ISSN: 2414-1895 DOI: 10.6919/ICJE.202311_9(11).0009

Research Progress of Non-excavation Rehabilitation Technology for Drainage Pipe

Zhiqiang Wang[1,2], Tao Ma[3], Xiaohui Yu[1,2], Qing Wang[1,2], and Nan Wu[1,2,*]

[1] Key Laboratory of Smart Breeding (Co-construction by Ministry and Province), Ministry of Agriculture and Rural Affairs, Tianjin Agricultural University, Tianjin 300392, China

[2] College of Engineering and Technology, Tianjin Agricultural University, Tianjin 300392, China

[3] College of Chemical Engineering and Material Science, Tianjin University of Science & Technology, Tianjin 300457, China

Abstract

With the progress of urbanization in China and the development of underground pipeline networks, the demand for city drainage is also increasing. The improper planning and use of drainage pipes result in pipeline breakage and serious aging. The repair cost of traditional excavation of pipelines is huge, so pipeline non-excavation repair has become a focus. The study reviewed the common pipe trenchless repair methods, such as the spiral winding method, in-situ curing method, spraying method, etc. The whole technological process of the pipe trenchless repair and the application of a digital management system in pipe trenchless were summarized and prospected. On this basis, the non-excavation repair methods of pipes were compared, aiming to provide technical references for pipe non-excavation repair works.

Keywords

Drainage Pipe; Non-excavation; Rehabilitation.

1. Introduction

With the expansion of the city scale and the increase in population, the drainage needs of the city are also increasing. A properly designed and effectively managed drainage system is essential to ensure the normal operation of the city and the quality of life of its inhabitants. Underground drainage systems include drainage pipes, drainage wells, pumping stations, and other facilities for collecting, transmitting, and treating urban drainage. Underground drainage systems can effectively collect and transmit wastewater, but once the drainage pipes are damaged, the drainage system will be paralyzed, which can cause urban flooding, road collapse, and other problems. Inspection and rehabilitation of drainage pipes are essential to protect urban property and people's safety.

In the process of underground drainage pipe network rehabilitation, the traditional excavation construction method may have some problems, such as interference with urban traffic and life, long construction periods, and difficulty in ensuring the quality of the project. Therefore, pipe trenchless technology is getting more and more attention and application. Pipeline non-excavation technology refers to the methods of pipeline laying, repair, and maintenance without large-scale excavation of the ground. These technologies include the folded lining method, in-situ curing method, spraying method, spiral winding method, and so on. They can reduce damage to the urban environment, shorten the construction period, reduce costs, and improve the quality and safety of the work.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202311_9(11).0009

2. Process Overview for Pipe Rehabilitation

Before rehabilitating a pipeline, three general steps need to be performed: pipeline diagnosis, identification of needs, and selection of rehabilitation options and techniques, as shown in Fig. 1 [1,2].

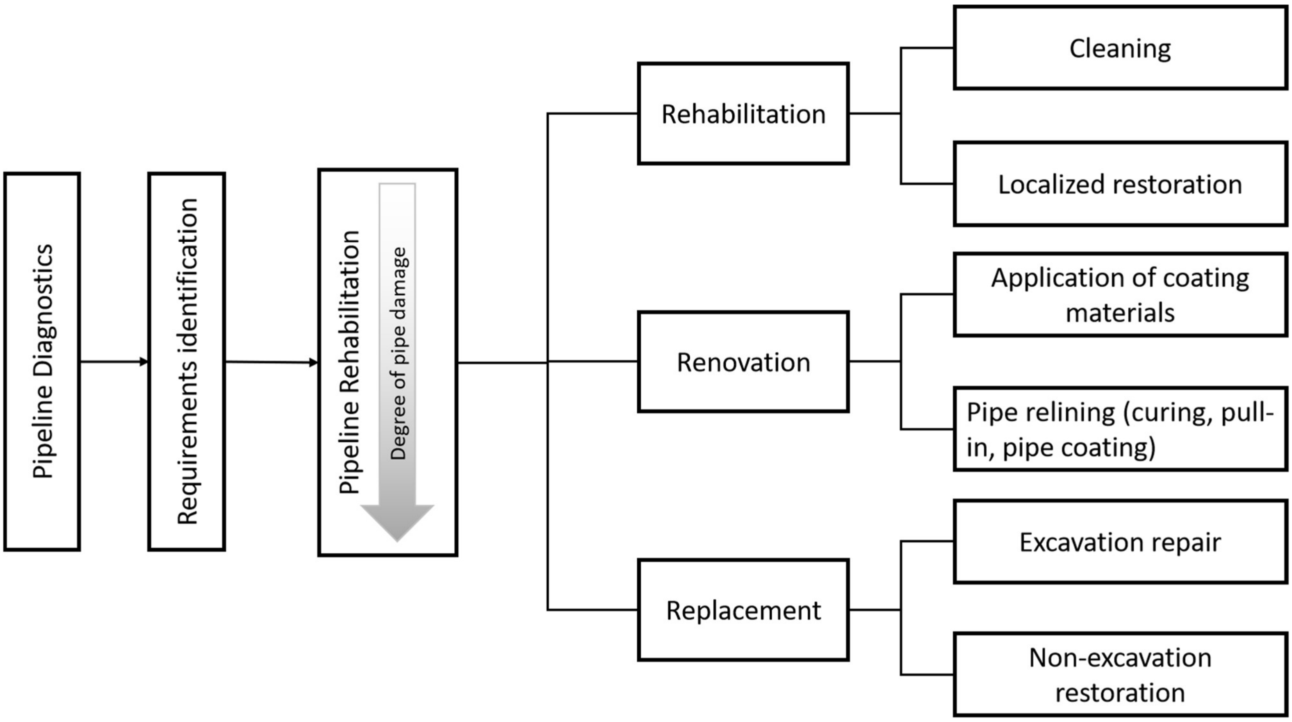

Fig.1 General process of pipe rehabilitation.

2.1 Pipeline Diagnostics

An accurate diagnosis of the current condition of the pipe is required before performing pipe rehabilitation. For larger pipelines, a manual inspector can assess the condition of the pipeline through visual inspection, including checking for damage, leaks, and other issues. However, for pipes that are smaller or not easily accessible to manual inspection, the option of using a pipeline robot will be used. Pipeline robots can carry cameras, sensors, and other devices to enter the interior of the pipeline by remote control or autonomous navigation to obtain real-time images, data, and conditions of the pipeline to help detect and assess pipeline problems.

2.2 Determining the Need

Before performing pipeline rehabilitation, the current pipeline problems and needs need to be identified. This includes identifying the extent of damage to the pipeline, determining the urgency of the rehabilitation, and assessing the economics and feasibility of the rehabilitation.

2.3 Selection of Restoration Options and Techniques

Based on the diagnosis of the degree of damage to the pipe and the assessment of current needs, appropriate rehabilitation programs and techniques are selected, including the selection of suitable rehabilitation materials, processes, and equipment to implement the rehabilitation work. Common pipeline rehabilitation includes localized repair, pipeline filling, and pipeline replacement. The most suitable rehabilitation program is selected based on the specific conditions and characteristics of the pipe

3. Pipeline Inspection Technology

According to the Technical Procedures for Detection and Evaluation of Urban Drainage Pipes (CJJ181-2012) [3], pipeline defects are categorized into functional defects and structural defects.

ISSN: 2414-1895
DOI: 10.6919/ICJE.202311_9(11).0009

Functional defects refer to the fact that with the prolonged use of drainage pipes, the pipes gradually show deposits, scaling, obstacles, etc., leading to a reduction in the drainage capacity of the over-water section. Structural defects refer to the physical defects such as rupture, corrosion, misalignment, etc. that occur with the aging of the drainage pipe, resulting in leakage of the pipe and pollution of the surrounding environment. Structural defects (denoted by R1) can be divided into 2 stages: $1<R1\leq 4$, more obvious defects appear, which need to be repaired in time; $R1>4$, indicating that the pipe has obvious defects, which need to be repaired immediately [2]. Regular inspection of the drainage pipe can timely detect leakage, seepage, blockage, and other problematic defects of the pipe, to carry out targeted repair of the pipe to avoid its further deterioration and reduce the possibility of disaster.

Drainage pipe defect detection technology can be divided into traditional detection technology and modern detection technology, traditional drainage pipe defect detection technology such as visual inspection of the pipe, measuring mud rod, and other methods in many aspects there are limitations, and cannot meet the requirements of the modern drainage pipe evaluation system, and there may be personnel safety problems [4]. Therefore, with the development of science and technology, the modern drainage pipe defect detection technology is being continuously improved and applied, the formation of a new technical system. A comparison of traditional detection technology and modern detection technology [4-6] is shown in Table 1.

4. Pipeline Non-excavation Repair Technology

Table 1. Overview of traditional and modern inspection techniques for drainage pipes.

	Traditional detection techniques		Modern detection techniques		
	Measuring clay rods	Reflecting-mirror method	Pipeline Closed Circuit Television (CCTV) Inspection	Sonar Detection	Pipeline Periscope Inspection
Inspection Systems	-	-	CCTV Operating System	Sonar Detection System	QV Detection System
Utilization equipment	Clay rods	Reflective lenses, retractable probes, and frames	Pipeline robot crawling system, power supply, camera, cable reels, main controller, etc.	The main controller (with dedicated acquisition software), probe (also known as an underwater unit with a floating carrier), and cable tray	Telescopic hand-held poles, support poles, high-zoom lenses, lights, controllers, and video recording systems
Applicable Diameter	-	-	>300mm	300~600mm	150~1500mm
Applicable Scenarios	Drier and harder sludge pipes	Shallow pipe	Low or no water status	High water status	Shorter pipes
Advantage	Simple, fast, and low cost		Easy to operate, high security, fast detection, high image quality, high judgment accuracy	Provides accurate data on pipe diameter, size of deposits in the pipe, water level in the pipe, and pipe deformation	Fast, low-cost, images can be viewed and analyzed on-site for easy computer storage
Disadvantages	Low accuracy, large human factor, low testing efficiency, more qualitative content, less quantitative results, low safety		Higher requirements for pipe cleaning and higher equipment requirements	Testing is cursory and does not detect all defects	Only suitable for shorter pipes

ISSN: 2414-1895 DOI: 10.6919/ICJE.202311_9(11).0009

Table 2. Common trenchless repair methods

	Restoration type	Applicable pipe size (mm)	Restoration materials	Cleaning require-ments	Work with water	Advantage	Disadvantages	Precedents
Folded lining method	Semi-structural restoration	150~1200	Fiberglass and other composite materials	Lower	Yes	Fast construction speed, less affected by the buried condition of the main line, long single repair distance	Straight pipes only, large construction space.	Beiling Pumping Station at the intersection of Mudanjiang Street and Qianshan Road, Shenyang [2]
Spraying method	Non-structural repairs	15~300	Spraying materials such as mortar and cement	High	Yes	Less service interruption, low construction intensity, and no environmental pollution.	Reduced inner diameter of pipes	Sewage inverted siphon crossing the Jin'an River in Xindian Area, Fuzhou City[7]
Spiral wrap	Structural Repairs	150~3000	PE-type material, PVC-U-type material	Lower	Allo-wed (not to exceed 1/3 pipe diameter)	With high strength, at the same time can work with water with high strength, a large diameter, a smooth inner surface, low construction noise, construction cycle is short.	Requires grouting, not suitable for maintenance-ance of pressure pipes	Rehabilitation of sewage pipes on a road in Wuxi [3]
Cure-in-place-pipe (CIPP)	Semi-structural repairs	100~2500	Thermoset or photoset materials	High	Yes	Close fit to the main pipe, no need for grouting, fast construction, suitable for curved and deformed pipes	Irreversible construction, high construction requirements, long resin curing time, special construction equipment, high technical requirements for workers' experience	Rehabilitation of sewers on South Beijing Road, Xuzhou City [5]

Pipeline trenchless rehabilitation technology first appeared in the 1970s in developed countries, and has nearly 20 years of exploration in China. Many different methods have emerged in the development process of trenchless technology, and after continuous optimization and improvement, the present folded lining method, spraying method, spiral winding method and in-situ curing method have been formed. These methods can effectively repair broken pipelines, extend the service life of pipelines, and improve the structure and function of aging pipelines, while having less impact on the ground, traffic, environment, and surrounding underground pipelines [7-8]. Table 2 summarizes the common non-excavation repair methods [2,8-14], each of which has its applicable pipeline conditions, which are specifically described below.

4.1 Folded Lining Method

The folding lining method through the deformation equipment will be HDPE pipe or stainless steel pipe folded into a "U-shaped" or "C-shaped", the amount of reduction in the control of 30% -35% or so, with a non-metallic winding tape bundled and fixed after the hauling and pulling into the original pipeline, and then through the pressurized or heated method to make it completely expanded and restored to the original pipe lined with a new pipe to complete the rehabilitation of pipelines. Then by pressurization or heating method to make it completely expansion recovery in the original pipeline lined with a new pipeline, complete the pipeline repair. When utilizing this restoration technique, the sealing treatment of the combined area must be done well to avoid the problem of sewage leakage [15,16].

The construction process is as follows: work pit excavation, water shutdown and pipe breakage, pipe pretreatment, PE pipe welding, mechanical pressure U-shape, shaping tape winding, hauling PE pipe to the old pipe, pipe end shaping, repairing the pipeline, pressure test and acceptance, pipe connection, and work pit restoration [17,18].

The beiling pumping station in northern Shenyang to Mudanjiang Road and Qianshan Road intersection pipeline project, the pipeline total length of 3895m, due to the original pipeline aging, local collapse, and misalignment problems need to be repaired, and the nearby communication, gas, drainage and other pipelines. With a comprehensive selection of "U" type HDPE pipe insertion technology for repair, the project has excavated a total of 12 operating pits, divided into 9 sections for connection, after a total of 1 month of construction to complete the repair [9].

4.2 Spraying Method

In the early 1930s, cement mortar was started to be mechanically sprayed to repair pipelines. In 1934, an 8.4km section of steel pipeline was repaired in Newark, New Jersey, USA, by spraying to eliminate leakage problems [19].

The spraying method is to spray the spraying materials such as cement mortar or organic chemicals on the inner wall of the pipeline for spraying repair. According to the different spraying methods can be divided into manual spraying and centrifugal spraying. Centrifugal spraying repair is a kind of repair method using centrifugal force to spray special cement mortar on the inner wall of the pipe. The specific operation is the pre-formulated special cement mortar through the pumping system to the high-speed rotating nozzle, the nozzle is driven by compressed air so that the mortar in the case of high-speed rotation uniformly thrown to the inner wall of the pipe. At the same time, the rotating spraying equipment is driven by the traction winch, traveling slowly along the central axis of the pipe. In this way, the repair material can form a continuous dense lining layer, and the thickening effect can be realized by round-trip operation [15].

Construction process: pipe pretreatment, rotary sprayer in place, liner spray construction, and pipe inspection [2]. In the broken sewage inverted siphon pipe repair project across Jin'an River in the Xindian district of Fuzhou City, the inverted siphon pipe is located at the bottom of the riverbed, with multiple internal leaks, but no structural deformation or damage, and the artificial spraying method is selected for the repair, and after water blocking, water transfer, pipe cleaning and unblocking, and spraying construction, the acceptance inspection of the repaired pipe is free of water seepage and dripping, and the surface of the inner liner is smooth and even, with no partial scratches, cracks, abrasions, bubbles, folds, and other defects that affect the structure and use of the pipeline. Wear, bubbles, folds, and other defects affecting the structure and use of the pipe function, the quality of repair is qualified [13].

4.3 Spiral Wrap

The mechanical spiral winding method was invented in 1985, initially developed by Tokyo City Drainage Service (TGS), Sekisui Chemical Company, and Adachi Construction & Industry Company, and the technology has been continuously developed and optimized [20] and was marketed by non-

ISSN: 2414-1895 DOI: 10.6919/ICJE.202311_9(11).0009

excavation restoration companies represented by Tianjin Yitong in 2013 with the introduction of equipment and materials for spiral winding [21].

The spiral winding method is the principle of prefabricated PVC, PVC-U, and other strip profiles and stainless steel belts through the inspection wells to the well in advance of the installation of the winding machine, the construction process of the winding machine in a spiral winding way will be synchronized with the winding of PVC-U strip profile and stainless steel belt, in the winding process of PVC-U strip profile edges of male and female locking interlocking the formation of a continuous and seamless high strength and good water tightness of the new pipeline, and then in the original pipeline and the new pipeline between the injection of slurry, to achieve the purpose of repairing the pipeline [21,22].

This process is generally as follows: construction preparation, pipe cleaning, pipe pretreatment, downhole pipe making, pipe grouting, and pipe testing [22]. In a road restoration project in Wuxi City, the restoration pipeline has a pipe diameter of DN500~DN600, the length of the pipe is 1199m, and the material of the pipe is reinforced concrete pipe and solid wall PE pipe. Near the pipeline, there are many kinds of pipelines such as electric power, fiber optic, etc., and the original pipeline interface has different degrees of rupture, disconnection, and leakage, and the pipeline repair level is assessed to be III, with a repair index of 6.4 [10], which needs to be repaired immediately. The project adopts a spiral winding method to repair, and the PVC-U strip profile and stainless steel strip are spirally wound to implement the "pipe-in-pipe" composite structure through the winding machine in the well. After the construction was completed, the quality of the pipeline was tested, and the test results were qualified and accepted.

4.4 In-situ Curing Method

The in-situ curing method first appeared in the UK in the 1970s and is one of the most widely used trenchless repair techniques. The working principle is that the outer polymer coating with a non-woven lined pipe or fiberglass, impregnated with polyester resin or epoxy resin, and then put into the drain pipe by pulling it in or flipping it over, and inflating it to make it close to the inner wall of the pipe. Water vapor heating or ultraviolet light, etc. to make it form a new liner pipe [14,23], to be closely integrated with the original pipe to complete the purpose of repairing the pipe. The different curing methods can be divided into heat curing methods and ultraviolet light curing methods.

The steps of in-situ curing are construction preparation, matting film laying, pulling in the hose, tying the head bundle, inflating the hose, carrying out curing, removing the head, treating the ports, and pipeline testing [23]. In the pipeline rehabilitation project on the west side of South Beijing Road in Xuzhou City, the rehabilitated pipeline is a DN800 concrete pipe, with a large area of broken pipes, serious water seepage at the wrong end of the pipeline interface, and a complex geographical location, and the pipeline is rehabilitated by UV curing method [12]. The will be lined pipe through the pull-in type into the pipe for inflation so that the hose is close to the repair of the inner wall of the pipe through the ultraviolet light curing hose repair pipeline, the calibration conforms to GB 50268-2008 "water supply and drainage pipe engineering construction and acceptance specification" provisions. After repair the pipe wall is smooth and smooth, the apparent quality is qualified, and the tightness test after repair is qualified.

5. Digital Management System

The process of non-excavation construction, it involves the collection and management of much information, including construction plan, material procurement, pipeline layout, underground facilities, etc. If this information cannot be effectively integrated and managed, it may lead to many unnecessary problems, such as inconsistent information and lack of timely updates, which in turn affects the efficiency and quality of the entire construction process. By integrating various information into a unified digital platform to form a digital management system (Fig. 2), more efficient and accurate construction management and monitoring can be achieved. The digital management system can integrate and manage a variety of data such as construction information,

ISSN: 2414-1895 DOI: 10.6919/ICJE.202311_9(11).0009

material information, piping information, etc., and provide a unified data storage and access interface. Through the digital management system, the following functions can be realized: centralized information management, real-time data updating, data sharing and collaboration, data analysis and decision-making support, and data recording and tracking.

The digital management system should be established under a cloud platform and should utilize technologies such as the Internet of Things, cloud computing, big data, and artificial intelligence. The digital management system should include a data transmission system, a data storage system, and a data application system. In addition, the system should have developable ports to meet the needs of secondary system development or system configuration. The digital management system should be able to accept manually collected data and contain a remote monitoring module, using large screen display equipment to show the overall layout of the digital management system and the interface of each system. Through the digital management system, the municipal drainage pipe in-situ curing repair project can be carried out in a scientific and standardized manner. This can improve the level and quality of the restoration project at the same time, but also ensure the safety of applicable, advanced technology and economic rationalization.

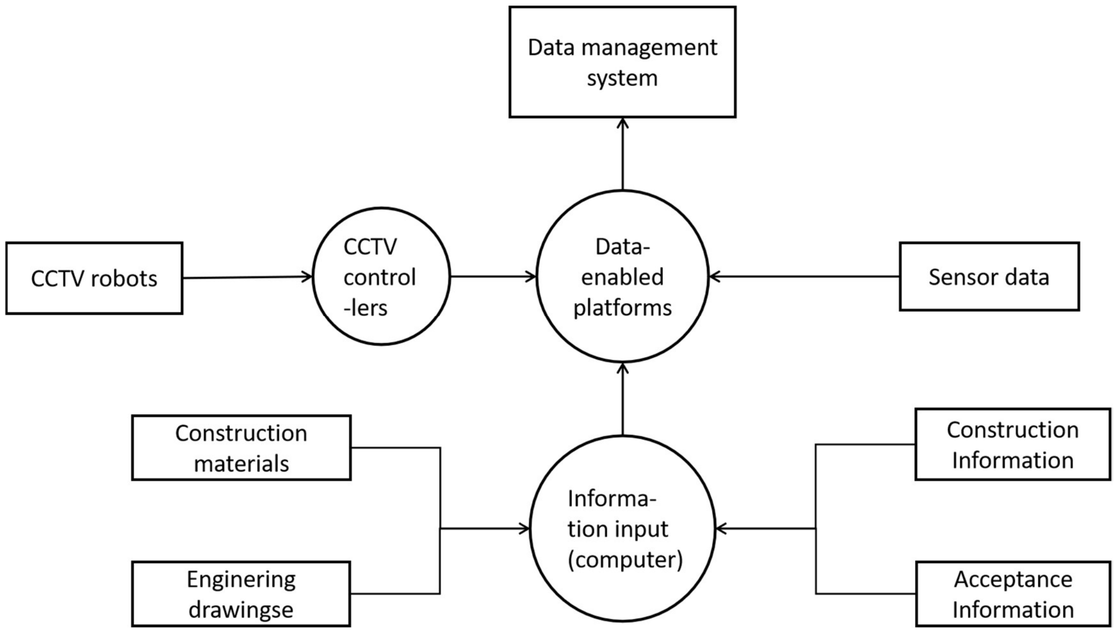

Fig. 2 Digital Management System

6. Summary

The aging and destruction of urban drainage systems create many problems for the urban environment. Traditional pipeline rehabilitation methods have a great impact on residents, and the emergence of trenchless technology provides new options and possibilities for rehabilitating pipelines and infrastructure. Compared with traditional open excavation methods, trenchless technology is more cost-effective and environmentally friendly. Although there are still some limitations of trenchless technology, such as limited scope of application, high technical requirements, and high cost, with the progress and innovation of science and technology, trenchless technology will have more advantages and broader prospects.

The development of an efficient digital management system combined with trenchless rehabilitation technology can realize the whole process monitoring and data management of trenchless rehabilitation works, reduce information redundancy and errors, and improve the quality and efficiency of the works. The digital management system can also provide real-time data analysis and decision-making support to help decision-makers make more scientific and accurate decisions, further enhancing the effectiveness of the trenchless rehabilitation project. In addition, while promoting the development and application of trenchless technology, relevant laws, and technical specifications should be formulated and perfected to ensure the quality and safety of trenchless rehabilitation works and provide guidance and support for the promotion and application of the technology.

Acknowledgments

This work was supported by the Tianjin Research Innovation Project for Postgraduate Students (2022SKYZ260) and Open Fund of Key Laboratory of Smart Breeding (Co-construction by Ministry and Province), Ministry of Agriculture and Rural Affairs (2023-TJAUKLSBF-2202).

References

[1] Tomczak E, Zielińska A. Example of sewerage system rehabilitation using trenchless technology. Ecological Chemistry and Engineering S. Vol. 24 (2017) NO. 3, p. 405-416.

[2] WEI Jia, XU Huai'ao, FANG Shuai, et al. Non-excavation repair technology for large-diameter interceptor pipeline renovation project. China Water Supply and Drainage. Vol. 39 (2023) NO. 10, p. 126-132.

[3] Ministry of Housing and Urban-Rural Development of the People's Republic of China. Technical specification for inspection and evaluation of urban drainage pipes: CJJ 181-2012[S]. Beijing: China Construction Industry Press, 2012.

[4] Li Jing. Research on inspection technology and residual bearing capacity assessment of urban drainage pipes. Railway Construction Technology. Vol. 2 (2023) p. 170-173.

[5] FAN Li, TANG Yinyin. Status quo of urban drainage pipe inspection technology and exploration of innovation. Shanxi Construction. Vol. 47 (2021) NO. 17, p. 104-105.

[6] LONG Tiantian. Application and applicability analysis of urban drainage pipe inspection technology. Urban Water Supply. Vol. 6 (2020), p. 79-84.

[7] WU Jianhui. A review of drainage pipe non-excavation repair technology. Urban Roads and Bridges and Flood Control. Vol. 8 (2012), p. 267-269, 273, 394.

[8] Bin L, Wei Y, Yongen X, et al. Trenchless rehabilitation of sewage pipelines from the perspective of the whole technology chain: A state-of-the-art review. Tunnelling and Underground Space Technology incorporating Trenchless Technology Research. Vol. 134 (2023), 105022.

[9] Li Rui: Research on the application of pipe lining repair technology in water supply expansion in Shenyang city (Master of Engineering, Harbin Institute of Technology, China 2019). p. 28, 36-46.

[10] QI Leiting, CHEN Qiuping, ZHOU Binyu. A case of a road sewage main using mechanical spiral winding repair project in Wuxi. Urban Road and Bridge and Flood Control. Vol. 3 (2023), p. 190-192, 221, 26.

[11] LI Yuanyuan, ZHAO Weiji, ZHOU Chao. Application of non-excavation repair technology of urban drainage pipe in a southern region. Urban Road and Bridge and Flood Control. Vol. 4 (2023), p. 142-145, 148, 19.

[12] Zhang Dengxiang. Application of ultraviolet light in situ curing method in the rehabilitation of sewage pipe network. Jiangxi Building Materials. Vol. 10 (2022), p. 406-407, 412.

[13] HE Ying. Research on the application of spraying repair technology in non-excavation repair of drainage pipe. Fujian Construction. Vol. 3 (2020), p. 114-117.

[14] WU Tian, LIU Qi. Application of non-excavation technology of UV in-situ curing method in pipeline rehabilitation. Water Conservancy and Hydropower Technology. Vol. 52 (2021) NO. S2, p. 143-147.

[15] YANG Xiaohui: Research on Repair Technology of Urban Drainage Pipeline and ItsEngineering Application (Municipal Engineering, XI'AN Technological Unioversity, China 2019). p. 25-28.

[16] Zhou Xiang. Introduction to the use of non-excavation lining repair technology for urban pipelines. Construction and Budget. Vol. 10 (2021), p. 107-109.

[17] JIN Jiazhong. Analyzing the application of U-type HDPE lining technology for pipe rehabilitation. Water Purification Technology. Vol. 35 (2016) NO. S2, p. 117-118.

[18] LIN Yongzhi, Mingqi. Underground pipe rehabilitation technology by U-shaped high-density polyethylene pipe lining method. Gas and Heat. Vol. 22 (2002) NO. 6, p. 500-502.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202311_9(11).0009

[19] LIU Lei: Theoretical Research on Spraying Repairof Sewer Pipe Strength (Master of Engineering, China University of Geosciences, China 2018). p. 6-15, 21.

[20] Li Ziming: tudy on the theory of spiral wound repair of drainage pipe in soft soil foundation (Geological Engineering, China University of Geosciences, China 2020). p. 28-29.

[21] YANG Jiaxing, CAO Jingguo, YANG Zongzheng, et al. Comparative study on domestic and international standards of mechanical spiral winding repair technology for drainage pipes. Water Supply and Drainage. Vol. 58 (2022) NO. S2, p. 617-625, 630.

[22] ZHANG Yingqiu, WANG Feng, YANG Wanhang. Spiral winding method for non-excavation repair of oversized drainage pipe. China Water Supply and Drainage. Vol. 38 (2022) NO. 6, p. 5-9.

[23] YANG Peifen, GUAN Cong, LIU Jianwei, et al. Research on the application of non-excavation detection and repair technology for underground pipe network[C]. Construction Technology Magazine, 2021, p. 312-315.