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Practical Paper

New development of pipe-network management in Kobe City

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ABSTRACT

Distribution pipelines now require a lot of maintenance and mass renewal. We need to determine measures to maintain water quality and to carry out reconstruction of the pipeline system. In addition, the mass retirement of engineers also provides us with a serious challenge on how to transfer their knowledge and skill. In 2008 Kobe City established *Kobe Waterworks Vision 2017*, in which plans have been set out to realize 'safety', 'relief', 'sustainability' and so on. In order to realize the vision in the field of distribution pipelines, pipe-network reconstruction and the *Manual for Water Safety Control in Distribution Network* are the key practices to achieve the highest level of pipe-network management. In this paper, we present the outline and application example of these practices.

Key words | behaviour of turbid materials, mass renewal, reconstruction of distribution network, renewal priority, transfer of technology and skills, water safety plan

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INTRODUCTION

Kobe City has provided and expanded its waterworks facilities in line with its overall development. Because the waterworks facilities were seriously damaged by the Great Hanshin-Awaji Earthquake in 1995, we actively carried out several countermeasures including a maintenance project on large-capacity transmission mains, earthquake-resistant distribution pipes, and establishing an emergency storage system, based on the *Kobe City Basic Plan for Earthquake-Resistant Water Supply Facilities* (Kobe City Waterworks Bureau 1995). As a result, the facilities are now remarkable in terms of hardware, with the ratio of earthquake-resistant distribution pipes reaching about 30% and effectiveness at 95% or more, both of which are better than before the earthquake. However, as the facilities have reached the age when major maintenance is required, we are encountering a problem: namely, that the facilities constructed in large quantities during the high growth period now require renewal; there are also new problems, such as the demands of customers for water of higher quality.

Such being the case, Kobe City established in July 2008 *The Kobe Waterworks Vision 2017* (Kobe City Waterworks Bureau 2008*b*), which indicates the direction of the waterworks projects to be realized in the coming 10 years. This vision, supported by the six concepts of: 'relief', 'stability', 'satisfaction', 'continuity', 'environment' and 'new development', clearly shows the direction in which Kobe waterworks will head by proceeding with respective measures in such a way that the requirements based on the ageing of facilities and customers' needs will be met. The projects for maintenance, renewal and seismic strengthening of pipelines are the concrete measures to realize the 'relief', 'stability' and 'continuity' aspects of this vision. In addition, Kobe City recently developed a pipe-network diagnosis and evaluation system to efficiently carry out the

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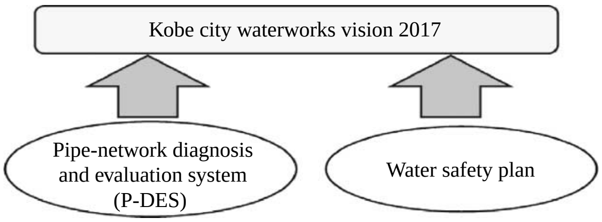

Figure 1 | Concrete measures for Kobe City waterworks vision 2017.

projects designated for maintenance, renewal and seismic strengthening of pipelines and also drew up a *Manual for Water Safety Control in a Distribution Network* for the daily monitoring of water quality (see Figure 1).

PIPE-NETWORK DIAGNOSIS AND EVALUATION SYSTEM

Background of system development

The diagnosis and assessment of pipelines selected for renewal and seismic strengthening have been implemented individually in respect of degradation degree, seismic resistance, functionality as pipeline, etc. However, this method is not always the best for diagnosis and assessment in terms of investment effect as we are unable to make any comprehensive decisions. On the other hand, it is necessary to establish renewal plans that are more understandable for citizens, which show cost reduction, reassessment and accountability of public works, which are now emerging as social requirements. In addition, as waterworks facilities constructed during the economic high growth period (1955–1973) will all reach the time for renewal at around the same time in the near future, the renewal plan must be cost effective. With the background mentioned above, we began development of a pipe-network diagnosis and evaluation system, hereinafter called 'P-DES' from financial year (FY) 2001 which started full-scale operation in FY2007. This system enables us to calculate and fix the renewal priority of water pipelines by diagnosing first their functionality and service level based on their objective data, and then making a comprehensive assessment.

System outline

P-DES is a system that, according to the flow shown in Figure 2, allows various pipe-network diagnoses, comprehensive functional evaluation and renewal planning.

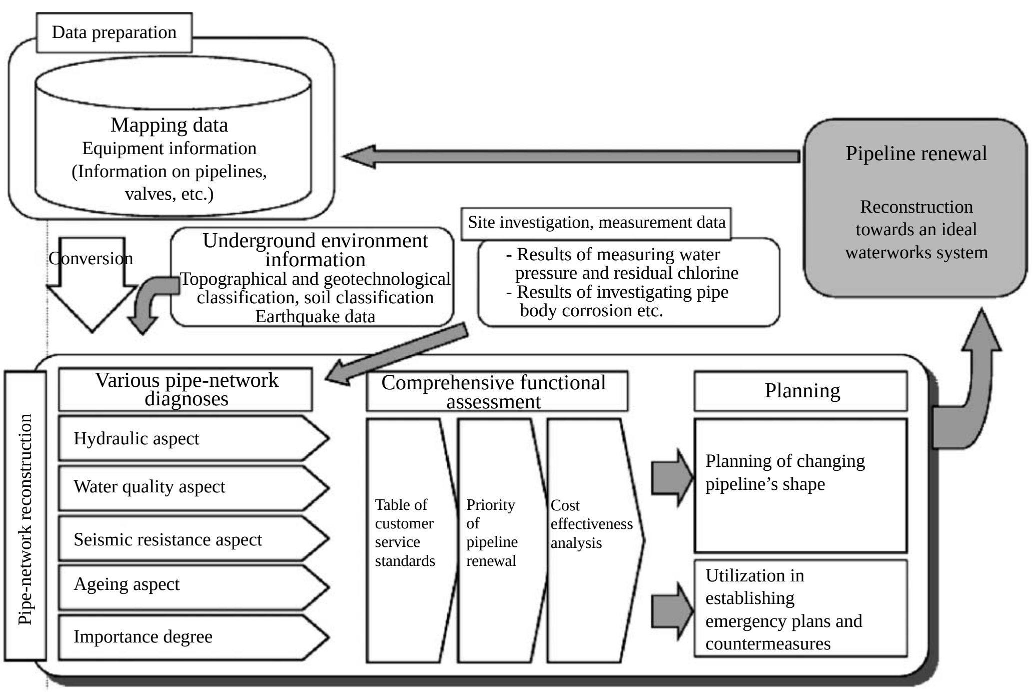

Figure 2 | Outline of pipe-network diagnosis and evaluation system.

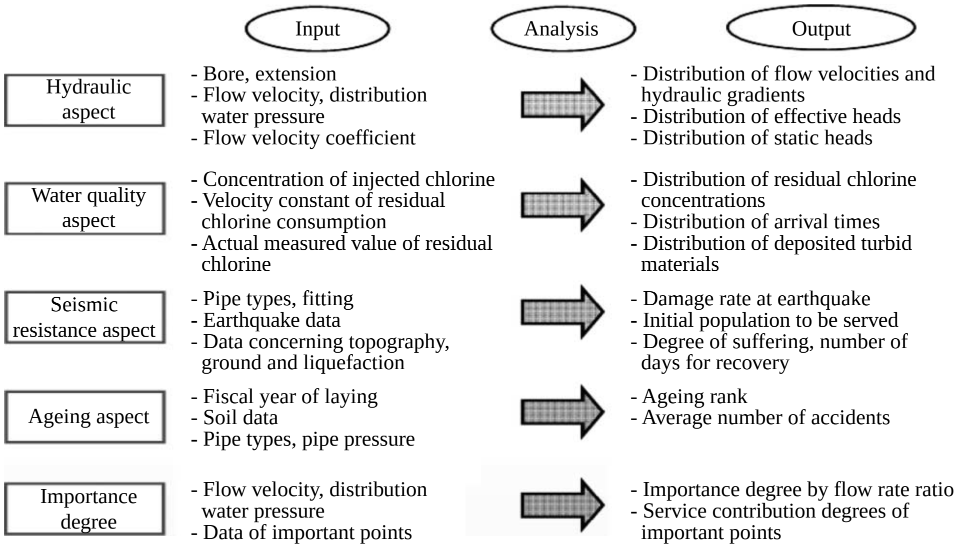

Figure 3 | Input and output of diagnostic evaluation.

Besides enabling diagnosis and evaluation based on objective data such as pipeline data and underground environment data, this system is characterized by the capacity to visualize the results of such diagnosis and evaluation.

Pipe-network diagnosis and evaluation

The objective data mentioned above are used to quantitatively diagnose and evaluate the present state of pipe networks in terms of hydraulic, water quality, seismic resistance, ageing and hydraulic importance aspects. The data used in respective diagnoses and their outputs are as shown in Figure 3. For example, regarding seismic resistance, the rates of estimated damage when an earthquake occurs can be obtained, allowing us to determine which are the most resistant and the least resistant pipelines. Meanwhile, regarding ageing, the system enables us to locate those pipelines where exterior corrosion is likely to have advanced.

Overall functional evaluation

By putting scores on diagnosis and evaluation results, service standard levels as a pipe network can be presented on a radar chart (see Figure 4). This scoring allows greater comprehension of their characteristics, such as in what aspect they are superior as a pipe-network in their present condition, and also allows an overall functional evaluation: for example, where the emphasis of maintenance should be placed in regard to the pipe networks of respective distribution regions.

Prioritizing renewal and establishing a renewal plan

Based on the results of diagnosis and evaluation, it is possible to prioritize pipelines for renewal, implement cost effectiveness analysis, and establish the most efficient renewal plan. These are actually carried out in the following steps.

Step 1: calculate priority index for renewal

Based on the results of various diagnoses and evaluations, calculate an index to set the priority of each pipeline for renewal in terms of hydraulic, water quality, seismic resistance and ageing aspects (refer to Table 1).

Step 2: make plural renewal plans

Vary the weighting coefficients shown in Table 1 in relation to the index and make plural renewal plans. In the P-DES system, five different plans will be automatically produced

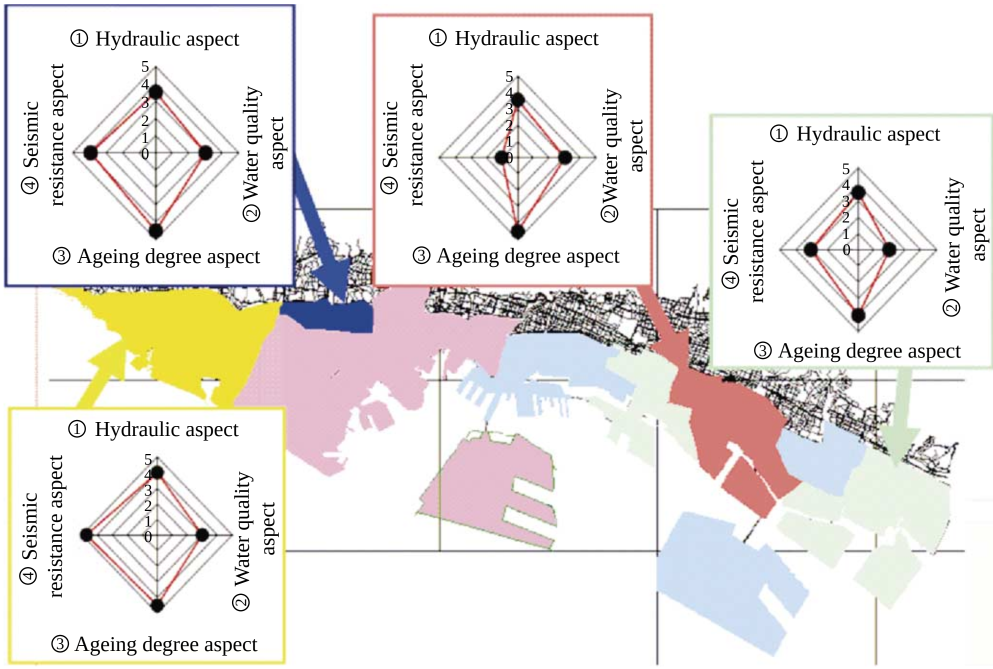

Figure 4 | Overall evaluation by distribution region (radar chart).

Table 1 | Priority index for pipeline renewal and weighting coefficient

Priority item	Index to indicate priority (higher value has higher priority)	Renewal purpose (example)	Weighting coefficient
a) Attach importance to hydraulic aspect	(Hydraulic gradient) × (importance degree by flow rate ratio)	1. Eliminate regions of poor water supply	Ka
		2. Levelling of water pressures within a region	
		3. Reduce daily variation of water pressure	
b) Attach importance to water quality aspect	(k value of velocity coefficient of residual chlorine consumption) × {1/(flow velocity)}	1. Eliminate regions of low residual chlorine concentration	Kb
		2. Eliminate regions of high residual chlorine concentration	
c) Attach importance to seismic resistance aspect	(Damage ratio at earthquake) × (importance degree by flow rate ratio)	1. Reduce number of days for recovery	Kc
		2. Reduce damage degree following earthquake	
		3. Improve water supply probability at key points for disaster prevention	
d) Attach importance to ageing aspect	(Number of accidents under normal conditions) × {1/(renewal cost of pipeline in question)}	1. Reduce maintenance cost	Kd

Table 2 | Weighting coefficients set in P-DES

Pipeline renewal plan		1. Attach importance to hydraulic aspect	2. Attach importance to water quality aspect	3. Attach importance to seismic resistance aspect	4. Attach importance to ageing aspect	5. Overall renewal
Value of weighting coefficient	Ka	1	0	0	0	1
	Kb	0	1	0	0	1
	Kc	0	0	1	0	1
	Kd	0	0	0	1	1

according to the weighting coefficients already set as indicated in Table 2.

Step 3: cost–benefit analysis

Next, perform a cost–benefit analysis at the time when the respective projects of the pipeline renewal plan have been completed. The analysis is carried out according to the *Manual for Cost-effectiveness Analysis of Waterworks Project* (JWWA 2002) together with Kobe City's own additional analysis. Analysis is implemented according to each plan. In addition, make a plan with weighting changed, taking account of dispersion of benefits in respective plans, and perform cost–benefit analysis on this plan. That is, in total six plans for renewal will be finally formulated.

Step 4: select the best renewal plan

By selecting from the above six plans a plan accruing the largest benefit, the most effective pipeline renewal plan can be established that comprehensively takes into account pipeline functionalities, such as hydraulic, water quality, seismic resistance and ageing aspects and has the highest cost–benefit ratio.

Application examples of P-DES

At present, the renewal priority calculated by utilizing P-DES is reflected in the renewal plan of each fiscal year. As an example, results of cost–benefit analysis in relation to plural renewal plans prepared for a distribution region in Kobe City are shown in Figure 5. All plans are judged appropriate for project implementation because the benefit/cost (B/C) ratio is more than 1.0 in respective plans. Plan 6 taking account of dispersion of arising benefits was found to provide the largest B/C ratio of 2.76.

While P-DES is utilized in this way for efficiently drawing up renewal plans, we also use its analysing function when undertaking diagnosis for water quality control. The *Manual for Water Safety Control in a Distribution Network* gives instructions to utilize this function for efficient water quality control.

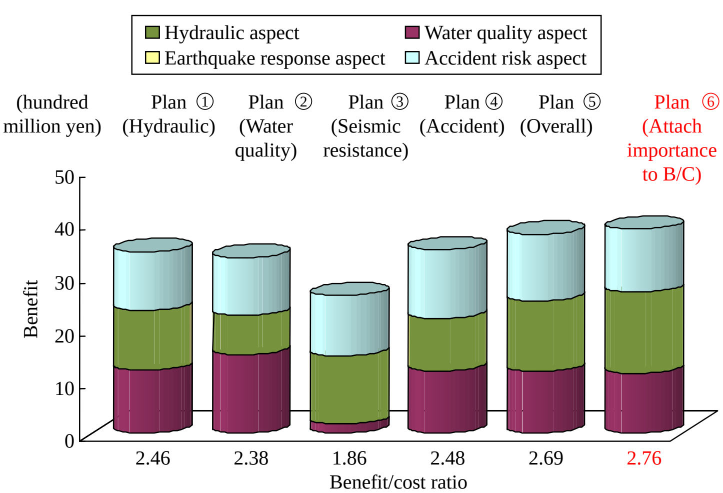

Figure 5 | Results of cost–benefit analysis (project cost: ¥1.27 billion).

MANUAL FOR WATER SAFETY CONTROL IN A DISTRIBUTION NETWORK

Kobe City water safety plan

To secure the safety of drinking water in the waterworks system as a whole, the Water Supply Division, Health Service Bureau, Ministry of Health, Labour and Welfare prepared the *Guideline for Formulating a Water Safety Plan* (MHLW 2008). In accordance with this guideline, Kobe City has been drawing up its own Water Safety Plan from FY2007 to FY2008. Kobe City now possesses plural water sources for stable water supply and crisis control. As different water sources exhibit different risks with regard to water safety, we have prepared individual Water Safety Plans for each purification plant system in each water source (Sengari purification plant, Uegahara purification plant, Okuhirano purification plant, Motoyama purification plant, Rokkosan purification plant, Inagawa purification plant (Hanshin Water Supply Authority), Amagasaki purification plant (Hanshin Water Supply Authority), Sanda purification plant (Hyogo Corporate Agency), and Kande purification plant (Hyogo Corporate Agency)), all of which are combined in the Kobe City Water Safety Plan (see Figure 6). In this plan, we seek to realize comprehensive risk assessment and risk management in all stages from the water source to the water tap.

Manual for water safety control in a distribution network

The water safety control manual

Among waterworks facilities, water sources and purification plants that are open to their environment and located upstream of waterworks tend to suffer from external factors and wide-ranging damage. On the other hand, as almost all distribution networks are buried underground and have inner pressure, they suffer little from external factors and generally the influence of damage is limited. However, distribution networks that are located at the end of the water supply system and closest to the citizens affect the citizens immediately if, for example, water quality deteriorates. Thus, we have introduced the *Manual for Water Safety Control in a Distribution Network* (hereinafter called 'Water Safety Control Manual') in order to secure water safety in distribution networks, thus allowing citizens to use water without anxiety. This manual, while being in accordance with the intention of Kobe City Water Safety Plan, incorporates actual measures to control and respond to problems in distribution networks. Specifically, by setting independent control levels apart from the risk management levels of the Kobe City Water Safety Plan, we aim to implement more detailed control: for example, in preventing red water occurrence and control of residual chlorine.

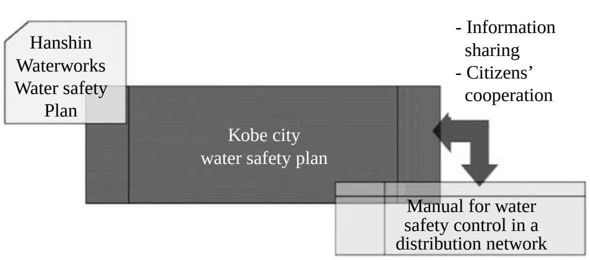

Figure 6 | Relation between Kobe City water safety plan and manual for water safety control in a distribution network.

Outline of water safety control manual

This manual is composed of planned measures against predicted problems such as red water and low residual chlorine concentration, and countermeasures to be implemented after occurrence of such problems.

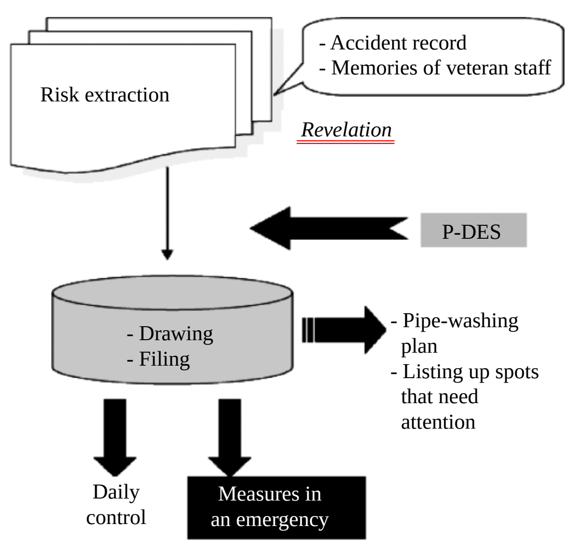

Figure 7 | Outline of water safety control manual.

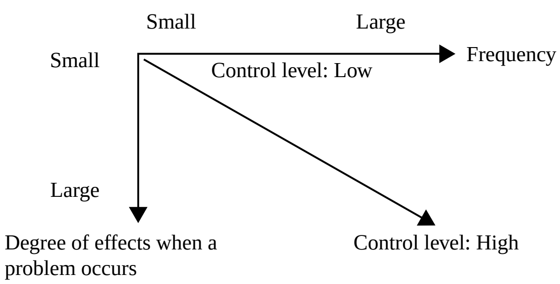

Figure 8 | Risk classification.

Planned measures

After investigating all risks that might occur at the downstream side of the distribution pipeline, summarize information on the area and pipeline which affect water safety, draw up a control map and establish scheduled measures such as pipe washing and water discharging to prevent unforeseen problems. In drawing up this map, we tried to use lessons learned from past cases and the know-how that has been accumulated within Kobe City Waterworks Bureau. In addition, we utilized the hydraulic and water quality functions and the simulation of turbid water behaviour provided by P-DES to predict spots where, although no problem was indicated, one might occur judging from the conditions inside the line compared with the line's previous record (refer to Figure 7).

Countermeasures after occurrence of problems

Carry out risk analysis for the problems that occurred. We intend to calculate and set respective control levels for all problems from the relation between their frequency of occurrence and degree of influence, and establish countermeasures at respective levels so that prompt and adequate actions can be taken when any problems occur in the future (see Figure 8). In addition, these countermeasures are recorded, periodically summarized and verified for revision of the plans and for the precision improvement of P-DES.

Application of water safety control manual utilizing P-DES

Within the countermeasures for turbid materials, such as red water, occurring in pipelines and the control of residual chlorine concentration, 'post-measures' responding to claims from citizens have played a large part. From now, however, it is necessary to promote 'preventive control' even further in order to meet citizens' increasing demands for higher water quality. Presented here is an effort in which we tried to achieve preventive and scheduled pipe-network management by utilizing P-DES within the Water Safety Control Manual.

While, in general, zones of low residual chlorine concentration are often found at the end part of distribution regions, sometimes they are observed in the middle part. As for the origins and causes of red water (hereinafter 'foreign matter'), it is difficult to identify them in a pipe network. The mechanism of red water will remain uncertain in many cases. In order to secure 'water safety' it is necessary to know the water quality conditions at any time in distribution networks, but it is difficult to confirm the water quality conditions in all pipe networks. Therefore, by utilizing P-DES, we tried to locate those points where monitoring can be carried out most effectively. Specifically, we calculated average conditions in distribution networks

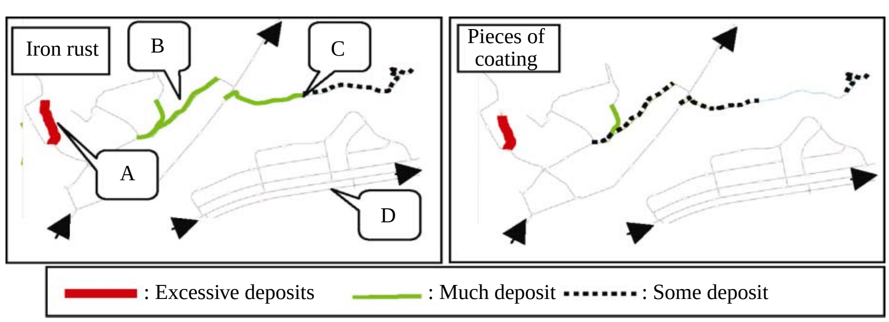

Figure 9 | Map of foreign matter.

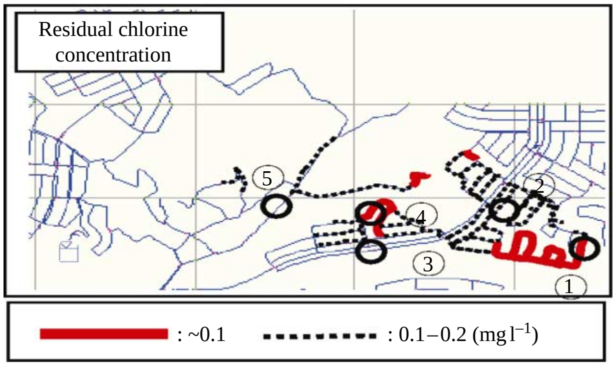

Figure 10 | Map for monitoring residual chlorine concentration.

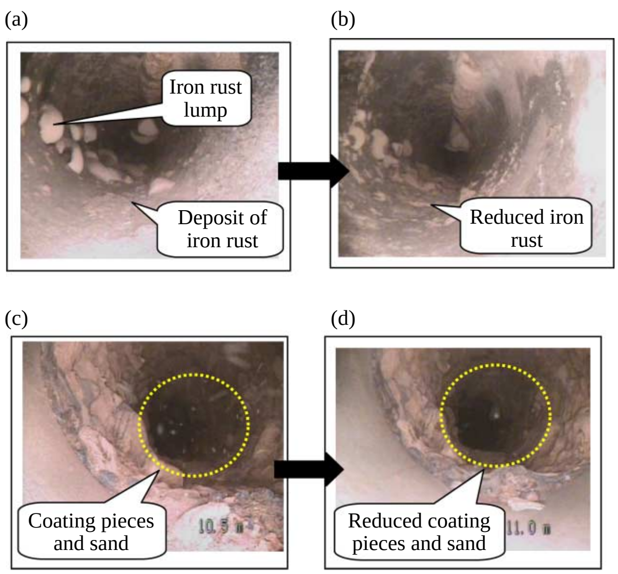

Figure 11 | In-pipe camera view of the inside of the pipes: (a) point A before pipe washing; (b) point A after pipe washing; (c) point C before pipe washing; (d) point C after pipe washing.

by using P-DES and then estimated the distribution of residual chlorine concentrations in distribution regions and the retention spots. Next, comparing past records and the results obtained with P-DES, we searched for those points to be designated as control points, illustrated below in Figures 9 and 10.

Map of foreign matter and map for monitoring residual chlorine concentration

Figures 9 and 10 show the distribution of foreign matter and residual chlorine concentrations, respectively, which were obtained from analyses using P-DES. Iron rust and pieces of coating showed almost the same distributions, indicating they were both deposited after having been transferred not so far from their places of origin. The regions of low residual chlorine concentration exhibited a tendency to spread widely in those areas mainly located at the ends of the distribution reservoir region.

Verification at site and setting of monitoring point

Based on the map of foreign matter, we extracted spots for confirmation, visually verified with the in-pipe camera (see Figure 11), of how foreign matter was deposited, collected various samples of foreign matter by pipe-washing, and investigated residual chlorine concentration at respective sites. As a result, the deposits of foreign matter were found at almost the same points as shown on the map of foreign matter. While the values of residual chlorine concentration obtained on the map for monitoring residual chlorine concentration indicated nearly the same tendency as the measured values, those values were a little different from one another at some points.

From the results mentioned above, it was confirmed that the map of foreign matter and the map for monitoring residual chlorine concentration, both of which are the results of analyses by P-DES, provide a useful means to predict important monitoring regions on which emphasis should be placed. However, because some discrepancies between the predicted and measured values were evident (see Table 3), it is necessary, in the application of the Water Safety Control Manual, to further build up data, improve precision of P-DES, and review and revise the Water Safety Control Manual as required.

Table 3 | Comparison between results of simulated residual chlorine concentrations and measured values

Investigation spot		1	2	3	4	5
Residual chlorine concentration (mg l^{-1})	Simulation	0.093	0.202	0.262	0.036	0.241
	Measurement	0.100	0.300	0.400	0.300	0.400
	Error	0.007	0.098	0.138	0.264	0.159

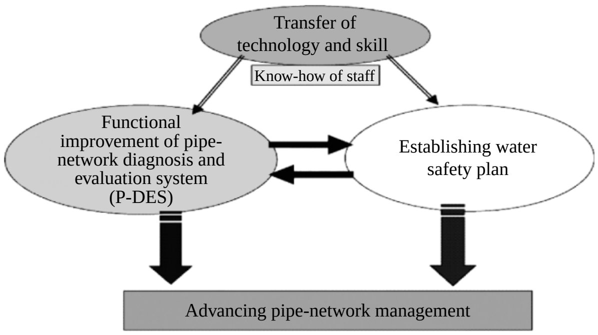

Figure 12 | Conceptual drawing of pipe-network management.

NEW DEVELOPMENTS IN PIPE-NETWORK MANAGEMENT

As can be seen in the cases described above, P-DES and the Water Safety Control Manual provide useful tools to compensate for the lack of experience of technical staff. Furthermore, these tools are not only utilized individually but also bring a wider application range when used in relation to each other. The system and the manual, which have recently been put in operation, however, need further improvement of precision and refining of content.

Kobe City recognizes the process, in which we operate these measures for pipe-network management and for building up of related data, as a place for technology transfer. For example, while the monitoring maps for the turbid materials and residual chlorine concentration prepared by using P-DES are compared and confirmed with the data obtained on site, we are also trying to apply this site-confirmation method to other points where the experience and sense/intuition of veteran staff suggest a necessity for monitoring. Those results and data will be analysed and built up in order to improve the precision of P-DES as a system and to review the Water Safety Control Manual to improve the content. When deciding the affected area during a system changeover or following an accident, we also try to establish the washing plan and monitoring points taking into account the results of analyses and the experience and ideas of veteran staff.

In recent years, as can be seen in most places, many veteran technicians have reached retirement age, providing us with a serious challenge in terms of transferring their technical know-how. Thus we must proceed with formulating our *Technology and Skill Transfer Plan* (Kobe City Waterworks Bureau 2008*a*). The steps to improve the functions of P-DES and to draw up the Manual for Water Safety Control in a Distribution Network are nothing other than a process of building up technologies (see Figure 12). We believe the process is a 'new development' that includes a factor to advance the maintenance of pipeline systems by offering feedback to ongoing operations.

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