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Original Paper

Practical Analysis of Leakage Control Measures for Water Supply Pipe Network in a Urban Area in Eastern China

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Abstract

A city in eastern China regards the leakage control and control of urban water supply pipe network as an important means to improve the efficiency of urban fine management and water resource utilization. Through the implementation of construction content and implementation plans such as water supply pipe network transformation, water supply pipe network zoning measurement, water supply network pressure control, and intelligent construction of water supply pipe network, the leakage rate of urban water supply pipe network in urban areas has reached ≤4%, forming an advanced model of global intelligence of "leakage control". Create a "demonstration model of intelligent water supply" for the construction of new urban infrastructure, explore the intelligent construction and management mode of urban water supply, gradually promote it to the city and other regions of the country, promote the deep integration of information technology and the urban water supply industry, and achieve high-quality development of the urban water supply industry.

Keywords

water supply pipe network, pipe network leakage control, pipe network leakage rate, governance measure

A city in eastern China is a plain area, and the average water resources for many years are lower than the provincial and national averages, which is a resource-based shortage area. In addition, due to the limited water storage of the plain river network and the lack of regulation of large and medium-sized reservoirs, the water level of the plain water network is more than 3.92 meters during the flood period. In order to further promote the construction of a water-saving city, the city regards the leakage control

and control of urban water supply pipe network as an important means to improve the efficiency of urban fine management and water resource utilization. In accordance with the requirements of the National Development and Reform Commission and the Ministry of Housing and Urban-Rural Development, the city has deepened the fine management of water supply, upgraded and transformed old facilities, fully realized intelligent water supply control, and achieved a leakage rate of ≤4% of the public water supply pipe network. Strive to promote the "intelligent" management of leakage in urban water supply pipe networks, promote the leakage control and governance system and governance capabilities of urban water supply pipe networks with high quality, actively strive for pilot cities for leakage control of public water supply pipe networks, and strive to create a "internationally advanced, domestic first-class, scientific and intelligent" model project for leakage control of urban water supply pipe networks, and provide intelligent leakage control examples and scenario-based experience for cities across the country (Sun & Yuan, 2024).

1. Current Situation of Water Supply Pipe Network Leakage

The city's water supply pipe network is a ring pipe network, and the diameter of the pipeline in the water supply area is mainly DN1800-DN1000, and the road water distribution pipe is ringed, with a diameter of DN500-DN800. The length of the water supply pipe network is about 5,570 kilometers, and the pipes are mainly ductile pipes, and most of the pipes are less than 20 years old. In some old communities (villages), due to the fact that most of the pipes are cast iron pipes and galvanized pipes, the pipe network is seriously aging, and the pipe network is frequently repaired in disaster weather such as rain, snow and freezing.

The city has initially established a five-level zoning measurement management system, which has realized remote meter reading instead of manual meter reading, realized real-time analysis of leakage at the end of the community every day, real-time monitoring of large pipeline leakage, and accurately found small pipeline leakage. In 2020, a total of 1,349 leaks were detected in the city, and 14.22 million cubic meters of water loss and economic losses of 39.1 million yuan/year were recovered, but it is necessary to further continue to increase the construction of zoning and the analysis and application of actual pipe network leakage control.

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According to the "CJJ92-2016 Leakage Control and Evaluation Standard for Urban Water Supply Pipe Networks" (2018 Edition), the analysis of the water balance and leakage situation is shown in Table 1.

Since 2001, the urban area has invested a lot of energy in comprehensively carrying out a comprehensive pipe network census, strengthening the construction of information systems, strengthening assessment and supervision, and continuously promoting the leakage control of the water supply pipe network. After more than 20 years of efforts, the leakage rate of public water supply pipe network has dropped from more than 20% to about 6%, and has remained low and stable. According to the National Development and Reform Commission and the Ministry of Housing and Urban-Rural Development's "Notice on Organizing and Carrying out the Pilot Construction of Public Water Supply Pipe Network Leakage Control" and the "Notice on Strengthening the Leakage Control of Public Water Supply Pipe Network", within the scope of the pilot, the water supply pipe network transformation, water supply pipe network zoning measurement, water supply pipe network pressure regulation, water supply intelligent construction and other construction content and implementation plan are implemented to achieve the leakage control goal of public water supply pipe network leakage rate of $\leqslant$ 4%.

Table 1. The City's 2020 Water Balance Table by 10k tons

Total water supply	11973.6	Registered user water volume	Calculate the amount of water volume	11085
			Free water onsumption	/
		Leakage of water volume	Leakage of water volume	426
			Measure the amount of water lost volume	443
			Other water losses	19.6

2. Leakage Control Measures

2.1 Water Supply Pipe Network Transformation

Water supply pipelines are the "blood vessels" and "lifelines" on which cities rely for survival and development, and are an important part of urban infrastructure construction. The renovation of the water supply pipe network mainly includes the renovation and transformation of municipal water supply pipelines and valve wells and other ancillary facilities that have exceeded the age limit, are backward and have been repaired at a loss, the transformation of the community pipe network and ancillary facilities, and the transformation of old secondary water supply facilities. Choose pipes that are corrosion-resistant, long-lasting, and low-maintenance, such as ductile iron pipes, and update them for critical areas. At the same time, consider the use of new environmentally friendly materials such as HDPE and the application of trenchless technology to reduce the impact of construction on the environment and community life, and minimize prolonged water service interruptions. From 2023 to 2025, a total of 29 communities or villages in the city will be renovated for water supply pipes; Replace the valves of the city's water supply pipe network with DN300 and above damaged and restricted use.

After the completion of the project, the collection, sorting, and archiving of pipeline identification and completion data should be done in a timely manner, as well as the GIS system entry of as-built drawings, laying the foundation for the leakage analysis and control of the pipe network after grid connection and water operation.

2.2 Zonal Metering of Water Supply Pipe Network

DMA (District Metering Area) refers to the method of dividing the pipe network into several relatively independent areas by cutting off the pipe section or closing the valve on the pipe section, and installing flow meters on the inlet and outlet pipes of each area, so as to realize the monitoring of the inflow and outflow flow in each area (Li, Tang, Liu et al., 2024; Zhao, Hou, He et al., 2023).

The city's current zoning measurement level is level 5, and the overall division standard is the first level of measurement division: a total of 5 divisions in the main branch pipeline, urban area, eastern district, southern district, and west district (Figure 1); The second level of measurement zoning: the first phase of the general branch, the second phase of the general branch, the third phase of the general branch, etc., the administrative towns (streets) under the jurisdiction of each branch, a total of 20 second-level divisions; The third level of measurement zoning: the general branch pipeline section and the branch secondary measurement zone are divided into several zones according to the sparse pipelines, rivers, main roads, and mountains; The fourth level of measurement zoning: the measurement zone with communities, villages (natural villages), and small industrial agglomeration areas as the measurement unit; Level 5 measurement zoning: zoning with units in the community, village branches, and enterprises in industrial zones as the unit of measurement.

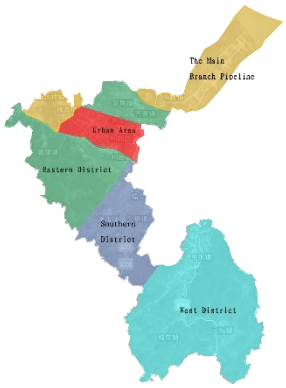

Figure 1. Schematic Diagram of the Partition

Combined with the scope of the water supply area and the current situation of the pipe network, improve the construction of the second and third level zoning metering layout from 2024 to 2025, and install 49 zoning flow meters (42 electromagnetic flow meters, 7 electromagnetic water meters); Improve the construction of the metering layout of the fourth and fifth levels, and install 138 water meters (89 in the fourth level and 49 in the fifth level). After the completion of the project, the city will

form a zoning measurement management system of first-level metering area, second-level metering community, third-level community, rural general assessment and unit assessment table, realizing the five-level zoning measurement management system that combines points, lines and surfaces of "company, branch, region, community, and unit", which provides effective technical support for subdividing measurement cells, mastering water volume changes, and scientifically controlling pipe network leakage.

2.3 Water Supply Network Pressure Regulation

Pipeline network pressure control management is an important technical means for pipeline network leakage control and one of the important ways of pipeline network operation and scheduling. Reasonable control of the pressure of the water supply network is a fast and effective technical method to reduce the leakage of the water supply network. Adopt pressure control measures that combine overall pressure control (water plant outlet, first-level) and local pressure control (branch line, community) to control pipe network leakage. By the end of 2024, the overall pressure control adjustment plan will be completed, and the online pressure monitoring point settings and pressure management systems for water plant outlets, water supply disadvantages, regional transfer points, and gravity water supply branches will be improved. By the end of 2025, the local pressure control plan will be completed, and if possible, it will be changed to a remote control flow control valve (suitable for pool outlet adjustment) or an electric valve (suitable for pipe network adjustment), and several pressure zones will be established according to the height difference and pressure demand of the local force, and water supply will be carried out according to different pressure standards. Carry out general pressure measurement of the pipeline network, and add pressure reducing valves at the entrance of the pipeline for local full-time pressure exceeding 35 meters of branch lines and DMA areas, and implement constant pressure or time-adjustable control (Wu, Wen, He et al., 2024).

2.4 Intelligent Construction of Water Supply Pipe Network

In order to realize the intelligent operation and management of the water supply system, through the long-term monitoring of the partitioned flow of the intelligent pipe network system, grasp the law of water volume changes in the area, especially pay attention to the change trend of the minimum flow at night, which can accurately judge whether there is a new leakage, and finally shorten the perception or discovery time of the leakage, and can also effectively guide manual auxiliary leak detection and improve the efficiency of leak detection.

By the end of 2024, the city will improve the layout of the water quality monitoring and perception system, realize a three-level water quality monitoring network of the main pipe network, branch pipe network, and terminal pipe network, focus on strengthening the intelligent monitoring and construction of water quality for users, especially the intelligent monitoring of residents' drinking water terminal water, improve the ability of water sample monitoring risk assessment and research and judgment, and add water quality pipe network monitoring facilities. Promote the application of intelligent equipment and the construction of information security systems, achieve comprehensive improvement of the

intelligent business management level of water supply and leakage control management capabilities, and form management standards and technical systems. By the end of 2025, through the deep integration of advanced control technology, information technology and water business in the industry, models and scenario algorithms of complex systems will be built, intelligent management tools and core support software will be created, and an intelligent management system for water supply business control will be realized, and the urban water supply data brain will be truly realized.

2.4.1 Construction of Noise Monitor for Water Supply Pipe Network

Noise monitors are mainly used to detect and analyze specific noises caused by water leakage during the operation of water supply pipe networks, so as to detect and warn potential pipeline leaks in time.

In order to further improve the coverage of the pipe network of leakage early warning equipment, ensure that the factors affecting the safety of pipeline operation can be discovered and eliminated in a timely manner, effectively improve the leakage detection efficiency of the pipeline network, and establish a leak control mechanism of "fixed-point monitoring, dynamic distribution and manual positioning". It is planned to deploy 450 early warning instruments in important pipe sections of DN300 and above in the region.

2.4.2 Hydraulic Model Construction

The intelligent online hydraulic model management platform integrates various functions such as dynamic hydraulic model, GIS, pipe network monitoring, scheme management, early warning management, intelligent analysis, and accuracy statistics to form a comprehensive and efficient management platform suitable for the daily operation of water supply enterprises. The platform enables the management departments distributed by the water supply company to operate conveniently through the network, and becomes an operation management platform for real-time monitoring and dynamic decision-making of the water supply network.

The mainstream platform is used to establish a dynamic hydraulic calculation and analysis platform for the application of water supply pipe network for the city's DN100 and above caliber water supply pipe network and ancillary equipment and facilities, and proposes a scientific and reasonable operation and management plan for the future pipe network management. Combined with geographical topography, pipe network topology and operation status, the zoning optimization mode of pressure balance is realized. On the basis of making the best use of existing pipelines, valves, meters and other facilities, reduce energy consumption and pipe network leakage without affecting normal water supply. The optimized water supply mode will improve the city's pipe network management and bring economic and social benefits to the city's water supply.

2.4.3 Water Meter Intelligent Remote Transmission Transformation Project

The traditional mechanical water meters of residential communities and users will be upgraded to the construction project of smart water meters with remote data transmission functions. Thus, it improves the modernization level of urban water management, realizes intelligent and refined management, and also facilitates residents' lives. In 2024, it is planned to renovate about 30,000 multi-storey corridor

meters, so that the long-distance transmission coverage rate of residents' water meters will reach 45%, and in 2025, it is planned to renovate about 22,000 multi-storey corridor meters, so that the long-distance transmission coverage rate of residents' water meters will reach 50%.

2.4.4 Construction of Noise Detector for Water Supply Pipe Network

Noise monitoring technology enables leak detection by capturing sound signals in specific frequency bands (typically 20-3000 Hz) generated by pipeline leakage. As of the research cycle, the city has completed the deployment of 575 fixed noise monitors, forming a preliminary monitoring network covering the main pipe network (DN500 and above), as shown in Figure 2. The data analysis shows that the average detection time of leakage events has been shortened from 48 hours to 9.6 hours by traditional manual inspection, but there are the following limitations: the coverage rate of secondary pipe network (DN300-DN500) is insufficient (only 42%); complex geological areas (such as soft soil areas); The signal attenuation is significant, and the false alarm rate of multi-noise source jamming scenarios is high (about 18%). In response to the above problems, the optimization plan of "three-zone linkage" is proposed: 450 new equipment will be added in the three key areas, and priority will be given to the deployment of DN300 and above pipe sections.

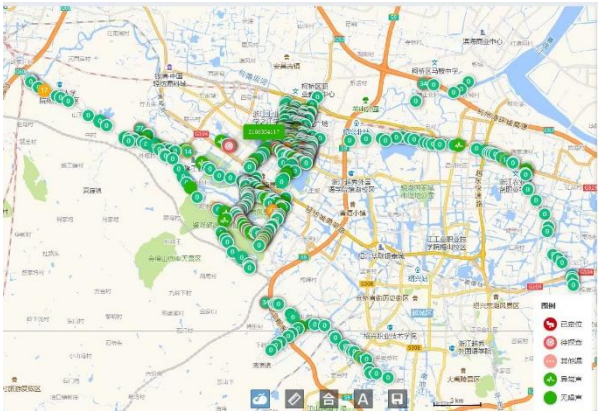

Figure 2. Noise Monitor Platform

3. Conclusion

The leakage control measures of the public water supply pipe network will further improve the city's existing leakage control system, form a basic data map of the water supply pipe network, pumping stations, water plants and other information through GIS, and establish a new mechanism for data dynamics, and continuously improve the intelligent management and control system of "zoning metering, zoning pressure control, and zoning early warning" to build a long-term management that supports the long-term management of pipe network leakage control, that is, to realize the new improvement of water governance capabilities and the reengineering of pipe network operation and maintenance mode with intelligent collaborative and refined management, and build pipe network scheduling, leakage warning, and pipe burst warning , water quality early warning, hydraulic model

and other systems to achieve optimal water supply scheduling, auxiliary decision support, intelligent leakage control, and long-term management of leakage control, and achieve the demonstration goal of building a model project for the construction of intelligent leakage control in national water supply (Wang, Tao, & Yan, 2024).

With the deepening of leakage control, the input-output benefit of unit leakage control gradually decreases, or the cost of reducing unit leakage water gradually increases, when the enterprise invests in leakage control more than the water-saving benefit (cost), from an economic point of view, the water supply enterprise will have a loss, this critical value is the economic leakage level of the enterprise. Taking the level of economic leakage as the control leakage goal of enterprises is to ensure the maximization of enterprise profits. At present, the city's water supply pipe network leakage control needs to find a balance between the optimal social control level and the economic leakage control level of enterprises, and the government coordinates the leakage control of water supply enterprises according to the interests of the whole society, and encourages enterprises to continue to promote leakage control and the transformation to intelligent leakage control.

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