Pipeline management in Tokyo - measures for leakage prevention

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ABSTRACT

Tokyo Metropolitan Government has promoted measures for leakage prevention as one of our major activities. In recent years, we have been particularly targeting replacing lead pipes where leakage outbreak probability is high. In 1945, at the end of World War II, the leakage rate was about 80%. However, in 2005, the leakage rate decreased to 4.2% of the distribution water volume of 1.616 billion m^3. This report describes our approach to preventing leakage.

Key words | lead pipe, leakage prevention, leakage prevention statistics data, planned work, preventive measures, stainless steel pipe

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INTRODUCTION

It is said that the beginning of water supply in Tokyo was the "Kanda water supply" which was built in 1590. In those days, water was supplied with wooden and stone pipes. But in the Meiji Era (1886), many problems arose, and the prevalence of cholera, which spread in Japan with fatalities numbering around 10,000, urged the people to establish the modern waterworks. In 1898, Tokyo began to supply pressurized water through iron pipelines.

After the modern water supply system was established, water consumption per capita increased with the improvement of a cultural standard. Therefore, in the summer, in the area at the end of distribution pipes, water suspension often occurred. To deal with increasing consumption of water, Tokyo hurried the construction of waterworks facilities. And to sustain a stable water supply until completion of construction works, it was thought that it was effective to prevent a leakage. In 1913, Tokyo commenced the work of searching for and repairing leaks for the first time.

After that, Tokyo placed the prevention of leakage as one of our major activities. We have employed various policies to use precious water resources effectively, for example, restoration of waterworks facilities which were damaged by The Great Kanto Earthquake (1923) and World War II (1945), enforcement of premeditated prevention of underground leakage, and introduction of before the fact preventive measures against leakage. In recent years, we have been particularly targeting replacing lead pipes. In 1945, the leakage rate was about 80% from war damage. However, in 2005, the leakage rate decreased to 4.2%.

This report describes our approach to preventing leakage.

OUR ACTION TO PREVENT LEAKAGE AND TRANSITION OF THE LEAKAGE RATE

From 1913 to 1945 (the period from leakage investigation start to war end)

From 1913, since starting leakage investigation, we performed various studies about work methods. Leakage volume was measured by two kinds of foreign-made flow meter at the same time to secure the accuracy. A foreign-made acoustic rod was used to find a leakage point.

It is considered that the leakage rate was 12.6% as a result of leakage investigation carried out from 1913 to 1917. After that, the leakage rate increased to 20% because of the Great Kanto Earthquake. And as about 60% of water

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taps were burned by the war, leakage volume extremely increased to 80% of distributed amount (Figure 1).

From 1945 to 1960 (the period of leakage rate decreased by the war damage restoration)

The war damage restoration

From 1945 to 1948, emergency leakage preventive measures due to the war damage were carried out with much labor and expense. To adduce an actual example, we pressed lead pipes in to the area damaged by the war, and dug stop valves out of the ground and shut valves to prevent surface leakage. However, in August, 1946, it was considered that the leakage rate was still over 50%, since leakage by the war was not completely prevented and leakage increased by the lack of maintenance.

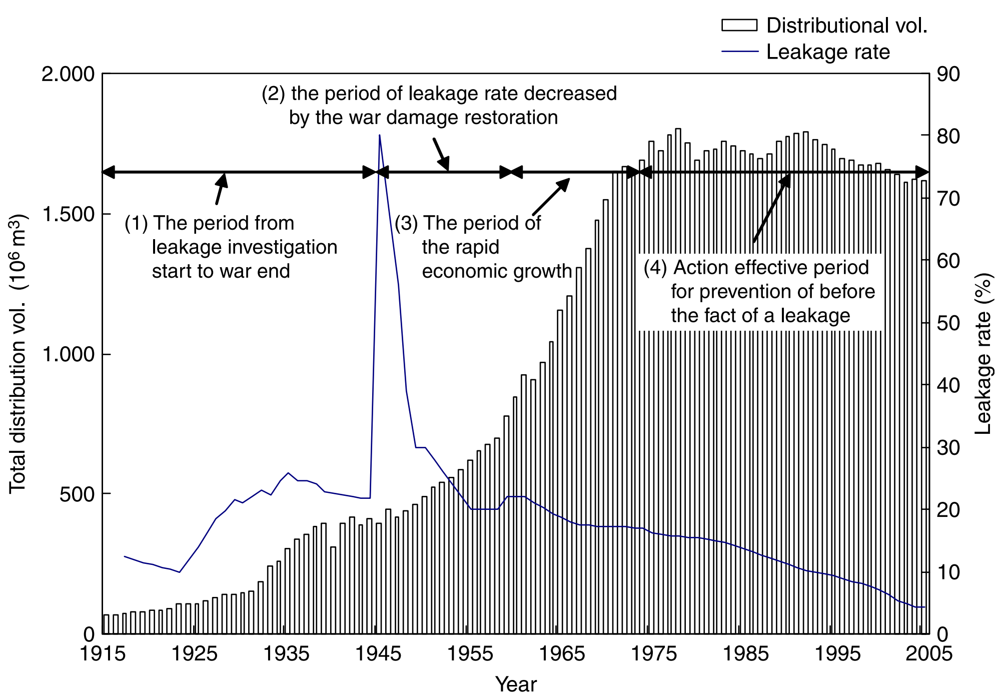
We started leakage prevention measures in not only the war destruction area but also in all areas from October 1946 to March 1949. At first we carried out the prevention of both "surface leakage" and "underground leakage", but because of a shortage of workers and term of works, we carried out preventing "surface leakage" work mainly. As a result, we were able to decrease the leakage rate to about 30% which was the targeted value.

Introduction of a trial block and expansion of a work scale

From 1949 to 1952, we used a higher performance leakage detector and pipe locator, and we prevented leakages as a business for four years for all wards.

In 1950, though leakage preventive measures due to war damage were almost completed, the ratio of accounted-for water to distributed amount was extremely low. And due to an increase in concentration of population and progress of facilities construction, it was judged that reinforcement of prevention of leakage was an important issue. Therefore, we established a trial block to investigate the situation of distributed amount, water consumption, leakage volume, distribution supply facilities, and water service installation. And we reexamined leakage preventive measures. As a result, it became clear that it would be extremely difficult to decrease the leakage rate to less than 30% at the current scale of work.

Therefore, we set an objective of 15% leakage rate within 4 years of work, targeted all of the areas and started



※ Data of leakage rate by 1944 contains average in 3~5years

Figure 1 | Trends in leakage rate and total distribution volume.

the leakage prevention work in 1952 with double the scale compared to the traditional work. Then, the second term of leakage prevention work was started in 1956. And we were able to reduce the leakage rate to about 20% in the 1960s.

From 1960 to 1974 (the period of rapid economic growth)

The National Government sent a notice to every Local Government to demand the reinforcement of leakage prevention. In the notice, The National Government showed the necessity of analyzing the distributed amount as preciously as possible to grasp the actual situation and the concrete leakage preventive measures technique to reinforce the maintenance of water service to Local Government.

On the other hand, the water demand of Tokyo was largely increased by population concentration in metropolitan areas and by a rise in service pervasion rates because of the period of rapid economic growth. To deal with this, we pushed forward the reinforcement of capacity of facilities and construction of facilities at a faster pace.

The plan of leakage prevention work in 1962

In 1962, we drew up a detailed plan about leakage prevention work. To carry out leakage prevention work economically, we established the number of years ("circulation years") needed to complete work in an area so that a whole sum of loss by leakage and cost of prevention of leakage became the minimum. We decided "cycle years" as four years in central areas, as five years in intermediate areas, and as seven years in surrounding areas, according to the past work results, a water supply area, age of distribution pipes, the ground and traffic conditions.

The concrete method of leakage prevention work is as follows; 1) set the working range every 10 km of distribution length, 2) shut all the valves of the service pipe, 3) measure the leakage volume. It is based on this way of thinking that we detect and repair much leakage effectively if we can grasp the quantity of leakage in each work area. However, a lot of labor and perseverance was spent on digging out buried stop valves. We repeated the measurement, investigation, and repair of leakage until the quantity of leakage volume became less than the permissible leakage volume in the block that exceeded the maximum permissible level.

With regard to mobile work (repair work of ground leakage with distribution pipe), we proposed that we should perform early repair. We coped with the reorganization with an increased work load, staff increase plan, and increase in the outbreak of leakages.

Furthermore, we thought about the "repetition phenomenon" of leakage in a plan of leakage prevention operation. As time goes on, leakage volume increases naturally without the leakage prevention work. This is referred to as the "repetition phenomenon" of leakage. The repetition phenomenon of leakage has been examined through model construction of the mechanism, but we calculated a tentative aim from the past work results in those days. This shows that we carried out an examination of the cause of leakage as well as merely performing search and repair work of the leakage.

Introduction of a simple work method in 1964

It took for 4–7 years to make a round of all water supply areas by a method applied in the leakage prevention plan operation in 1962. In this way we could prevent a leakage, but, because of the repetition phenomenon of leakage in the meantime, leakage prevention was ineffective.

Therefore we shifted to a simple work method which omitted the measurement of leakage volume. From 1964, we adopted an acoustic method mainly and we proposed to promote efficiency so as to make a round of all water supply area in about 2 years.

By introduction of this simple work, work efficiency rose remarkable at first, but, as we omitted the measurement of leakage volume in this method, grasp of leakage volume was impossible and there was not an aim for a worker. As a result we realized the importance of the leakage volume measurement in workers' motivation.

Introduction of a block water meter in 1970

In addition to a simple work method, we carried out the work that took in leakage volume measurement work from 1970.

This method paid attention to the time period when there was no water usage in a block at night (Figure 2). First, gate valves surrounding the block to be investigated were

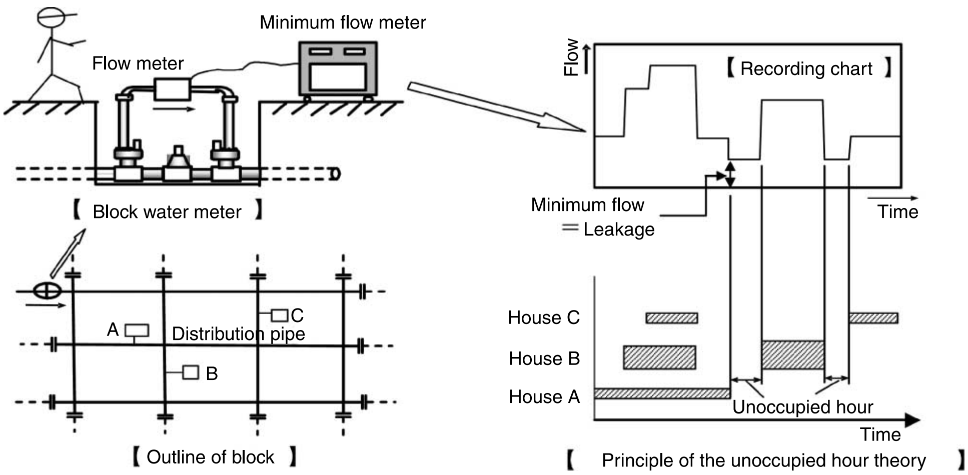


Figure 2 | Theory of minimum night flow measurement method.

closed and the water from other blocks was shut down. Then the water was sent into the block through minimum flow measuring equipment set in the block water meter and the flow rate was measured. The minimum flow rate measured during the vacant period was considered to be the leakage.

To measure the smallest flow quantity, we reduced the size of blocks to around a quarter of their previous size and divided the ward into 3,600 blocks and we carried out setting a block water meter in 1978 from 1970.

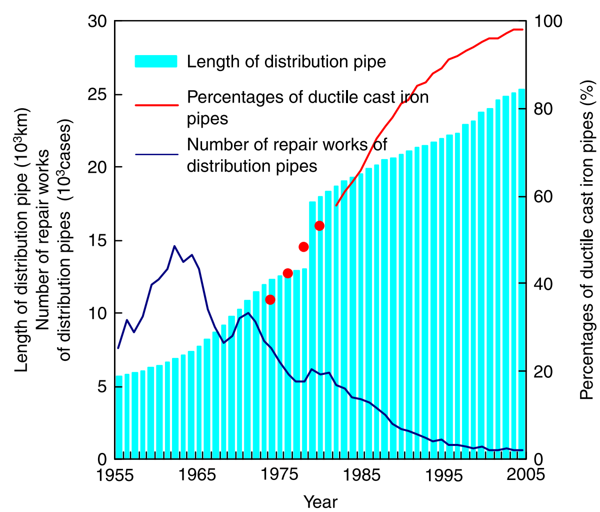
Adoption of a ductile cast iron pipe to distribution pipes after 1955

With respect to distribution pipes, cast iron pipe was mainly used since the modern water supply system was established. As the domestic cast iron pipe production ability was low in those days, cast iron pipes made in foreign countries were used. After that, since 1960, a ductile iron pipe having about 3 times the strength of a cast iron pipe was adopted in large diameter distribution pipes (φ1,000 ~ φ1,500). We expanded the range of an application diameter and used it as the main material for distribution pipes now. As a result, the leakage repair number of distribution pipes decreased greatly (Figure 3).

In addition, in 1978, a seismic coupling pipe with a restraint mechanism in the coupling was adopted on the distribution pipe, more than a diameter of 400 mm and a seismic coupling pipe was adopted after 1998 in response to lessons learned in the great Hanshin Awaji earthquake disaster which occurred in 1995.

Water conservation policy in 1973

Ahead of other cities, we announced "the measure to control water demand" in 1973 and, under the social situation of the large increase in water demands due to rapid economic growth, we placed leakage preventive measures as a part of saving water measures.



※ The length of distribution pipe by 1978 is data of 23 wards
※ Percentage of ductile cast iron pipes by 1984 are date of 23 wards
※ Percentages of ductile cast iron pipes are ductile cast iron pipes and steel pipes that is not target replaced to the total length of distribution pipes

Figure 3 | Trends in length of distribution pipe, number of repair works of distribution pipes and percentages of ductile cast iron pipes.

At this time, the basic recognition was established that leakage preventive measures were very important for the utilization of water resources and reasonable management of a pipeline. This is the basic thinking used to the present day.

From 1975 (action effective period for prevention of before the fact of a leakage)

A leakage prevention work guideline in 1975

The leakage volume measurement which used the block water meter had been carried out experimentally since 1970. A leakage prevention work guideline was organized in 1975 based on this guideline and started the real enforcement. In addition, this guideline is used currently.

However, during this time when the leakage rate became less than 20%, the repetition phenomenon occurred, and only through corrective measures was an underground leakage discovered and repaired, the leakage prevention effect fell. Therefore we attached a great deal of importance on preventive measures against leakage.

Adoption of a stainless steel pipe in 1980

In 1979, the leakage repair number of service pipes accounted for 90% of the total. (Figure 4). On the basis of this, we confirmed the necessity of radical improvement of structure materials of water service installations in the bureau council and considered at the related sections.

As a result, we decided to adopt a superior stainless steel pipe as a service pipe because of corrosion resistance, strength and pressure resistance characteristics in comparison with other materials from 1980.

The stainless steel pipe was adopted only by new construction and remodeling construction at first, but coverage was enlarged to the exchange of service pipes with distribution pipes, and service pipes with all distribution pipes were constructed of stainless steel.

As materials of service pipes under public roads were improved from a product made of lead which had been used as the main water supply device material into stainless steel, in an effort to prevent leakage, the leakage of public road parts decreased steadily. That largely contributed to reduction of the leakage rate (Figure 5).

In 1993, the leakage rate was less than 10% (9.9%) through having carried out preventive measures steadily, which we had wished to do for a long time (Figure 6).

The leakage repair number of public road basements decreased greatly in those days because stainless steel pipes were adopted. However, as service pipes were the possessions of customers, early repair of leakage did not occur in leakage on residential land.

A change of leakage repair expense burden division of 1994

To promote early repair of service pipe leakage and to use water resources thoroughly, we enlarged the bureau expense

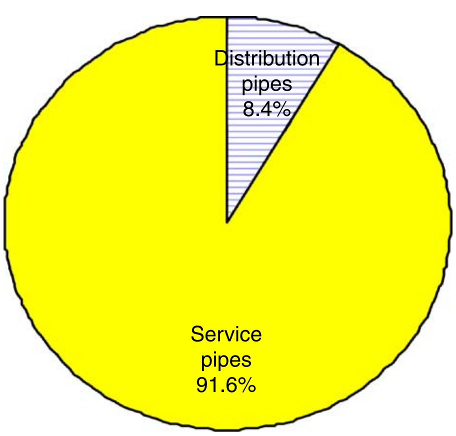


Figure 4 | Specifications of leakage case in 1979.

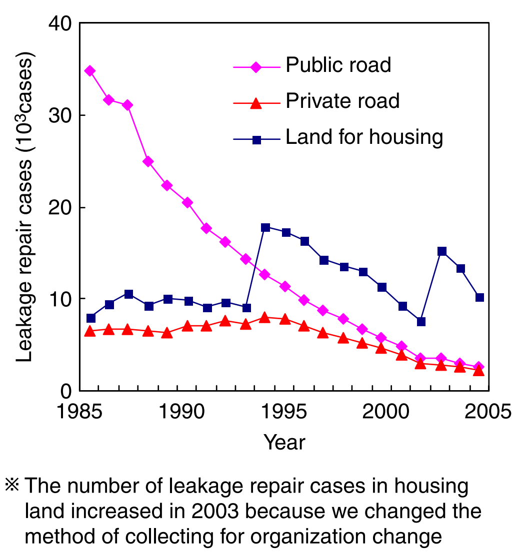


Figure 5 | Trends in locations of leakage case (23 wards).

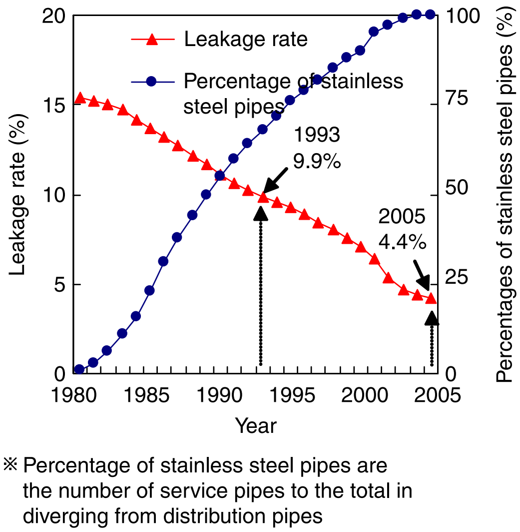


Figure 6 | Trends in percentages of stainless steel pipes and leakage rate.

burden division at the time of leakage repair of water meters on residential land to 1 meter of residential land from the border of conventional residential land and public road from 1994. By expansion of this leakage repair execution range, the leakage repair number of 1994 increased greatly and exceeded that of public road parts (Figure 5).

The leakage repair number increased temporarily, but decreased afterwards (Figure 5). It was thought that this was caused by the fact that service pipes were replaced from lead pipes with plastic pipes that could withstand corrosion. It was clear that leakage volume would be decreased if we replaced lead pipes, because in those days half of the repair number of service pipe leakage was from lead pipes.

An action of lead pipe removal after 1997

In 1997, we examined the action of lead pipe removal and pointed out problems such as lack of independent measures for lead pipe removal, and lack of PR to customers. We concluded that it was necessary to draw up a new plan.

We investigated about 3,500,000 drawings of water service installations to understand the basic data of an action of lead pipe removal and established the number of customers for whom lead pipes were used between faucets from a distribution pipe. Furthermore, we designed an action to remove 900,000 lead pipes which stayed on the side of the upper reaches of the meter which was our aim. For the customers who used lead pipes of more than a meter at the same time on the down stream side, we mailed them a news document and decided to ask to exchange the lead pipes. It strengthened PR to customers and we started making pamphlets about the exchange of lead pipes. A publication, the monthly PR newsletter *Tokyo Water News* was published by the Bureau of Waterworks and on our homepage, water quality tests for the customers who wished for them. In this way we have faced the action of lead pipe removal up until now.

By the action of lead pipe removal, we made a plan to remove service pipes made by lead under public roads for the first time in three years from 2000–2002. Because a considerable number of lead pipes remained in public roads, for three years from 2000, the service pipe construction section worked together with the leakage prevention section. As a result, at the end of 2002, we were able to remove almost all lead pipes.

From 2003, we established a section which mainly performs the improvement of materials of service pipes because the execution number on residential land is enormous. We are hoping to complete this by the end of 2006.

In addition, we used PR through homepages or “Notices of water and sewage consumption” because it is indispensable to obtain the understanding and cooperation of customers to smoothly push forward the work on private land. This initiative takes the new water quality standard of the country devised in 2003, into consideration.

A trend of a current water service-related measures and leakage prevention

“The water service vision”, was announced in 2004, which analyzed the present conditions of the water service in our country and the future prospects, and showed concrete measures and processes for the realization of the future image of the water service. The ideas of main importance based on this vision were, “reduce to zero the number of service pipes and the water service installation accidents as early as possible” and “reduce to half in five years and to zero as early as possible the lead service pipe used “. These were raised as the aims of a policy concerned with a safe and comfortable water supply.

In addition, we commenced “The Project for the Provision of High Quality Tap Water” in June 2004 in an

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attempt to respond to the increasingly sophisticated and diversifying demands of customers. In this project, we placed emphasis on an exchange of old distribution pipes and the removal of lead pipes as a concrete measure from the point of view of the maintenance of water pipes and the prevention of leakage.

In 2004, we drew up a guideline called the "Tokyo Waterworks Management Plan 2004 -Realization of a suitable water service for the capital Tokyo", in which we set the target value of a leakage rate of up to 4%.

In 2005, the leakage rate became 4.4% (Figure 6). When the action of lead pipe removal is completed, we think that the leakage rate will be reduced to around 4%.

We reduced the leakage rate greatly through a longtime effort, but it is clear that leakages increase if reasonable maintenance is neglected, and it is important to maintain a low leakage rate.

EFFECTIVE LEAKAGE PREVENTIVE MEASURES

We have carried out various leakage preventive measures to date, and performed them with a limited number of staff for a large area. "How to perform it effectively" is an important proposition of leakage prevention (Figure 7).

Technical development

We established an Office of Leakage Prevention in 1974 to cope with the prevention of leakage machinery and to the study and development of leakage prevention technology. Environment leakage searches by acoustic methods became extremely difficult due to the increase of city noise, traffic density, and congestion of buried structures. Therefore, development of new leakage search technology which was not influenced by the difficult work environment (i.e. was easy to operate) and that made work more efficient, was necessary. We established a "Training and Technical Development Center" to plan the reinforcement of the development system and the general improvement of waterworks technology and to carry out the technology development that could cope with a change of on-site needs immediately (Figure 8).

Table 1 summarizes the main technology and machinery concerned with prevention leakage which we developed and improved.

Leakage prevention statistics data

We understood the leakage factor and took measures which led to the adoption of stainless steel pipes by recognizing the necessity of a radical improvement of structural materials for water service installation. We made clear the necessity to

- Corrective measures — The work of finding and repairing leakages that occur at the surface or underground.
  - Mobile work — The repair work of surface leakages identified by reports from residents etc.
  - Planned work — The work that we find and repair hidden potential underground leakages by investigation deliberately.
    - The work that we measure the minimum flow rate (leakage volume) at nighttime and in blocks with large leakage volume, we detect and repair leakages by investigation using the acoustic leakage sound detection method or correlative leak detection method.
    - The work that we repair leakages, by the all house investigation which find leakages to use acoustic rod to the meter of each home per working blocks that is refered to past results mainly.
    - The work that we measure leakage volume in order to grasp trend of leakage.
- Preventive measures — The workin order to prevent an incidence of leakages and to reduce leakage volume.
  - The work that we replace the old distribution pipes with ductile cast iron pipes.
  - The work that we replace the lead pipes with the stainless steel pipes.
  - The work ,in locations where some service pipes are laid, distribution submains are to be laid even under private roads, to ensure that long distance service pipes are in good order.
- Technical development leakage prevention
  Development related to technic and equipment about leakage prevention.

Figure 7 | System of leakage prevention measures.

Figure 8 | Portable minimum flow meter.

expand the bureau's execution range of leakage repair by a meter in residential land from a public road to aim at improving further an effective water ratio. It is the conventional leakage repair results which became the basic document.

To take leakage preventive measures effectively, it is necessary to analyze data statistically. Therefore we started leakage prevention statistics data calculation by computational process in 1980.

To put it concretely, we accumulated materials, a coupling of the pipe, and the installation year (only in the case of a distribution pipe and a stainless steel service pipe) which leaked water as data. We consider that closer analysis is needed about the cause of leakage. And we subdivided the cause of leakage from 1998. For example, we were able to distinguish what kind of leakage occurred, e.g. "corrosion of this part of pipeline", or "crack of this pert of pipeline" from expression only for causes such as "corrosion", and "crack".

An action for electric corrosion

An electric current flowing through a railroad drifts to the underground as a leak electric current and flows into the nearby underground and out into the vicinity of a transformer substation of an electric railroad and returns on a rail. The point where it is strongly influenced by a leak electric current corrodes in several years which can cause leakage. The social consequences such as the suspension of a train are huge, especially in the case of water leakage occurring on a railway crossing part. Thus a drainage unit apparatus is installed for corrosion prevention in the point around a railroad.

Table 1 | Technical developments in leakage prevention by Tokyo Metropolitan Government

Apparatus	Contents
Electric leakage detector	This instrument can pick up the leakage noise electrically on ground surface
Freezing method	This method remains water by freezing up the water inside the pipe with liquid air in repairs
Portable minimum flow meter	This flow meter is used at the minimum night flow measurement
Correlation type leakage detector	This instrument locates the leakage by processing leakage noise picked up at two point on pipe
Underground radar	This radar radiates electro-magnetic wave to ground so as to search the underground condition
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
Non-metal pipe locator	Making use of the transmission noise, this instrument can locate the non-metal pipe
Leakage detector using helium gas for buried pipes	This method can detect the leak point despite its surrounding noises
Water leak detector using electromagnetic waves	This leak detector can identify a spot of leakage by detecting fluctuations of reflected electromagnetic waves in accordance with the movement of leaking water

In recent years, due to the influence of corrosion prevention institutions of other companies, an electric corrosion becomes a complication, so we must investigate the trend continuously.

Since the consequences of a leakage accident are very strong, for main pipelines made of steel, we have installed outside power-supply units to prevent corrosion. In addition, we carry out investigations on high-risk points of electric corrosion.

Therefore, to promote effective leakage preventive measures, it is important to progress with technology development and analyze leakage factors based on work data of the past.

AIM AT A WATER SERVICE SYSTEM WITH LOW-RISK

Importance of risk management

In August, 2003, a large-scale leakage accident occurred on the riverside land of Arakawa and caused turbid water in 400,000 houses. In this accident, the riverside land sank by an area of 20 m by 17 m and 5 m deep (Figure 9), and the quantity of the leakage amounted to 8,000 m^3. In addition, in the accident which occurred in March, 2005, an arterial road sank, and serious consequences occurred such as flooding above and under ground as well as an outflow of water to a basement parking area.

These accidents were caused by "aging deterioration of a pipe". In these cases, it is possible to reduce leakage by replacing a pipe comprising a seismic coupling. However the aging and function deterioration of the pipes cannot be avoided as times goes on, even if they are replaced pipes and facilities. Therefore, to utilize limited water resources effectively and secure stable water supply for the future, it is necessary to establish a stable water service system such as performing replacement of pipes according to the plan.

Figure 9 | The leakage accident.

Measures in a distribution pipe

Through the replacement of old pipes, we intend to decrease the outbreak factor of a leakage in distribution pipes. In the case of accidents, we make an effort to react quickly, such as by making the range where the influence of the suspension of a water supply is small, by keeping water pressure in the distribution pipeline in a block equal and by decreasing leakage by the improvement of management capability by making water supply areas in smaller blocks.

Furthermore, we are going to progress with technology development such as the prevention of iron corrosion and mortar neutralization by improvement of Langelier's index, improvement of a polyethylene sleeve and investigation of a ductile iron pipe of high corrosion resistance characteristics.

Measures in a service pipe

In a service pipe, we take away a long-distance service pipe and improve a further effective water ratio. In addition, with consideration to corrosion by a different kind of metal making contact between the stainless steel pipe and the pipe material (a coupling, a saddle corporation cock cap) made of gunmetal, we replaced it with stainless steel underground beneath the public roads from 2006.

Leakage investigation in the future

We carried out the work aimed at detection of underground leakages as "planned work", but it is necessary to pre-establish effective work so there is a low leakage rate and the leakage number decreases when a service pipe made by lead is almost all removed. In addition, since the investigation of a leakage takes much time and expense, it is necessary to take cost-effectiveness into consideration.

In order to solve these problems, we carried out the secular change analysis with the past leakage data to perform the examination about effective leakage prevention work. These investigations require specific analysis theory and method, so we are promoting the collaboration with Tokyo Metropolitan University to develop effective leakage prevention and the achievement is greatly anticipated.

CONCLUSION

Until now, the leading part of investigating leakage is "man power" and "experience", but as efficiency is demanded when a leakage rate reduces, there is a limit to investigation techniques by man power.

We have to assign a focus on the pipes where leakage outbreak probability is high. In addition, it is necessary to develop a multi-points correlation type leakage detector to establish a water service system with low risk.

Tokyo established the "Tokyo Waterworks Management Plan 2004". In the plan we set an aim of a leakage rate of up to 4% and to cope with leakage preventive measures to achieve the goal. We will proceed with leakage preventive measures to achieve a reliable water system.

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