Strategic Restructuring of Waterworks Facilities through the Utilization of Asset Management

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Abstract
By adopting an asset management system, Tokyo Waterworks has promoted a strategic plan for restructuring the purification plants that are to be renewed almost simultaneously during the same period in the near future. The implementation flow of asset management in renewal planning is composed of a cycle of the following three stages: In *the inspection* stage, various factors in terms of concrete deterioration of purification plants are objectively quantified through inspection at certain periods of time based on uniform standards. In *the compilation of a database* stage, vast amounts of data are comprehensively managed. In *the deterioration prediction and life-cycle cost (LCC) calculation* stage, outputs of several tens of thousands of LCC calculation results are obtained based on repeated calculation of assumed renewal patterns. From the results, optimal plans for purification plant renewal were formulated through the selection of scenarios with the minimum LCC that met the necessary water treatment capacity, intended service life and matters necessary for services operations. It has been confirmed that it takes long to complete the renewal plan, and thus that it is necessary to formulate facility repair plans that aim to reduce unevenness in, and extend the lives of, those plants. Thus, Tokyo Waterworks is utilizing asset management from a perspective of LCC minimization in facility repair plans.

Keywords
Restructuring of water facilities; asset management; alternative facilities

INTRODUCTION
Tokyo Waterworks intensively expanded waterworks facilities in order to respond to the surge of water demand in the high economic growth period. In particular, many of purification plants were developed between the 1960s and 1970s, which are to be renewed almost simultaneously during the same period in the near future. It has been pointed out that the deterioration in the concrete used for purification plant facilities has been accelerated compared with general facilities due to physical factors such as reverse cleaning and chemical factors including chemical dosing (Eiji et al., 1996, 1997). In addition, as for the advanced water treatment system that we recently introduced, it has been reported that the deterioration of frame concrete is likely to be accelerated, compared with conventional waterworks facilities, due to the acidic atmosphere and flow friction in the biological activated carbon adsorption basin (Noriya et al., 2015). Most of the structures at purification plants are composed of concrete; thus, appropriate understanding and prediction of the concrete's deterioration level are crucial in facility renewal and repair. In this regard, Tokyo Waterworks has promoted the strategic restructuring of such facilities by establishing an asset management system based on deterioration evaluation through regular concrete inspection and utilizing the system for medium- and long-term deterioration prediction. This paper describes the process step by step.

INTRODUCTION OF ASSET MANAGEMENT

Implementation flow
The implementation flow of asset management that Tokyo Water Works has adopted is composed of the following cycles: (1) inspection, (2) compilation of a database, and (3) deterioration prediction and life-cycle cost (LCC) calculation. By regular inspection, we understood, and compiled a database of, the deterioration level of concrete that makes up facility buildings, thereby predicting the deterioration progress and evaluating the LCC.

Inspection

The inspection is the most basic and crucial step in the implementation flow of the asset management. There was no established evaluation method to predict deterioration based on the inspection data because the structures of purification plants differ in materials and usage environments depending on their intended purposes. For this reason, we started with consideration of setting up a uniform inspection standard because we thought that to do so would be necessary for proper understanding of future deterioration progress and comprehensive planning of renewal and repair projects for multiple purification plants. As an example of the results of the consideration, Table 1 shows an inspection standard in terms of concrete cracks. We categorized inspection details, subjects and frequencies according to their purposes.

Table.1 Inspection standards of concrete cracks

Deterioration category	Detailed survey, - Quantitative evaluation by crack density d(m/m^2) -	Brief survey, - Qualitative evaluation by visual inspection -
A	d < 0.01	No crack
B	0.01 ≦ d < 0.03	No leakage and free lime
C	0.03 ≦ d < 0.25	Free lime identified
D	0.25 ≦ d < 0.50	Minor leakage
E	0.50 ≦ d	Running leakage

Regular inspection. A detailed survey of representative facilities to be carried out once a decade to quantitatively understand the deterioration levels (e.g. crack density, width and length) and then rank them depending on the obtained values. This survey aims to select repair methods by estimating deterioration evaluation and causes, and calculate the costs.

Midterm inspection. A brief survey of 25% of all the purification plants once in five years aiming to prevent fatal events by understanding the deterioration levels of places that cannot be checked by daily and brief inspections (e.g. inside the basins). We rank those deteriorations depending on the status of leakage and the existence/nonexistence of free carbon dioxide, select repair methods based on the estimate of deterioration causes, and utilize them for setting unit prices.

Brief inspection. A conventional visual inspection of the status of facilities and their damage once in two years aiming to qualitatively understand the status of damage and the number of damaged places, and to take emergency measures.

Compilation of a database

Tokyo Waterworks established a database dedicated to its asset management system in which to input factors (e.g. developing history and capacity of purification plants) of each waterworks facility. In addition, we have accumulated the data obtained from inspections and repairs as needed.

Deterioration prediction and LCC Calculation

Deterioration prediction. By using inspection and repair data that are accumulated in the database, we become able to predict facility deterioration based on a probabilistic model. As for neutralization, a deterioration mechanism has been established; thus we predicted facility deterioration using the theoretical formula $y=bt^{0.5}$, where y = neutralization depth, t = time, and b = coefficient of neutralization velocity. In other cases, we predicted deterioration by analyzing the deterioration levels at different time points of construction and inspection based on the Markov transition probability matrix. Figure 1 shows the prediction based on the inspection data of cracks in the receiving well at the M Purification Plant in Tokyo. In this regard, the degree of deterioration at the time of its construction in 1975 was evaluated as A (i.e. zero degree), while deteriorations were categorized into A to E according to their progress at the time of its survey in 2009. The categories of deterioration 2010 and later are based on prediction.

LCC Calculation. The LCC at each purification plant is calculated from the sum of "construction and renewal costs during the evaluation period," "operating expenses such as chemical, electricity and effluent treatment costs," "facility renewal costs," and "repair costs of concrete structures." As for the cost of repairing concrete structures, Tokyo Waterworks calculated the future accumulated repair cost C by multiplying the number of future repairs that was obtained from the deterioration prediction by the future repair unit price based on the selection of the optimal repair method. In LCC, the evaluation period is to be fixed in the field of bridge development, whereas it varies in terms of purification plant renewal plans. In order to reflect the length of the in-service period in the evaluation, we evaluated the LCC against the value per unit year that was obtained by dividing the total cost by the evaluation period using Formula 1. Figure 2 shows the details of variable and invariable that were used for the calculation.

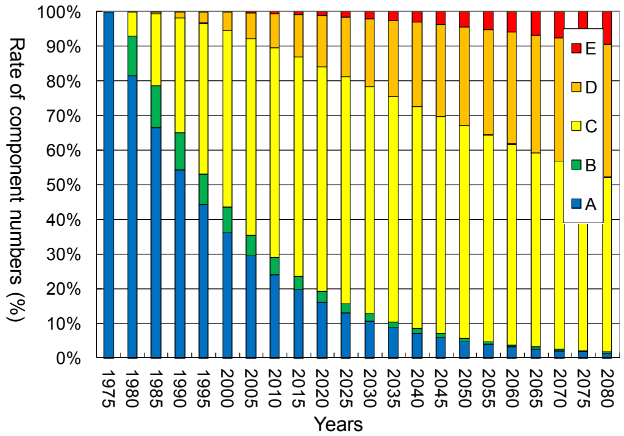

Fig.1 The rates of component numbers grouped A to E categories based on estimation of the concrete deterioration progress

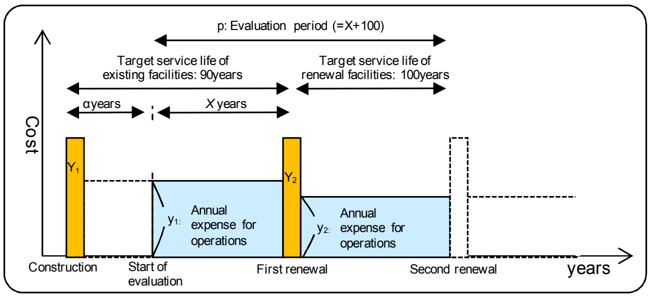

Fig.2 The symbols used for the calculation of LCC applied to replace planning of a purification plant. X is a variable. Y_1, Y_2, y_1, y_2 and α are constant

LCC (annual value)

$$= (Y_1+Y_2)/(p+\alpha)+(y1\cdot X+y2\cdot 100+C)/p \quad \text{(Formula 1)}$$

(Y_1: construction cost for a purification plant; Y_2: renewal cost for a purification plant; y_1, y_2: operating expenses; X: period until renewal; P: evaluation period)

Application of LCC analysis to purification plant renewal plans

It is required to minimize the renewal cost in order to reflect the calculated the LCC in purification plant renewal plans; this minimization needs to take account of matters necessary for services operations. In the following, I describe the scale of services and the required facility capacity of Tokyo Waterworks, which are the preconditions for the application of LCC analysis.

Scale of Services of Tokyo Waterworks. Tokyo Waterworks supplies water to about 1.3 million people in the area of about 1,200 km^2 including 23 special wards and 26 municipalities. There are 11 main purification plants which are mutually connected through transmission pipes, thereby forming a network. Their total capacity is 6.9×10^6 m^3 per day, the average daily water distribution amount is 4.2×10^6 m^3, and the total length of distribution pipes is 2.6×10^4 km.

Matters necessary for services operations. In particular, many of purification plants – about 70 percent of the total facility capacity – were developed between the 1960s and 1970s, which are to be renewed almost simultaneously during the same period in the near future. Their facility capacities have slightly decreased along with facility deterioration and strengthening of water quality control. Consequently, the amount of water available for supply is currently about 6.0×10^6 m^3 per day, which is tight in a state of water demand (planned daily maximum water distribution amount: about 6.0×10^6 m^3). On the other hand, they are required to retain the facility capacity of 6.8×10^6 m^3 per day to maintain water supply even in a serious situation such as a suspension of a purification plant associated with a disaster or a severe accident. Each purification plant is divided into multiple water treatment systems; therefore, we are mitigating the performance decline during the renewal work, by renewing a facility after system-by-system closure. Moreover, we decided to undertake a renewal work after developing an alternative purification plant that compensates the performance degradation in advance.

Deciding renewal periods by the asset management (LCC optimization). We considered that an optimal renewal plan is a scenario that the sum of LCCs of all the purification plants is minimized by taking into account matters necessary for services operations and then setting the renewal order and period.
First, we assumed the renewal period (see *X* year in Fig. 2) for each purification plant, thereby making a comprehensive renewal scenario that superimposes individual renewal plans of all the purification plants. In this case, however, the concentration of renewal periods leads to the insufficient capacity of water treatment. Next, we set the water treatment capacity required and the target life time as constraint conditions, and then regarded scenarios that meet the conditions as the first draft renewal plans. Although several tens of thousands of scenarios are extracted at this point, the unevenness of the renewal periods of all such scenarios are reduced by the setting out of the constraint conditions that lead to not only resolve the lack of sufficient water treatment capacity but also avoid the concentration of renewal periods. Lastly, we selected an optimal renewal plan in which the sum of all the purification plants' LCCs is minimized. At this stage, we selected the scenario with the minimum LCC from the scenarios that meet matters necessary for services operations such as the purification plant renewal by the system unit. This leads to the setting of the renewal order and period of each purification plant, and enables strategic promotion of a long-term renewal work while securing stable water supply. Figure 3 shows the process above.

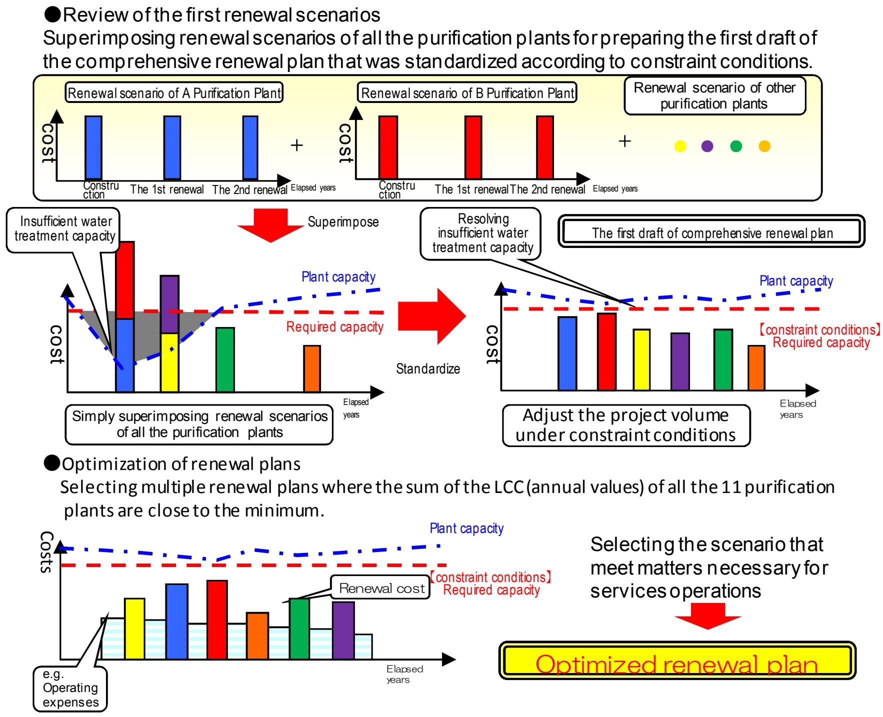

Fig. 3 the optimization process of renewal plans using LCC

Optimized renewal plan. By implementing asset management, it was confirmed that it takes about 60 years to renew all the purification plants by. A long-term renewal plan is divided into three stages according to the characteristics of services in each period. That is, they are the "renewal preparation period" for developing alternative water treatment facilities in advance to compensate for reduced capacities, "initial renewal period" for orderly renewing the target purification plants by system unit after the start of operations of alternative facilities, and the "stable renewal period" for reducing the unevenness in the volumes of renewal projects and stably implementing these projects (see Fig. 4). During this long-term period, we are restructuring the facilities at appropriate scales considering water demands and risk responses.

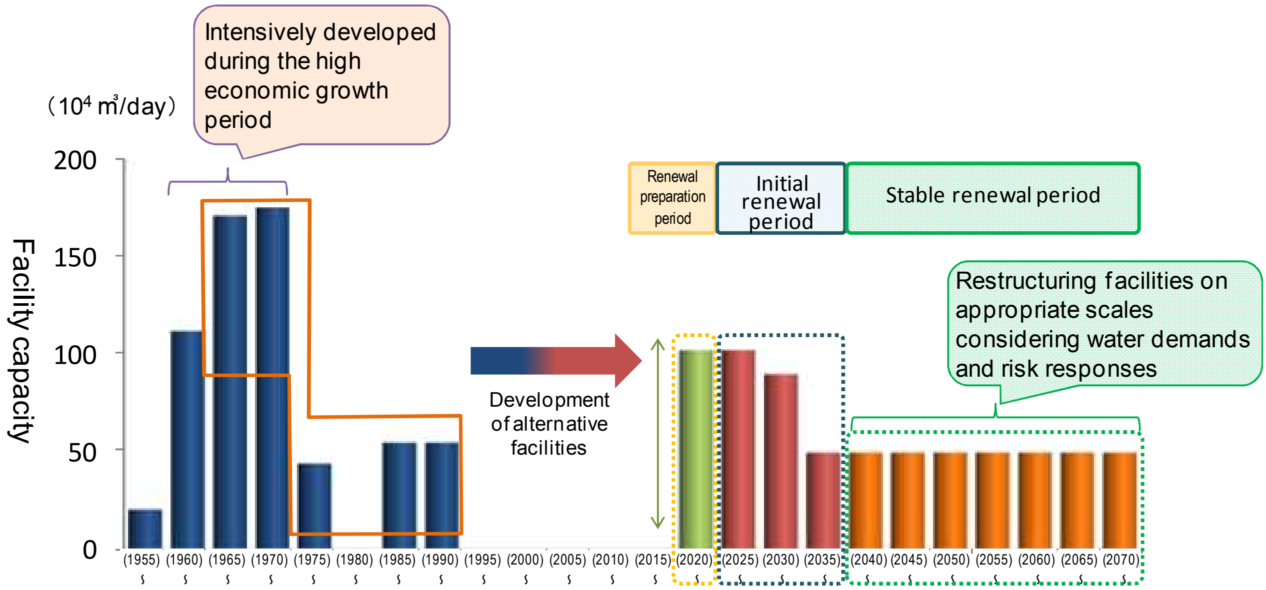

Fig.4 Conceptual diagram of the renewal periods of purification plants

Dealing with life extension of waterworks facilities

Necessity of life extension of facilities and asset management. As for facilities with a long in-service period until renewal, it may become difficult to ensure stable water supply along with the progress of aging. It is, therefore, necessary to promote life extension of facilities under optimal plans based on the understanding of the situation by utilizing asset management in terms of not only renewal of purification plants but also their repair. The Tokyo Waterworks Asset Management System includes a system that reviews repair plans for concrete structures within purification plant sites. The following describes a flow of the repair review.

Determination of degree of soundness based on degree of deterioration and repair priority. In order to extend the facility life by repairs, it is important how to evaluate the priority of facilities to be repaired. As for the decision on the priority, it is necessary to carry out an evaluation, taking account of the facility's functions and substitutability in terms of water supply in addition to the deterioration level and deterioration prediction that are categorised into A to E and already recorded on the database. Thus we introduced the soundness indexes (1 to 5) that reflect the influence on the substitutability and water supply functions of each facility (e.g. receiving wells and water distribution reservoirs) in the degree of deterioration. The priority among facilities to be repaired is automatically determined according to the degree of soundness and then reflected in the repair planning and LCC calculation.

Selection of minimum-LCC repair scenarios for each facility. Next, we calculate the LCC by setting representative multiple scenarios according to the soundness level in terms of the repair cost (e.g. repairs once in 5, 25, and 40 years) of each facility that constitutes a purification plant. The optimized renewal periods (X years later) are already determined for each purification plant; thus, from the multiple scenarios, we select the scenario with the minimum LCC in X years later for each facility.

Consolidation of repair costs in scenarios for each facility. We extract repair costs of all the individual facilities of all the purification plants in order to reflect them in the repair plan for the entire project. Figure 5 shows an example of a simple consolidation of scenarios for each facility. At this stage, the facility may frequently be shut down because the importance of that facility in the entire purification plant and each system, and the budget restrictions are not taken into account.

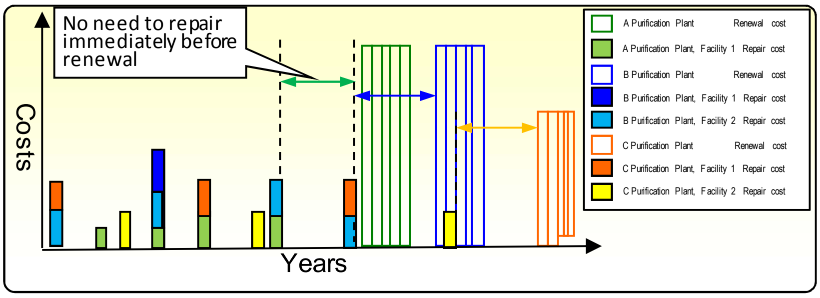

Fig.5 Conceptual diagram of consolidation of minimum-LCC repair scenarios for each facility of all the purification plants

Optimization of repair plans. Lastly, we select the optimized repair plans for all the purification plants by consolidating repair works at the same plant and stopping repair works at plants immediately before renewal. Also, because it is necessary to consider the reduction of unevenness in budget plans, we confirm the trend in the soundness level and postpone the repair period as required (see Fig. 6).

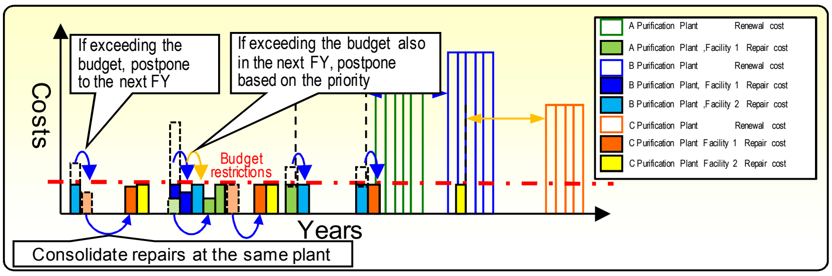

Fig. 6 Conceptual diagram of adjusting the cost unevenness of repair plans of purification plant facilities

Through the steps above, an optimal repair schedule is to be derived, which takes account of the reduction of unevenness in renewal periods and the repair costs.

CONCLUSION

This asset management system is what is used for the review of renewal and repair plans for concrete constructions at purification plants, which was introduced in 2012. Vast amounts of data of all the facilities were comprehensively managed under uniform standards by objective evaluation based on quantification of various factors; deterioration was predicted based on the data; the timings for renewal and repair of each facility were predicted, and their unevenness about the volume of renewal project was reduced from a medium- and long-term perspective; and the plan was strategically formulated.

In light of the evaluation based on this system, Tokyo Waterworks presented the Master Plan for Construction of Tokyo Waterworks Facilities in 2014 (Bureau of Water Works, Tokyo Metropolitan Government, 2014). This Plan sets the directions of not only renewal of all the purification plants of Tokyo Waterworks but also facility development including securing of water resources and renewal of pipelines. As additional values of restructuring of facilities, we have also taken account of our current challenges such as the Tokyo Inland Earthquake, heavy-rain and drought risks associated with climate change, deterioration of raw water quality, and the arrival of a population-declining society.

On the other hand, as for the purification plant renewal, we have undertaken the development work for alternative water treatment facilities. Following the start of operations of alternative facilities, we are undertaking a renewal work of a purification plant with the capacity of 1×10^6 m^3.

It takes a long period of time (about 60 years) to complete the renewal of all the purification plants; thus we strive to improve the accuracy of the system and utilize it for facility repair plans by continuing regular inspections to understand the facility status while taking account of water demand and risk responses as required.

References

Eiji O., Takeshi H., Toshiaki H., Reiko O. (1996), Deterioration of Concrete Used in the Water Treatment Plant with Activated Carbon. Proceedings of the Japan Concrete Institute, 18(1), 903-908.

Eiji O., Reiko O., Daiji N. (1997), Deterioration of Concrete Used in the Water Treatment Tank with Ozone. Proceedings of the Japan Concrete Institute, 19(1), 979-984.

Noriya M., Kentaro O., Kimitaka U., Shohei H. (2015), Investigation of concrete surface and water quality in existing water purification facility. Proceedings of the Japan Concrete Institute, 37(1), 625-630.

Bureau of Water Works, Tokyo Metropolitan Government, Japan (2014) Master Plan for Construction of Tokyo Waterworks Facilities