Accident Patterns and Risk Control in District Heating Pipeline Networks

Ying Chen[a]*, Guang Bai[b], Lianghai Lv[c], Yongqiang Bai[d], Mengyuan Xue[e], Tong Wei[f]

Institute of Urban Safety and Environmental Science, Beijing Academy of Science and Technology, Beijing, China

[a]*yingchen0511@outlook.com, [b]whitelight2001@163.com, [c]wellsea@163.com, [d]46926374@qq.com, [e]x15069203058@163.com, [f]975350221@qq.com

Abstract. District heating networks are critical urban lifeline infrastructure in northern China, yet their buried layout, high-temperature media, and winter peak-load operation make failures abrupt and socially disruptive. This study synthesizes publicly reported cases and a statistical review of accidents over the past two decades. Accidents are classified by subsystem (boilers, pipeline networks, heat substations, and pump stations), showing that pipeline leakage/rupture is the dominant event type. Corrosion-related degradation is identified as the leading cause (72%), followed by welding-quality defects (14%) and third-party damage (5%). An age-dependent failure mechanism is further observed: aging primary pipelines are mainly governed by corrosion and material deterioration, whereas newly commissioned pipelines are more sensitive to design and construction deficiencies. Based on accident-chain analysis—particularly water ingress, insulation degradation, and accelerated corrosion—this paper proposes a structured framework for risk identification and control to reduce casualties and service interruptions and enhance district heating resilience.

Keywords: heating, corrosion, resilience

1 Introduction

Urban space heating in China is delivered through a portfolio of supply configurations, including (1) city-scale district heating (DH) networks, (2) regional boiler-house heating using coal, natural gas, oil, or electricity, (3) geothermal and heat-pump-based heating, and (4) distributed household solutions such as clean-energy individual heating as well as legacy coal stoves in some areas. In many large northern cities, this portfolio has evolved toward a district-heating–led pattern in which multiple energy sources and heating modes coexist and complement each other.

This transition has been accelerated by air-quality and decarbonisation policies that promote "clean winter heating" and the substitution of dispersed coal combustion with cleaner options (e.g., efficient CHP-based district heat, gas boilers, electric heating, and

Y. Xu et al. (eds.), *Proceedings of the 2026 5th International Conference on Engineering Management and Information Science (EMIS 2026)*, Advances in Computer Science Research 130,
https://doi.org/10.2991/978-94-6239-652-4_22

heat pumps). At the same time, district heating systems are increasingly exploring renewable energy and waste-heat integration and large-scale heat pump deployment to diversify heat sources and reduce emissions.

However, the safety and reliability implications of this scale-up are non-trivial. Heating pipelines are typically buried and operate with high-temperature media; under winter peak loads, abrupt leaks or ruptures can escalate into scalding injuries, street subsidence, and widespread service disruption. Publicly reported incidents and investigation findings indicate recurring accident chains involving water ingress and insulation degradation that accelerate corrosion, construction and welding defects at critical interfaces, third-party excavation damage, and delayed reporting and isolation[1-4].

These patterns motivate a mechanism-oriented understanding of heating-network failures and practical risk controls. Accordingly, this paper synthesizes representative accident evidence to identify dominant failure modes and causal factors, and proposes a structured hazard identification and risk control framework for improving the resilience of district heating networks in dense urban environments.

In many cold-climate cities worldwide, district heating networks are not only a technical means of heat supply but also a strategic component of urban energy policy and sustainability transitions. By enabling large-scale utilization of combined heat and power (CHP), industrial waste heat, renewable energy sources, and heat pumps, district heating systems play a critical role in reducing primary energy consumption and greenhouse gas emissions. Consequently, their operational safety and reliability directly affect the effectiveness of clean-heating policies, urban resilience, and public acceptance of low-carbon energy transitions.

However, as district heating networks expand in scale and complexity, safety risks associated with buried high-temperature pipelines, aging assets, and dense urban environments have become increasingly prominent. Accidents in district heating systems can undermine policy objectives by causing service interruptions, public safety incidents, and social disruptions during winter peak-demand periods. From this perspective, improving the safety and risk management of district heating pipeline networks is not only an engineering challenge but also a prerequisite for sustainable urban energy systems.

2 Risk Characteristics of District Heating Pipeline Networks

District heating pipeline networks constitute a core component of urban district heating systems. As the scale of underground heating infrastructure continues to expand, risks remain despite continuous improvements in construction quality and operational management. These risks include asset aging, corrosion-induced leakage, third-party damage, and insufficient emergency coordination; they are more likely to be triggered under winter peak-load conditions and can produce substantial social impacts.

Representative publicly reported cases in recent years include: (1) on 1 December 2025, a main district-heating pipeline ruptured on Hongling Road, Shahekou District, Dalian (Liaoning Province), resulting in one fatality and one scald injury; (2) on 14 December 2024, a local rupture of a heating pipeline occurred at the intersection of Tianda South Road and Chaoyang East Road, Tianjiaan District, Huainan (Anhui Province), causing minor injuries to four pedestrians; and (3) on 20 November 2022, a service-line supply pipe at the Nanxiaoying No. 6 heat substation, Chaoyang District, Beijing leaked, and hot water backflowed through low-lying terrain into a nearby residential building's semi-basement dormitory, leading to two deaths and one injury. The official accident investigation attributed the Beijing event to damage of the outer protective casing that allowed corrosive media to intrude into the insulation layer, accelerating corrosion and perforation of the steel carrier pipe, while also highlighting delays in incident reporting and valve isolation.

Collectively, these incidents indicate that district heating network accidents often exhibit a compounded exposure of "high-temperature medium + concealed spaces/underground works + high pedestrian density", once leakage or rupture occurs, they can rapidly escalate into cascading consequences such as scalding injuries, asphyxiation risks, road subsidence, and widespread heating service interruptions.

Beyond pipeline leakage and rupture events, other accident types also contribute to safety risks in district heating networks. For example, failures of expansion joints or compensators have been reported in systems with improper fixed-support configurations, leading to axial displacement, joint pull-out, and subsequent leakage under thermal expansion loads. In addition, malfunctions at heat substations-such as valve failure or control-system errors-can result in localized over-pressure or delayed isolation, aggravating the consequences of upstream pipeline incidents. Pump-station accidents, although less frequent, may trigger cascading supply interruptions when redundancy is insufficient.

These diverse accident scenarios highlight that district heating safety risks are multidimensional and extend beyond simple pipeline corrosion, underscoring the need for integrated risk identification and differentiated mitigation strategies across system components.

3 Statistical Analysis of District Heating Pipeline Accidents

By collecting and reviewing district heating accident information from recent years in China and abroad, heating-system accidents can be categorized by the location of occurrence into boiler accidents, pipeline-network accidents, heat-substation accidents, and pump-station accidents[5]. A statistical assessment of accident cases over the past two decades indicates that the dominant event type is pipeline-network leakage. The principal contributing factors to leakage-related events include equipment corrosion, substandard welding practice/quality, third-party damage, and design deficiencies. In the data set analyzed, corrosion accounts for 72% of all accidents, welding-quality defects account for 14% of pipeline-network accidents, and third-party damage accounts for 5%. To enhance clarity, the statistical distribution of accident causes is visualized in Table 1 and Figure 1, illustrating the dominance of corrosion-related failures and the relative contributions of other factors. Beyond descriptive statistics, failure-probability assessment provides a quantitative basis for risk ranking and resource allocation in district heating networks [6].

Table 1. Factor Distribution Table for District Heating Network Leakage Accidents

Accident causes	Percentage
Equipment corrosion	72%
Welding quality	14%
Third-party damage	5%
Support failure	3%
Construction issues	1%
Casing leakage	3%
Design deficiencies	2%

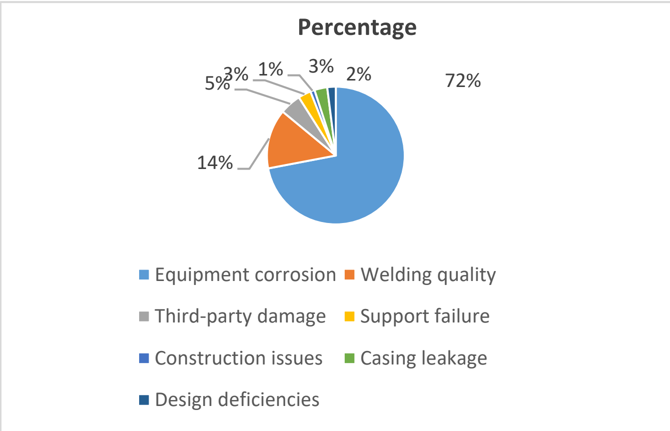

Fig. 1. Percentage Distribution of Contributing Factors for District Heating Network Leakage Accidents.

These results indicate that equipment corrosion is the leading cause of district heating pipeline accidents, primarily including corrosion of carrier pipes, corrugated expansion joints, air-vent pipes, corrosion associated with missing wall sleeves at wall penetrations, valve corrosion, and corrosion of drain/blow-down lines et al. Recent studies emphasize that district heating safety should be examined at the network level, where vulnerability and controllability jointly shape the propagation of failures and service disruption [7].

Equipment corrosion emerges as the leading contributor to district heating pipeline accidents largely because a substantial share of primary network pipelines has entered an aging stage, typically after 15-20 years of operation. For assets in this stage, failures are predominantly driven by corrosion-related degradation and material aging. In contrast, for newly commissioned pipelines in an early "infant" stage (approximately 1-5 years in service), accidents are more often attributable to design and construction deficiencies, such as inappropriate material selection and welding-quality problems. For pipelines in a relatively stable stage (roughly 5-15 or 20 years), accidents are more frequently associated with third-party damage, operational errors, and corrosion induced by external conditions. For example, inflow of water into valve chambers through manhole covers, which accelerates corrosion of pipes and components beneath the access opening.

3.1 Corrosion of Pipelines and Equipment

Leakage caused by corrosion of pipelines and associated equipment is primarily attributable to asset aging and long-term exposure to external water, which degrades or detaches thermal insulation and subsequently accelerates corrosion of pipes and components. Based on the analysis, the main sources of external water include[8-9]:

1. Wastewater, irrigation water from green areas, rainwater, road-washing water, and leakage from potable-water pipelines around the corridor, which result in structural water ingress into valve chambers and corrode equipment inside the chambers;
2. Inflow of external water through pipe trenches, leading to corrosion of pipelines within the trench;
3. Inflow of external water through manhole covers into valve chambers, causing corrosion of pipes and equipment directly beneath the access opening; and
4. Long-term exposure of directly buried pipelines to moist surrounding environments, where external water penetrates into the insulation layer and causes corrosion-related leakage.

3.2 Non-Compliant Construction Practices

Some accidents are attributable to construction that does not meet applicable standards. Typical issues include missing insulation and/or protective sleeves at end blind heads or wall penetrations, which promotes corrosion; inadequate sealing of trench cover plates or incomplete waterproofing that allows external water ingress and subsequent corrosion; and the omission of proper wall sleeves when installing directly buried pipelines at wall penetrations (e.g., passing a sleeve pipe or bare pipe through the wall), resulting in corrosion and leakage due to contact with damp soil. Targeted standards and detailed construction requirements should be established, and inspection and acceptance procedures should be strengthened accordingly.

3.3 Natural Aging of Equipment

Under high-temperature and high-pressure operation, particularly in environments with high ambient humidity, equipment aging is largely unavoidable. During routine inspections, aging equipment should be prioritized for condition checks under various complex environmental scenarios, and effective measures should be implemented to prevent emergent failures.

3.4 Third-Party Damage

During municipal works or building construction, contractors may fail to coordinate with district-heating operators to review utility drawings or conduct on-site surveys. As a result, rough excavation and "blind digging" can strike heating pipelines, causing fracture or deformation and impairing heat supply. Because such events are difficult to predict, a unified coordination mechanism is required to ensure timely information sharing, notifications, and warnings to contractors, thereby reducing the likelihood of incidents.

3.5 Design Deficiencies

Certain failures can be traced to design configurations in which one end of a directly buried pipeline is equipped with a composite tie-rod compensator and the other end with an axial bellows compensator, but no fixed support is provided in between. After a period of operation, anchorage between compensators can lose effectiveness, leading to pull-out of the inner pipe and damage to the compensator. In addition, insufficient compensation capacity or improper placement of fixed supports can also contribute to district heating network accidents.

3.6 Welding Process Issues

Defects in welding practice—such as misalignment at joints, omission of root-pass welding, or failure to prepare bevel grooves as required—can result in crack initiation and leakage at weld seams under sustained high-temperature and high-pressure operating conditions.

3.7 Equipment Defects

Common equipment defects include leakage from "maintenance-free" sleeves and rupture of metal flexible hoses. Maintenance-free directly buried sleeves are relatively new devices used in primary networks and may exhibit leakage during early installation/commissioning. Manufacturers should be required to improve sleeve design and workmanship based on field performance, for severe leakage, measures such as adding rubber sealing rings or replacement may be necessary. For metal flexible hoses, manufacturing defects at the connection between stainless steel and carbon-steel piping can lead to tearing and rupture[10].

3.8 Improper Operation

Improper operation may occur when personnel lack familiarity with equipment and operating procedures, or when working under special or emergency conditions that impose high psychological stress, fatigue, or reduced attention. Such circumstances increase the likelihood of misoperation, which can range from equipment damage to full system failure and, in severe cases, casualties.

4 Risk Identification for District Heating Pipeline Accidents

Heating is a fundamental prerequisite for maintaining normal daily life in northern cities and a basic guarantee for the continuous functioning of urban services. Systematic identification of hazards in district heating systems—by determining the underlying causes of accidents, clarifying the logical relationships among contributing factors, and pinpointing weak links within the system—provides a sound basis for developing effective safety measures, with the ultimate goal of predicting and preventing accidents.

According to the statistical analysis of heating-related accidents, two principal failure modes can be distinguished: complete interruption of heat supply and insufficient heating capacity. The accident types that most commonly lead to these failures include pipeline-network leakage events, boiler accidents, heat-substation accidents, and pump-station accidents, among which pipeline leakage is the dominant type. Major contributing causes comprise aging- and corrosion-related degradation, design deficiencies, construction problems, third-party damage, improper operation, and management shortcomings.

5 Conclusions

This study examined district heating accidents using publicly reported cases and a two-decade statistical review, and found that pipeline-network leakage and rupture are the dominant accident types. Corrosion-related degradation is the primary driver of incidents (72%), while welding-quality defects (14%), third-party damage (5%), and design deficiencies contribute additional risk. The results further indicate an age-dependent failure mechanism: aging primary networks are mainly governed by corrosion and material deterioration, whereas newly commissioned pipelines are more sensitive to design and construction defects; in the stable service stage, external impacts, operational errors, and water-ingress–induced corrosion become prominent. Typical accident chains involve external water intrusion, insulation degradation, accelerated corrosion, delayed reporting, and slow valve isolation, which can escalate consequences in dense urban settings. Based on these findings, a concise risk-control framework is proposed, integrating integrity management, targeted corrosion/leak monitoring, excavation coordination, and rapid emergency isolation to reduce casualties and service disruptions and enhance district heating resilience.

From a policy and engineering-practice perspective, the findings suggest that district heating safety management should be closely aligned with asset-age profiling and risk-based prioritization. Regulatory frameworks may benefit from incorporating mandatory integrity assessments for aging pipelines, enhanced excavation-permit coordination mechanisms, and performance requirements for real-time leak detection and rapid isolation. Such measures can reduce accident probability while supporting the long-term reliability of district heating systems under clean-heating policies.

Future research should further explore the application of advanced materials with improved corrosion resistance and durability for district heating pipelines, as well as innovative monitoring technologies such as distributed fiber-optic sensing, acoustic detection, and digital-twin-based condition assessment. Integrating these technologies with network-level risk models could significantly enhance early-warning capabilities and contribute to more resilient and sustainable urban heating infrastructures.

Acknowledgment

This work was supported by Beijing Municipal Science and Technology Program (Z251100004525003).

References

1. Y. S. Kim and J. G. Kim, Failure analysis of a thermally insulated pipeline in a district heating system, Engineering Failure Analysis, vol. 83, pp. 193–206, Jan. 2018.
2. S. H. Kim, S. J. Kang, W. C. Kim, and J. G. Kim, Failure analysis of low carbon steel pipeline for district heating and cooling systems: Case studies, Engineering Failure Analysis, vol. 166, Art. no. 108826, Dec. 2024.
3. Y. S. Kim et al., Failure Analysis on Localized Corrosion of Heat Transport Pipe in District Heating System, Corrosion Science and Technology, vol. 19, no. 3, pp. 122–130, 2020. J-CST
4. M. S. Hong, Y. S. So, and J.-G. Kim, Optimization of Cathodic Protection Design for Pre-Insulated Pipeline in District Heating System Using Computational Simulation, Materials, vol. 12, no. 11, Art. no. 1761, May 2019.
5. Zhang M, Gao L, Zhang X, et al. An infrasound source localisation algorithm for improving locationaccuracy of gas pipeline leakage detection system[J]. International Journal of Embedded Systems,2022,15(1):9-18.
6. M. Valinčius, I. Žutautaitė, G. Dundulis, S. Rimkevičius, R. Janulionis, and R. Bakas, Integrated assessment of failure probability of the district heating network, Reliability Engineering & System Safety, vol. 133, pp. 314–322, 2015.
7. D. Mao, H. Lin, J. Zhong, and J. Zheng, Understanding District Heating Networks Vulnerability: A Comprehensive Analytical Approach with Controllability Consideration, Sustainable Cities and Society, vol. 101, Art. no. 105068, 2024.
8. Pahlavanzadeh F, Khaloozadeh H, Forouzanfar M. Online fault detection and localization of multiple oil pipeline leaks using mode-based residual generation and friction identification. International Journal of Dynamics and Control, 2024, (1): 1-14.
9. D. Hallberg, B. Stojanović, and J. Akander, Status, needs and possibilities for service life prediction and estimation of district heating distribution networks, Structure and Infrastructure Engineering, vol. 8, no. 1, pp. 41–54, 2012.
10. Wang J, Ren L, Jia Z, ct al. A novel pipeline leak detection and localization method based on the FBG pipe-fixture sensor array and compressed sensing theory[J]. Mechanical Systems and SignalProcessing.2022.169:108669.