).

(1) Minimum night flow measurement method

Minimum night flow measurement method is a leakage investigation method that has been developed by taking the note of midnight idle time (unoccupied hours) of water usage in a certain block.

First, gate valves surrounding the block to be investigated are closed and the water from other blocks is shut down. Then the water is sent into the block through minimum flow measuring equipment set in the block water meter and the flow rate is measured. The minimum flow rate measured (The quantity of flow indicated in spite of a situation where nobody is expected to use water) during the vacant period is considered to be the leakage.

For measurement we use high prevision minimum flow meter joint-developed by the Bureau and a private company.

Fig.14 Theory of minimum night flow measurement method
(2) Acoustic leakage sound detection method

In the acoustic leakage sound detection method, the leakage sound is detected by a leakage sound detection bar or an electronic leakage detector.

The metal tip of the leakage sound detection bar is pressed against the water meter, gate valve or fire hydrant. An inspector then presses an ear against a vibration diaphragm set at the other end of the rod, and listens for transmitted sound of the leakage. The leakage sound detection bar can only tell whether the leakage is present in the neighborhood, and it is difficult to detect the position of leakage.

Using an electronic leakage detector, a detector (pickup) to convert the leakage sound into an electrical signal is placed on the ground, and the sound transmitted through the ground is amplified and heard through headphones. As the detector (pickup) is moved in order, the leakage sound is heard most strongly directly above the point of leakage and thus the position of leakage can be detected.

Among the sounds detected by an leakage sound detection bar or an electronic leakage detector, there are sounds quite similar to the leakage sound (pseudo leakage sounds). For that reason, skilled technique is required to discern leakage sounds.
Fig. 17  Electronic leakage detector

Fig. 18  Acoustic leakage sound detection method
(3) Correlative leakage detection method

In the correlation method, the position of leakage is detected by using a correlation leakage detection method (correlative leakage detector, sensor, amplifier, wireless transmitter, etc.).

Firstly we place sensors at two points (where exposed ground surface i.e. gate valve and fire hydrant), then obtain the leakage noise propagation time difference to both sensors with correlative leakage detector. The position of leakage is calculated by the time lag, distance between sensors, and velocity of leaking sound transmitting through the pipe.

Correlation leakage detection method has a benefit that enables investigation regardless of noise of cities and depth of pipes buried, because it directly detects the noise of leakage from the pipes.

The correlative leakage detection method was jointly developed by the Bureau of Waterworks and private industry.

![Diagram of correlation leakage detection method](image)

La = (L – Tm • C) / 2

La : Leakage noise propagation time difference
Lm : Leakage noise propagation time difference
C : Noise velocity on the pipe
L : Distance between A and B

Fig.19 Theory of the correlative leakage detection method

Fig.20 Correlation leakage detector
(4) Time integral type leakage detector

Time integral type leakage detector is the device that identifies the leakage by utilizing the nature that the leakage noise has the continuity. This device measures the noise to be transmitted for a certain period of time (1 second up to 5 seconds) by attaching the sensor to the exposure points of service pipes within individual meter box.

It has excellent characteristics such as being largely unaffected by intermittent usage sound of the waterworks or traffic noise transmitted through the ground, and not requiring skill to operate.

The time integral type leakage detector was jointly developed by the Burean of Waterworks and private industry.

(5) Transmission-type leakage detector

The transmission-type leakage detector is the equipment used to detect leakage in a pipe. Chemically inert helium gas mixed with water or air is injected into the pipe and the detector is used to detect the helium gas leaked from the pipe and seeped through the ground.

This type of method allows to detect very small amount of leakage or leakage in Main pipes such as main distribution pipes buried deep underground since it is not based on the leakage sound as it is necessary with the acoustic leakage sound detection method or the correlative leakage detection method.

The equipment used for the transmission-type leakage detector was co-developed by the and private organizations.
(6) Other methods

Leakage investigation requires not only the technologies to identify the leakage but also those to detect the position of laid pipes or to test water quality to determine whether leaking water is tap water.

Metal pipe detector and Water hammer Generator are used to detect the pipe location.

To identify whether such water is tap water, we facilitate easy method such as water temperature gauge, residual chlorine analyzer, pH meter, and conductivity detector, or precise method determining inclusion of trihalomethane.
Problems and the future of leakage prevention

Water resources are becoming increasingly precious as there is concern over streamflow reduction and increased risk of drought due to considerable snowfall reduction, early start of snowmelt season and increase in the number of dry days resulting from climate change and global warming.

Planned dam construction in the Tone River system, which is Tokyo’s major water source, is as yet incomplete, which along with rainfall levels in recent years, has led to lower Actual water supply capacity of dams than originally planned and has also contributed to the low level of safety with respect to drought.

Leakage prevention measures are of paramount importance because they lead to the effective utilization of valuable water resources and to the avoidance of secondary disasters such as road cave-ins caused by leakage. Furthermore, the measures lead to the reduction of energy used and carbon-dioxide emissions in the process of supplying water - water intake, water purification, water transmission/distribution -, hence contributing to the prevention of global warming.

As for these measures against leakage, 13 cities (including Tokyo, the host city, Seoul, Los Angeles and New York) agreed to make efforts to promote such measures and provide technical information at the C40 Tokyo Conference on Climate Change held in October 2008. So, the importance of those measures has now been recognized in the world.

Amid growing expectations for Japan’s technologies in order to tackle the global water problems, Tokyo Metropolitan Government has made a commitment, under the “Tokyo Waterworks Management Plan 2016” as adopted in February 2016, to cooperation in human resources development and business operations of domestic water suppliers by means of utilizing high-quality water engineering and operational know-how, in addition to our preceding efforts in international cooperation such as acceptance of oversea trainees and oversea dispatch of our staff.

The rate of leakage in Tokyo is 3.2% as of FY 2015, which indicates the outcome of the efforts that have been taken by the Bureau for leakage prevention as a major policy issue. This rate in Tokyo stands at an exceptionally high level, even in comparison with those in other cities of the same scale. We are trying to aim for keeping the leakage rate 3%.

In this respect, Tokyo Metropolitan Government’s efforts received acclaim at the 2012 International Water Association (IWA) Project Innovation Awards (PIA) in that our leakage prevention measures were significantly conducive to enhance operational efficiency in energy saving as well as efficient use of valuable water resources. Consequently, we received East Asia Awards (July 2012) and Global Honour Awards (September 2012).

We will continue to actively promote its technologies and know-how both at home and abroad, and pass them on to the next generation.

We will also keep the current low-leakage rate by utilizing all of our accumulated technologies.
5 Reference
Reference-1  Distribution volume analysis in FY 2015

<table>
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<th>Component</th>
<th>Water Volume (m³/year)</th>
<th>Component Rate (%)</th>
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<td>Effective</td>
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<td>Account for</td>
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<td>Charged</td>
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<td>Deduced consumption by settlement</td>
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Reference-2  Trends in total distribution, leakage volume and rate from FY 1996 to FY 2015

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<tr>
<th>Year</th>
<th>Distribution vol (10^6m^3)</th>
<th>Leakage vol (10^6m^3)</th>
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</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Distribution vol (10^6m^3)</th>
<th>Leakage vol (10^6m^3)</th>
<th>Leakage rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H18(06)</td>
<td>1,606</td>
<td>150</td>
<td>3.6</td>
</tr>
<tr>
<td>H19(07)</td>
<td>1,607</td>
<td>141</td>
<td>3.3</td>
</tr>
<tr>
<td>H20(08)</td>
<td>1,582</td>
<td>133</td>
<td>3.1</td>
</tr>
<tr>
<td>H21(09)</td>
<td>1,568</td>
<td>127</td>
<td>3.0</td>
</tr>
<tr>
<td>H22(10)</td>
<td>1,569</td>
<td>120</td>
<td>2.7</td>
</tr>
<tr>
<td>H23(11)</td>
<td>1,537</td>
<td>107</td>
<td>2.8</td>
</tr>
<tr>
<td>H24(12)</td>
<td>1,523</td>
<td>89</td>
<td>2.0</td>
</tr>
<tr>
<td>H25(13)</td>
<td>1,523</td>
<td>75</td>
<td>2.2</td>
</tr>
<tr>
<td>H26(14)</td>
<td>1,530</td>
<td>72</td>
<td>3.1</td>
</tr>
<tr>
<td>H27(15)</td>
<td>1,530</td>
<td>68</td>
<td>3.2</td>
</tr>
</tbody>
</table>
Reference-3 Specifications of leakage cases in FY 2015

1 By Uses

2 By Causes

   (Mains)

   Water pipes consisting of the mains with a bore diameter of 400 mm or larger that were installed to distribute water from service and booster-pump stations to water supply areas.

   (With a bore diameter of from 400 to 2,700 mm)

   (Sub mains)

   Water pipes with a bore diameter of 350 mm or less that branch off from distribution mains and directly connect to service pipes.

   (With a bore diameter of from 50 to 350 mm)

   (Service Pipes)

   Water pipes that branch off from small distribution pipes and connect to household taps.
Reference-4  Trends in number of each kind of repair works from FY 1996 to FY 2015

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</thead>
<tbody>
<tr>
<td>Planned work cases</td>
<td>9,177</td>
<td>8,028</td>
<td>6,964</td>
<td>6,627</td>
<td>5,073</td>
<td>4,199</td>
<td>3,450</td>
<td>3,516</td>
<td>2,592</td>
<td>1,908</td>
<td>1,287</td>
<td>1,097</td>
<td>1,026</td>
<td>848</td>
<td>801</td>
<td>684</td>
<td>542</td>
<td>503</td>
<td>454</td>
<td>434</td>
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<tr>
<td>Mobile work cases</td>
<td>33,757</td>
<td>31,345</td>
<td>30,575</td>
<td>28,476</td>
<td>27,569</td>
<td>23,135</td>
<td>18,996</td>
<td>24,186</td>
<td>22,987</td>
<td>19,361</td>
<td>16,460</td>
<td>15,173</td>
<td>14,083</td>
<td>13,046</td>
<td>12,090</td>
<td>10,900</td>
<td>9,597</td>
<td>8,752</td>
<td>7,881</td>
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</tr>
<tr>
<td>Total cases</td>
<td>42,934</td>
<td>39,373</td>
<td>37,539</td>
<td>35,103</td>
<td>32,642</td>
<td>27,334</td>
<td>22,446</td>
<td>27,702</td>
<td>25,579</td>
<td>21,269</td>
<td>17,747</td>
<td>16,270</td>
<td>15,109</td>
<td>13,894</td>
<td>12,774</td>
<td>11,018</td>
<td>10,100</td>
<td>9,206</td>
<td>8,315</td>
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</tbody>
</table>
Reference-5  Trends in percentages of ductile cast iron pipes in distribution pipes, stainless steel pipes in service pipes, leakage repair cases, leakage rate from FY 1996 to FY 2015

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</thead>
<tbody>
<tr>
<td>Percentage of ductile cast iron pipes %</td>
<td>91</td>
<td>92</td>
<td>93</td>
<td>94</td>
<td>95</td>
<td>96</td>
<td>96</td>
<td>97</td>
<td>98</td>
<td>98</td>
<td>99</td>
<td>99</td>
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<td>99</td>
<td>99</td>
<td>99</td>
<td>99</td>
<td>99</td>
</tr>
<tr>
<td>Percentage of stainless steel pipes %</td>
<td>79</td>
<td>82</td>
<td>85</td>
<td>88</td>
<td>90</td>
<td>95</td>
<td>97</td>
<td>99</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Leakage repair rate (×1000)</td>
<td>42,934</td>
<td>39,373</td>
<td>37,539</td>
<td>35,103</td>
<td>32,642</td>
<td>27,334</td>
<td>22,446</td>
<td>27,702</td>
<td>25,579</td>
<td>21,269</td>
<td>17,747</td>
<td>16,270</td>
<td>15,109</td>
<td>13,894</td>
<td>14,578</td>
<td>12,774</td>
<td>11,018</td>
<td>10,109</td>
<td>9,206</td>
<td>8,315</td>
</tr>
<tr>
<td>Leakage rate %</td>
<td>8.9</td>
<td>8.4</td>
<td>8.0</td>
<td>7.6</td>
<td>7.1</td>
<td>6.4</td>
<td>5.4</td>
<td>4.7</td>
<td>4.4</td>
<td>4.2</td>
<td>3.6</td>
<td>3.3</td>
<td>3.1</td>
<td>3.0</td>
<td>2.7</td>
<td>2.8</td>
<td>2.0</td>
<td>2.2</td>
<td>3.1</td>
<td>3.2</td>
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</tbody>
</table>
Reference-6  Technology and equipment related to leakage prevention that were co-developed by and private companies.

1  Freezing method
   This method suspends water by freezing up the water inside the pipe with liquid air in repair.

2  Electronic leakage detector
   This instrument can pick up the leakage noise electrically on ground surface.

3  Portable minimum flow meter
   This flow meter is used at the minimum night flow measurement.

4  Correlative type leakage detector
   This instrument locates the leakage by processing leakage noise picked up at two point on pipe.

5  Underground radar
   This radar radiates electro-magnetic wave to ground so as to search the underground condition.

6  Time integral type leakage detector
   Making use of the continuity of leakage noise, this instrument is able to check whether the leakage exists or not.

7  Transmission-type leakage detector
   It is a device to locate the place of leakage by detecting the helium gas injected into the water pipe and then discharged through the leakage spot to the soil.
Number of persons working in the Waterworks is 3,792 (at April 2016). 295 persons of them are engaged in leakage prevention of the 23 wards.
Ozonation
Treatment of decomposing substances causing musty odor and substances trihalomethane by strong oxidizing power of ozone.

Biological Activated Carbon Absorption Treatment

Advanced Water Treatment
Treatment aimed at removing odorous substances, trihalomethane precursors, etc. which cannot be adequately removed by ordinary water purification treatment such as rapid filtration method. Treatment using ozonation combined with biological activated carbon adsorption treatment.

Remaining Leakage Amount
Leakage amount that could not be prevented due to underground leakage etc. undiscovered during leakage prevention works.

Block
A range in which submain distribution pipes buried in a grid shape is separated by a certain length.

Circulation Period
Operation interval for carrying out planned works in each block.

Gate Valve
A valve provided in a pipeline to stop flowing water in the pipe (water outage) and adjustment of water pressure in the pipe (adjustment of flow rate) at a branching part of a distribution pipe or a section crossing a river, etc. Normally, it is installed at an interval of about 500 m to 1,000 m in a main distribution pipe, and an interval of about 150 m to 200 m in a submain distribution pipe.

Drain
A tap to drain foreign matters (rust, etc.) inside the pipe after the waterworks construction. It has the same function as fire hydrant.
Fire Hydrant
A tap installed in a submain distribution pipe as fire extinguishing water when a fire occurs. It is also used for drainage inside the pipeline.

Block Water Meter
Attached equipment of a submain distribution pipe combined with a single mouth fire hydrant and a gate valve. It is used for minimum night flow measurement during planning work.

Cast Iron Pipe
A cast iron pipe using gray cast iron (tensile strength 12.5N/mm²). It is used until around 1933.

High-grade Cast Iron
A cast iron pipe with improved tensile strength by improving manufacturing process of gray cast iron. (tensile strength 25N/mm²) It is used from around 1933.

Ductile Cast Iron Pipe
A cast iron pipe with enhanced material strength by adding magnesium to the conventional cast iron pipe and making the graphite in its structure in a nodular shape (tensile strength 45N/mm²). It is used from around 1965.

Aged Pipe
A collective term for low-strength cast iron pipes of which the inner surface is not lined and old cast iron pipes in installation year.

Early Ductile Pipe
A collective term for consisting of a mixture of straight pipes made of ductile cast iron and special fittings made of high-grade cast iron without inner lining.

Early Ductile Iron Pipe
Structure with detachment prevention function in joint part.