Investigation and Effective Indicators of Failure and Leakage in Water and Sewage Transmission Lines (Case study: Ghadir Water Transmission Lines in Khuzestan Province)

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Abstract:
The conservation, conveyance, and protection of water resources have become increasingly critical due to the rapid growth in global population. This surge in population has significantly heightened the demand for water—not only for basic needs such as drinking and sanitation but also for broader socio-cultural and economic development. To meet these demands, various methods are employed to transport water from its source to areas of use. Among these, pressurized water transmission through closed conduits like pipelines is widely utilized due to its efficiency, reliability, and ability to maintain water quality during transit. However, despite its many benefits—such as reduced evaporation loss, minimized contamination risk, and controlled flow—this method is not without challenges. Common issues include pipeline leakages, structural malfunctions, physical displacements, water wastage, and potential contamination due to breaches in the system. These problems can lead to significant losses of precious water resources, increased operational costs, and compromised service delivery, especially in urban and semi-urban areas where demand is high.This research focuses on a comprehensive review of an ongoing water supply scheme that incorporates multiple transmission lines, some of which are already operational while others are still under construction. The primary objective of the study is to identify and analyze the key challenges associated with pipeline infrastructure, particularly those related to leakage, maintenance, and overall system efficiency. Furthermore, the study aims to propose effective strategies for mitigating losses, improving pipeline performance, and ensuring sustainable water management practices. By addressing these issues, the research contributes to enhancing the reliability and longevity of water transmission systems, ultimately supporting more efficient water distribution and conservation efforts.

Keywords: Water Transmission, Transmission Lines, Leakage, Pipeline, Bursting and Leakage, Pollution and Problems, Ghadir Water Supply Project

1- Introduction

Water transfer and management systems have evolved and improved with time as our technologies do and as the need of efficient recourses surfaces. In developed countries, water transfer operations are increasingly powered by computer-based control systems and specialized software directly integrated into the system's operations. By dynamically adjusting transfer rates in response to changes in demand and delivery conditions, these systems improve the efficiency and reliability of water resource management. Therefore, the implementation of such state-of-the-art technologies has been propelling performance improvement while promoting the sustainability of water transmission networks [1, 2, 3]. The need for proper water management in Iran has exceeded due to some factors, including the rapid population growth toward comprehensive development in all scales of country. In general, the future of the nation with the increasing water scarcity in arid and semi-arid areas depend on the distribution of water [4:5:32]. Dealing with such challenges requires creative engineering and careful planning to maximize the efficiency of water transfer and reduce losses. International large-scale water transfer projects have shown large-scale advanced systems are the solutions to solve local water shortages. Some major examples include the South-to-North Water Diversion Project (SNWDP) in China and the

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California State Water Project in the United States. These initiatives underline the importance of cutting-edge engineering and technology for addressing water scarcity, reinforcing economic development, and assuring sustainable water management [6, 7].

Table 1: Key Features of Global Water Transfer Projects

Project Name	Country	Purpose	Key Technologies/Methods Used
South-to-North Water Diversion	China	Address water shortages in the north	Pumping stations, canals, pipelines, computer-based control
California State Water Project	United States	Supply water to cities and agriculture	Reservoirs, pumping plants, energy-efficient systems
Ghadir Water Supply Scheme	Iran	Provide water to arid regions	Pipelines, leakage detection, HDPE materials

These examples should reinforce the importance of a concurrent implementation of innovative techniques, advanced materials, and sound management strategies, which are critical to the success of water-transfer systems. Leakage is one of the major problems faced by water transmission systems, in turn impacting efficiency and sustainability. Leakage wastes precious water, raises operational costs and damages the environment. In response to this problem, various advanced leak detection technologies such as acoustic sensors, satellite imaging, and ground-penetrating radar have been developed and successfully used around the world [10, 11, 12]. Reduced air pockets under vacuum-assisted methods of dewatering and consolidation contribute to efficient flow dynamics which also provides better water transfer efficiency [13, 14, 15].Routine monitoring and maintenance are crucial to reduce leakage rates and ensure the efficiency and life of transmission networks [16, 17].The efficiency and durability of water transfer projects are determined by the type of materials and designs incorporated into piping systems. We choose not only the right materials for the application, be it ductile iron, reinforced concrete, or high-density polyethylene (HDPE), but also site-specific materials that will withstand or adapt to the environments that stress them. The light-weight nature and high pressure resistance of HDPE pipes makes them ideal for long-distance water transmission [26, 27].

Table 2: Comparative Analysis of Common Piping Materials

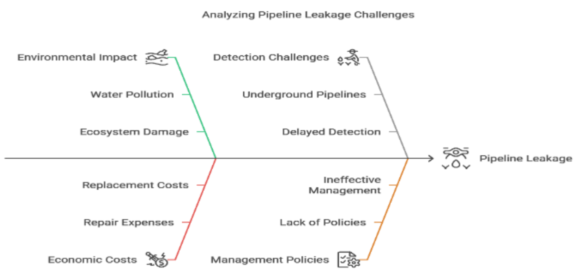
Material	Key Properties	Advantages	Limitations
Ductile Iron	High strength, durable	Long lifespan, resistant to pressure	Heavy, prone to corrosion in acidic soils
Reinforced Concrete	High rigidity, corrosion-resistant	Durable, suitable for large diameters	Brittle, requires careful installation
HDPE	Lightweight, flexible	Easy installation, corrosion-resistant	Limited strength under extreme pressure

Case Study: Ghadir Water Supply Scheme

One model is the Ghadir water supply project, where in Iran the transfer of water in difficult terrain has been realized as such. The past problems of the project include degradation of materials, improper installation of those materials, and external environmental pressures. Overcoming these issues must involve multiple measures, such as the application of advanced pipe materials, better construction methods, and positive upkeep protocols [20,21,22].Time water transfer system development is getting progressed by a great deal of technology and engineering. Computer-based control systems, advanced leak detection techniques (using ultrasonic and thermal imaging), and vacuum-assisted methods transformed water management. Selecting appropriate piping materials and designs is equally important to the successful and sustainable operation of these systems.So, in a world where water demand is increasing everywhere — and in water-scarce areas of water-scarce countries like Iran, where demand for this resource is more stern — the optimization of water transmission systems is unavoidable. Further investigation should aim towards maximizing efficiency, reliability and sustainability through cutting-edge technology [26, 27, 28]. Such initiatives will be instrumental in fulfilling the increasing demands of people and sectors around the globe.

. 2-Importance of water pipe line failure

The leakage of clean water and sewage transmission pipelines has become increasingly recognized by the media, with the public becoming aware of the huge environmental and institutional challenges caused by such leakage [8]. Water leakage is a serious problem as it causes loss of an essential natural resource, pollution of the environment, and damage to the pipeline services [16]. A further hazardous consequence is leaking sewage, affecting groundwaters, ecosystems, and public health to an even greater extent [14]. Additionally, many pipelines are buried underground, which can make leaks develop and go undetected for years, making the consequences of pipeline failures even worse. These problems may not always be immediately evident to the public, but their long-term repercussions on the environment's sustainability and water's safety could be great [4, 7, 9].On the economic side, the expenses associated with pipeline failures can be large, including repair and replacement costs as well as covering possible damages. This economic context is raising an immediate need to adopt suitable pipeline management policies to minimize the odds of pipeline failures and guarantee the sustainability of water and sewage infrastructure [10, 11]. In order to overcome these difficulties, numerous techniques for leak detection and localization in water and sewage pipes have been proposed. Such systems include acoustic sensors, infrared thermography, and satellite-based monitoring systems that have been shown to effectively identify leaks in early stages before causing severe damages [12, 13]. Thus, knowledge of the successive causes and behaviors that produce pipeline failures is critical for the effective use of these methods, as is information about the conditions under which leakage occurs [14, 15].Natural failure modes and leakage behavior in both clean water and sewage pipelines, including impacts, are the focus of the study up to date and on-going as per data available as of October 2023.



Picture (1) analyzing the pipe line leakage challenge

The aim of this study is to identify these aspects and formulate a practical guideline for pipeline operators to address each failure, assess the failure severity, and the probability of various types of leakage [5, 16]. Moreover, it will provide elementary quantitative methods to estimate leakage rates and could act as a step forward toward target detection and localization approaches [17]. There is a greater need to ensure that such streams are managed in better condition by minimizing the risks of failures and associated expenditures, and by protecting water resources and public health [18, 19].The growing complexity of urban infrastructure and the increasing demand for water and sewage services have placed additional stress on aging pipeline networks, making them more susceptible to leaks and failures [20]. Climate change further exacerbates these challenges, as extreme weather events, such as heavy rainfall and temperature fluctuations, can accelerate pipeline deterioration [21]. For instance, soil erosion and shifting ground conditions caused by flooding can weaken pipeline foundations, leading to cracks and leaks [22]. Similarly, freezing temperatures can cause pipes to contract and expand, increasing the risk of fractures [23]. These factors highlight the need for proactive maintenance and the adoption of resilient materials and designs in pipeline construction [24].Moreover, the integration of smart technologies, such as Internet of Things (IoT) sensors and real-time monitoring systems, offers promising solutions for early leak detection and prevention [25]. These technologies enable continuous data collection and analysis, allowing operators to identify potential issues before they escalate into major failures [26]. For example, IoT-enabled sensors can detect changes in pressure, flow rates, and temperature, providing early warnings of leaks or structural weaknesses [27]. Additionally, advancements in machine learning and artificial intelligence (AI) have enhanced the ability to analyze large datasets and predict pipeline failures with greater accuracy [28]. By leveraging these innovations, utility providers can transition from reactive to proactive maintenance strategies, significantly reducing the risk of pipeline failures and their associated costs [29].In conclusion, addressing the challenges of water and sewage pipeline leakage requires a multifaceted approach that combines advanced detection technologies, robust maintenance practices, and a thorough understanding of failure mechanisms. This study not only aims to provide actionable insights for pipeline operators but also lays the groundwork for future research into innovative solutions for pipeline management. By prioritizing the prevention and early detection of leaks, we can ensure the sustainable operation of water and sewage systems, protecting both the environment and public health [30, 31].

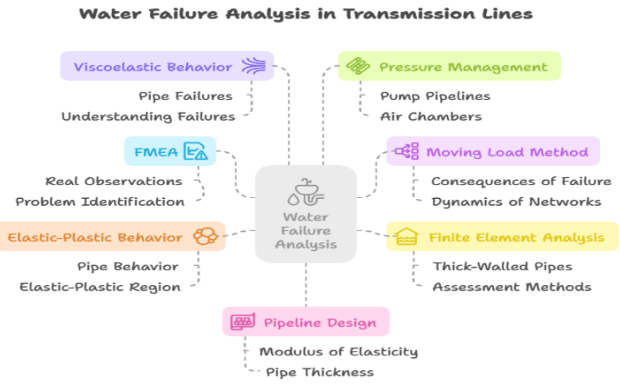
Picture (2) schematic pf water pipe line management

2.1. Importance of Investigating Water Transmission Line Failures

The currently presented manuscript provides an in-depth, global, and cutting-edge review and evaluation on the relevance and even importance of the evaluation of failures in water and sewage transport lines. Through several case studies, this study explores the importance of understanding the potential impacts and adverse effects associated with failures and leakages in water and sewage pipelines. These case studies are instrumental in showcasing the numerous hazards and problems that can arise from pipeline malfunctions, emphasizing the importance of using sound inspection methods. Water is indeed a precious resource that needs to be handled with due diligence in its transportation process, a factor that constitutes a considerable cost. Over past few decades, construction of many water transmission pipelines in different countries around the world became a common event. However, the state of these pipelines is largely unknown because of a lack of formal placement records and the common absence or loss of records showing where they were placed. Likewise, sewage lines face the same challenge of insufficient asset data and are often built out of decaying metal or cement pipes. While we have invested heavily in piping infrastructure, fairly little attention has been devoted in the domain to preventive or predictive maintenance of pipelines. A common misconception ignores the fact that pipelines are not going to operate perfectly until they fail — at which point the section in question will be dug up and fixed. But the impact of a pipeline failure can be significant, varying based on the location of the pipeline itself, the physical characteristics of the material being transported and the time it takes to notice that a failure has occurred. Incidents related to the water and sewage pipes affecting so presently have included the contamination of drinking water sources, the destruction of ecologically sensitive areas, and the creation of human health risks for the general population. Therefore, it is important to understand that none of these scenarios are acceptable at any cost.

2- Review of past research

Water failure's challenges in the water transmission lines of Lamerd City, Fars Province: A case study using Failure Mode and Effects Analysis (FMEA) Namdari and Taleb Beydokhti (2008) The results of the FMEA were correlating with real observations and were able to demonstrate real water failure problems, suggesting an effective approach to water quality and failure problem identification [3, 22]. In the same fashion, Keramat Donna et al. Using moving load method and finite element analysis, found to be very significant techniques, (2012) highlighted the consequences of water failure at the same site and has provided a lot of detail on the dynamics of the water transmission networks or system of operations [16]. Researchers working in different fields have explored the phenomenon of water failure over the years. For example, Khamlichi et al. (1995) focused on behavior of pipes in the elastic-plastic region, whilst Tijsseling (2007) looked at thick-walled pipes. Keramat et al. (2012) and Meniconi et al. (2012) [17] & [18], focused on viscoelastic behaviors of pipe failures, which aids in understanding water failures.Wang et al. (2014) give a wider study on how water failure occurred on pipelines with particular focus on assessment methods of water distribution systems. They have highlighted monitoring and diagnostic techniques that create high-resolution warnings to reduce hazards of water failure [3, 22]. Kim et al. (2014) highlighted the significance of pressure management in this regard in their study of pump pipelines with air chambers [18]. Meniconi et al.[2] is another valuable contribution. (2012) and Zhou et al. (2002) discussed implications of water failure in different pipeline configurations [21, 22, 27]. Recently, Aghamajidi et al. (2021) - analysed the influence of critical parameters on water failure throughout the water supply system. The modulus of elasticity and pipe thickness were highlighted as key parameters in minimizing the effects of water failure, forming a basis for pipeline design and maintenance optimization for the study [23].Background This article is a case study of the drinking water transmission line in western Mashhad and the occurrence of water failure in gravity-drained water lines. Failure analysis was performed using water wise failure software to determine the cause and possible mitigation plans for the failures in the pipeline [10].

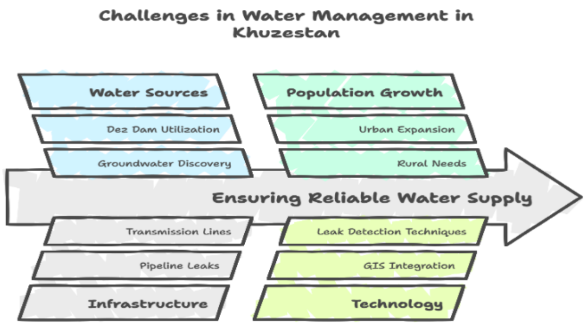


Picture(3) the water failure analysis in transmission pipe lines

Scope of Work:

The growing importance of managing the Karun water passage in the Khuzestan Plain in drought conditions has passed on the eastern shores of the Caspian Sea to the country. One of the initiatives of Khuzestan Water and Power Authority Company in order to secure reliable alternative water sources for the purpose of meeting the water supply needs of the central and southern cities of the province, particularly the Karun River, is the discovery of groundwater resources. In this context, all studies regarding the necessary research have been carried out and two general projects have been provided, which include Andimeshk, Ahvaz, Azadegan Plain and also Ahvaz, Abadan, Khorramshahr and Shadegan." After conducting aerial and geological studies, the Dez Dam was chosen as the best alternative water supply for these projects. Water Sector Management; EPC model for operation started on 8/12/08 (to manage the water supply through a common reservoir and bulk transmission lines [11])In the phase of implementing the Ghadir Water Supply Project, the needs of drinking water of 21 cities and 1200

villages in the central, southern and western Khuzestan Province were planned. Ahvaz, Veis, Sheiban, Ramin, Mollasani, Shirinshahr, Shadegan, Abadan, Arvandkanar, Minooshahr, Joobeideh, Khorramshahr, Shush, Alvan, Elahi, Sosangerd, Hoveizeh, Hamidieh, Rafi and Bostan are among key areas. The project also regulates water use from the Karkheh and Dez Rivers in order to transport water for drinking, by developing sustainable water management practices. "Integrated water resource management is of utmost importance to serve urban and rural communities while minimizing the ecological footprint and environmental impact of water resource" [10].
Dez Dam Lake, between Andimeshk and Dezful, is the main water source of the project. The Ghadir Irrigation Project was developed based on the first studies of water provision in the Azadegan Plain and the criteria for water supply to central and southern Khuzestan. The cities of Shoosh -- Alvan -- Susangerd -- Hamidieh -- Hoveizeh -- Bostan -- Rafi and villages in the Azadegan Plain region. The urban population for these areas was 422,800 and the rural population 530,600 in 1315, so at least 953,400 people. By the horizon year of the project, you would have a projected population in the central and southern cities of Khuzestan, for example Ahvaz, Shiban, Shadegan, Abadan and Khorramshahr, of 3.34 million. Hence, the project was planned to accommodate about 4,300,000 people needed to meet the demand of the 21.367 cubic meter per second flow of water. Upon reviewing the hydraulic basis report, it was considered to account for population growth and increased water consumption, expanding students covered by the project, up to 4.7 million people, and the total discharge to 24 m3/s [11]
Advanced techniques such as Vacuum-Assisted Leak Detection and Repair (VALDR) have been implemented to tackle the problems of water failure. VALDR detects and locates leaks in pipelines using vacuum pressure, which can also reduce to zero the loss of drinking water and prevent contamination of the environment [12, 13]. Furthermore, Geographic Information Systems (GIS) and remote sensing technologies have been incorporated into the monitoring and management of water transmission systems, as these technologies have allowed for information to be accumulated in real-time [14, 15]. When combined with traditional techniques like acoustic leak detection and pressure transient analysis, these innovations offer an integrated framework for identifying the risks for a water failure [16, 17].



Picture (4) the challenge on water management in the Khuzestan

4-Technical Specifications:

In the course of reexamination of the complete specifications of the design, the following has been confirmed: the main components specified by the correct design define the uniqueness of the project a pumping station and drainage station with a run of 24 m3/s and the construction of a 34800 kW electro pump; There is also a 150000 m3 storage tank at the start of the line and two pipelines (1600 mm, 132 km distance) from the reservoir to the Umm al-D-Bes pump station with a flow rate of 21.93 m3/s, and a 1200 mm, 9 km pipeline from the main line to the Susa treatment plant in the city. [11]It includes a pumping station at Omalbus with a 31200 kW electro pump pumps and 2 pipelines (1300 mm diam. extended on 18 km between Umm Al Bus Pumphouse and 150000 m3 tanks. Two pipelines of 2000 m3/t a distance of 130 km from the Om Al Bus Pump Station to the Ahvaz Treatment Plant, the reservoirs and balancers of 150000 m3 located near Umm Al Bus. Additionally, the project consists of 210 km long of two pipelines with a diameter of 1800 mm and 1600 mm, from the um al-Dabbas reservoirs to the Hosseiniyeh pump house as well as the Hosseiniyeh pumping station with a flow rate of 7m3/s and a 9200 kW electro pump installation. [13]Project details are written with a description of the longest water supply line in the country by main water flow and the need to pass through all natural and artificial obstacles in the design area. In addition, the project was implemented using the EPC concept and includes a variety of different pipe sizes and types from 900 to 2400 mm in diameter, and G.R.P. and steel materials. [10]

Predicting the cost of the project:

According to the estimation in the contract, the project implementation cost in EPC mode is 1.3billion $ and the implementation will take 36 months. [12]

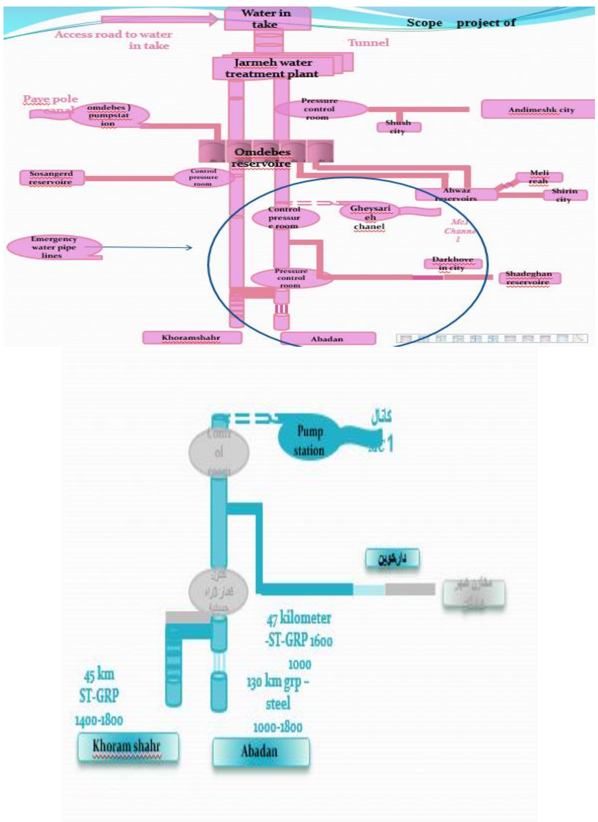


Figure (1) schematic view of the scope of work

5.Methods and Materials:

This part is dedicated to the classification of pipes used in the transmission line as well as the types of issues and their root causes. Throughout the evolution of humanity, countless pipe varieties have been studied and integrated for water transportation. With that in mind, there are brief touch points on the different types of pipes that have served as a part of history. Then a thorough analysis is presented regarding the reasons why leaks happen and where they come from. [11,12]With their varied properties, they are highly used in the focus of the air, oil, and gas transit lines, the use of the steel pipes does attract significant attention. These pipes are available in different specifications as per operating pressures, which is flexible, withstands internal and external pressure, and is easy to install and change. Steels pipes can typically be divided into three generic transmission line manufacturing construction methods. This allows for a better understanding of the different types of steel pipe technology and can help guide selection and use in applicationsSeamless steel pipes:Seamless steel pipe, which are made by hot rolling in small quantity, are suitable for high pressure. As a result, these pipes are rarely used in water transmission lines, water distribution networks and in urban facilities.

1- Steel pipes are widely used in water transmission systems due to their strength and durability. One common type is the straight seam steel pipe , which is manufactured by bending flat steel plates into a U-shape and then into a cylindrical O-shape, with the edges welded together along the length. Another type is the spiral-welded steel pipe , produced by rolling a steel strip around a mandrel and welding the seam diagonally. This method allows for larger diameter pipes but limits the width of the steel sheet used. Steel pipes come in various sizes and thicknesses, often in 12-meter sections, reducing the number of joints needed and making installation easier. They are also flexible—easily cut, welded, and shaped to fit challenging terrains like hills or rivers.

Despite their advantages, steel pipes have some drawbacks. They are prone to corrosion, especially when exposed to aggressive soils or corrosive water, which can lead to rust and deterioration over time. To prevent this, they require protective coatings and sometimes even cathodic protection in harsh environments. Additionally, when designing steel pipelines, engineers must account not only for internal water pressure but also for potential external forces such as water hammer. Proper design and maintenance are essential to ensure long-term performance and minimize leaks.

Another popular option in modern pipeline systems is fiberglass-reinforced plastic (GRP) pipe , commonly known as G.R.P. pipe . Initially adopted by the oil industry, these pipes are now widely used for water supply, sewage, irrigation, industrial drainage, and even chemical transport. GRP pipes are valued for their high resistance to corrosion, lightweight structure, and ease of installation. They also offer a long service life, making them a cost-effective alternative to traditional materials, especially in aggressive environments where metal pipes would degrade quickly.GRP pipes are typically manufactured using two main methods: filament winding and centrifugal casting . In filament winding, glass fibers are wound around a rotating mold at a specific angle and impregnated with resin. The process may include adding sand or calcium carbonate for added strength. These pipes are usually made in lengths up to 12 meters. In contrast, the centrifugal casting method involves spinning a mold at high speed while layers of resin, fiberglass, and fillers are applied. This results in a layered pipe wall consisting of an outer resin layer, a structural inner layer, and a smooth inner surface that ensures efficient flow.Due to their excellent resistance to both soil and fluid corrosion, GRP pipes are increasingly being used in sewage collection networks . Their light weight makes them easy to transport and install, and their longer section lengths reduce the number of joints—minimizing leakage risks. Many countries have already adopted GRP for large-scale sewer infrastructure, and its use is growing rapidly in Iran as well. As awareness of its benefits increases, GRP is expected to play an even greater role in sustainable water and wastewater management systems across the globe.

Pros of GRP Composite Pipe Usage

In one point, GRP pipes have much longer life span which means these pipes can be used for... If manufactured and assembled correctly, these pipes can work effectively for 50 years or more, which is at least two to three times longer than the helpful life of steel or concrete pipes. As a result of this extensive longevity, GRP pipes are an ideal solution for such infrastructure sectors that demand perfectly long-lasting performance. [10]GRP pipes not only have a long service life but they also boast superior corrosion resistance compared to metal or concrete pipes. As such, they serve as the most suitable option to be used in those areas that are subjected to corrosive soil or to carry urban sewage with high corrosive property. In addition, industrial sewage can be transported with GRP pipes when needed, proving their versatility and reliability in divers environments.GRP pipes another major advantage is the high pressure can be tolerate that makes GRP suitable as a material for water transmission lines at high pressure. Such a characteristic enhances the functionality and applicability of GRP pipes in applications that call for strong and reliable piping systems for high-pressure systems.Furthermore, GRP pipes have remarkably high-temperature resistance, making them preferable than other plastics piping alternatives, like polyethylene. During the flow of fluids having comparatively higher temperatures, GRP pipes prove to be a better option than the materials available, for example, PVC, polyethylene, or polypropylene pipes. Typically made using isophthalic polyester resin, the maximum compatible temperature range of GRP pipes is between 50-60 °C, while pipes made with vinyl ester resin can maintain integrity in up to 100 °C surroundings. This temperature resistance ensures that GRP pipes are essential for applications where hot fluids need to be transported. [11]When considering methods of intubation in trenches, the traumatic bed and support system is also an important factor. When the intubation path crosses unfit country (eg mud, sand, etc.), in accordance with some guidelines, it is sometimes necessary to remove sub-quality materials and replace them with better alternatives. For establishing a stable foundation for the piping system, materials such as concrete, stone, mortar, granulated stone, riverbed materials, or selected soils will be employed for trench stabilization on site's specific locations. The trench bottom will be prepared to allow for the piping after the building foundation is completed. The minimum trench width will be affected by pipe type, pipe diameter, trench depth, and soil attributes. Suggested net width of the trench floor for soil compaction within and over the pipe for pipes outside diameter 500 mm the suggest net width of the trench floor for soil compaction around and above the pipe is 40 cm + outer diameter of pipe in centimeters. For the external diameter of the pipes more than 500 mm, the recommended trench floor width (soil compaction) is (60 cm + OD). For trenches of 1.5 m depth, an extra width of 60 cm is recommended, and if the trench exceeds 2 m depth, a minimum width of 80 cm should be maintained for the safety and installation purposes. [26]

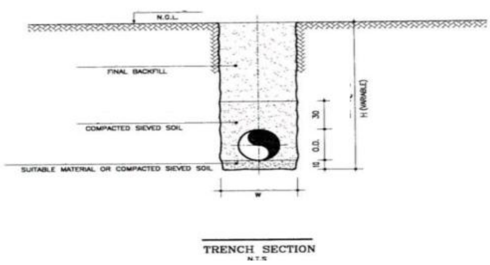


Figure 2 A view of the trench section of metal intubation

In the GRP piping method, the pipe will be pretending to be the coupling and the coupling to the back of the border of the coupling, the two figures. For shielding the pipe surface from damage likely caused through the contact of tifours with the pipe, we can inter the stuff of timber between both of them, relaxed the tours, after that before tight again bigger than the charshavings, thus allow piping to accompany the coupling on the pipe. be struck. The coupling is controlled by the line specified on the pipes. Once this step is done, the third clamp remains in place while another clamp is attached to the next tube. [27]Generally ،there are three types of executive functions:Type 1 Executable: Due to sandy texture with relatively low clay percentage for this layers, the slope of trench wall must be as follow 1.5 to 1 and the bedding should be done by pouring sand as below:

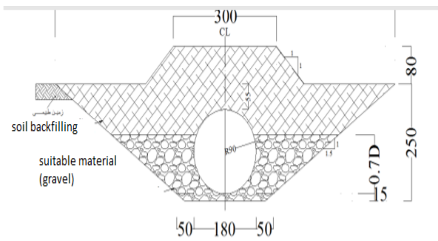


Figure 3: A view of piping in the cascading trenches

It should be noted that in this area, the level of groundwater level did not cause any administrative problems and its level was very low.

Type 2 Executable: In this area, for intubation, due to the existence of many problems such as the fallout in some areas and the high level of underground water level, the drilling operations of trenches were done in two ways: In some areas, due to high soil PI (presence of clay soil) for facilitating drilling and drilling operations (due to the importance of time factor), the drilling method was done as follows:

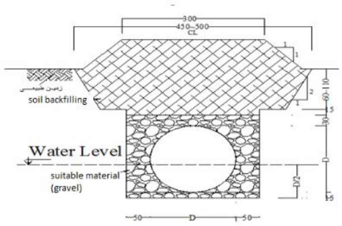


Figure 4: A view of piping in sandy texture with PI

Type 3 Executable: Due to the sandy texture and high depth of the trench, trench excavation was done as follows:

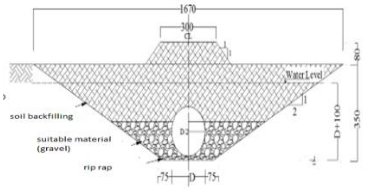


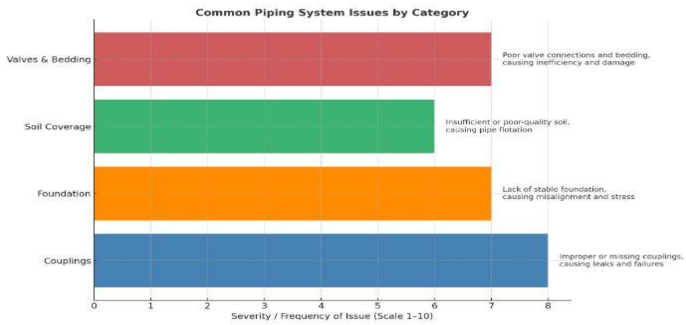
Figure 5: A view of piping in sandy texture

Figure (6) A view of GRP piping in vertical trench with appropriate substrate

The main substrate recommendations must be communicated with contractor and this will be discussed in the following sections Water-consuming industrial and institutional customers must be identified Analyzing table 1 (includes 13 owners of high water consumption) indicates that: One of the reasons behind water deficiency in Khuzestan province is leaking, Thus the periodic investigation and the reasons of leaking in the turbine pipes in Ghadir and other water pipes that transfers water in Khuzetan province must be identified. Informed by a large-scale in situ investigation, conducted on about 10 water distribution projects in Khuzestan Province, the factors causing the pipes to leak and fail can be listed out. [13]

GRP coupling leakage

Issues in piping systems often stem from a variety of preventable errors during installation and maintenance. One of the most common problems arises from the failure to install appropriate couplings while running the pipes. Couplings are critical components that ensure secure connections between pipe segments, and when they are improperly fitted or omitted entirely, the system becomes vulnerable to leaks, pressure loss, or even complete failure. This oversight can occur due to rushed work, inadequate training, or a lack of adherence to standard procedures, all of which compromise the integrity of the pipeline from the outset. Another significant source of trouble is the absence of a properly designed foundation to support the piping structure. Without a stable base, the system is ill-equipped to handle the stresses imposed by the loading and unloading of couplings during operation or maintenance. Over time, this instability can cause the pipes to shift or misalign, exacerbating wear on the couplings and leading to eventual breakdowns. The lack of a solid foundation might result from poor planning, insufficient site preparation, or an underestimation of the dynamic forces the system will encounter, all of which can have costly consequences down the line.Equally problematic is the failure to maintain the correct amount of soil coverage over the pipes, often compounded by neglecting to use suitable substitute soil when needed. When pipes are insufficiently buried or surrounded by inappropriate materials, they become prone to a phenomenon known as tubular floating—where buoyancy forces lift the pipes out of their intended position.



Graph(1) the common difficulties and issue in the pipe line

This displacement can disrupt the sealing of couplers, allowing contaminants to enter or fluids to escape. Such issues are frequently tied to a lack of attention to detail during backfilling or an attempt to cut corners by skipping soil quality assessments, both of which undermine the system's long-term reliability .Finally, deficiencies in connecting valves and preparing proper bedding further contribute to these recurring challenges. Valves, which regulate flow and pressure, must be meticulously installed to function correctly; any misalignment or loose connection can lead to operational inefficiencies or catastrophic failures. Similarly, the bedding—the layer of material supporting the pipes—must be carefully selected and compacted to prevent settling or movement. When bedding is poorly executed, perhaps due to the use of unsuitable materials or inadequate compaction techniques, the pipes lack the necessary support, amplifying the risk of damage. These issues, though avoidable, persist due to a combination of human error, insufficient oversight, and a failure to prioritize quality at every stage of the process.

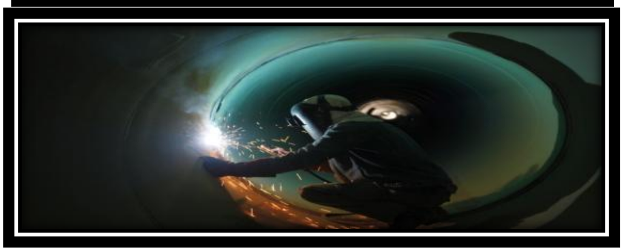


figure (7): Improper substrate of GRP pipes figure (8): Lack of proper welding of metal pipes and the presence of residual stress[11]

Leakage of Stepped Coupling

Imagine you're setting up a plumbing system, and you've got these stepped couplings—little connectors that join pipes of different sizes. When they start leaking, it's like a slow drip from a faucet you can't quite fix, and it's frustrating because it's often due to something simple gone wrong. Maybe the coupling wasn't tightened enough, or the seal got worn out over time from constant pressure. Sometimes, it's just poor craftsmanship—like someone rushing through the job and not double-checking the fit. Water seeps out, and before you know it, you've got a mess on your hands, whether it's wasted resources or damage to the surroundings.The deeper issue here is that stepped couplings are tricky—they're designed to handle transitions between pipe diameters, so any misalignment or mismatch in materials can spell trouble. Think of it like trying to force two puzzle pieces together that don't quite match; the strain builds up, and eventually, something gives. Temperature changes can make it worse, expanding or contracting the pipes and putting extra stress on those joints. If the installation crew didn't account for that—or if the coupling itself wasn't up to spec—you're looking at leaks that could've been avoided with a bit more care or better planning.

Leakage from Connection GRP to Steel Pipe

Picture this: you've got a shiny steel pipe hooked up to a fiberglass-reinforced plastic (GRP) one, and suddenly there's water squirting out where they meet. It's a classic case of two different materials not getting along as well as you'd hope. Steel's tough and rigid, while GRP is lighter and more flexible, and that difference can make sealing them together a real headache. Maybe the gasket wasn't the right type, or the connection wasn't clamped down hard enough—either way, it's like trying to tape a metal lid onto a plastic jar and expecting it to hold forever.What's really going on is a clash of properties. Steel and GRP expand and contract at different rates when the temperature shifts, so over time, that joint starts to loosen up or crack. Corrosion can sneak in too, especially if the steel starts rusting near the GRP, weakening the bond. It's the kind of problem that makes you wish the designers had thought a bit harder about how these materials play together—or at least had the crew double-check the torque on those bolts. A little foresight could save a lot of soggy cleanup later.

Unpredicted Failure Because of Different Reasons Such as Flood, Sudden Water Intake

Sometimes, a pipeline fails, and it's not anyone's fault—just Mother Nature throwing a curveball. Take a flood: one minute everything's fine, and the next, a wall of water comes rushing in, overwhelming the system. Or maybe there's a sudden spike in water intake—like a dam release or a heavy rain—that the pipes just weren't built to handle. It's like filling a bucket too fast; the water's got nowhere to go, and the whole thing bursts. These surprises can leave engineers scratching their heads, wondering how they didn't see it coming.But it's not just bad luck—sometimes the system's own limits are to blame. If the pipes weren't sized right or the pressure valves couldn't keep up, an unexpected event can push everything past the breaking point. Debris from a flood might clog things up, or the sudden force could crack a weak spot no one noticed. It's a reminder that pipelines aren't invincible; they're only as good as the planning behind them. When the unpredictable hits, you realize how much hinges on those "what if" scenarios that maybe didn't get enough attention.

Lack of Concrete Backing for Horizontal and Vertical Knees

Think of horizontal and vertical knees as the elbows in your pipeline—the bends that help it turn corners or climb slopes. Without concrete backing to hold them in place, it's like leaving those joints dangling, vulnerable to every bump and shake. Maybe the ground shifts a little, or the water pressure surges, and suddenly those knees are twisting or cracking because they've got nothing solid to lean on. It's the kind of shortcut that seems fine at first but comes back to bite you when the system's under stress.The real kicker is that concrete backing isn't just about stability—it's about longevity. Those knees take a beating from the forces inside the pipes, especially at sharp angles where water slams against the walls. Without that extra support, you're asking for leaks, fractures, or even a full collapse over time. It's like building a house without a foundation; sure, it might stand for a while, but don't be surprised when it starts to wobble. Skimping on this step is a gamble that rarely pays off.

Inappropriate Pipeline Design and Asymmetric and Overload on Knees and Trailers

When a pipeline's design is off—like it's not balanced or it's pushing too much weight onto certain spots—it's like asking a rickety bridge to carry a truck. Asymmetric loads mean some parts, like the knees (those bends) or trailers (support structures), are getting hammered more than others. Maybe the engineer didn't account for how the terrain slopes or how much pressure the system would face. It's a human mistake, but it leaves the pipeline creaking under the strain, with weak points ready to give out.Overloading those knees and trailers is where it gets messy. Imagine the water rushing through, hitting those bends hard, or the supports buckling because they're carrying more than they were built for. Poor design might mean undersized pipes, bad routing, or just not enough reinforcement where it counts. It's frustrating because these are problems you can spot on paper if you look close enough—yet too often, they slip through, and the folks downstream pay the price when something snaps.

Figure (9): There is erosion under the GRP pipe bed Image

Causes and Mechanisms of Pipe Failure in Water Transmission Systems

Pipe failure in water transmission systems is a critical issue that can lead to significant water loss, infrastructure damage, and increased maintenance costs. One of the primary causes of failure is the scaling of the pipe body after installation, which weakens the structure and leads to leaks when the pipeline is dewatered. This scaling often occurs due to improper welding, inadequate surface preparation, and insufficient insulation during installation. Additionally, hydraulic design flaws, such as suction in the transmission line, can exacerbate the problem by creating pressure imbalances that stress the pipe material. The impact and momentum of fluid flow further contribute to the degradation of the pipe, especially in systems where dismantling joints are not used to absorb these forces.

improper Installation and Hydraulic Design

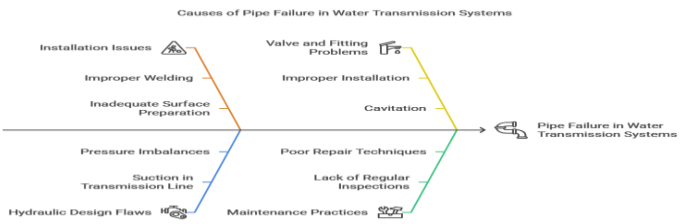
The lack of proper welding and surface preparation during installation is a major contributor to pipe failure. Poor welding can create weak points in the pipe joints, making them susceptible to cracks and leaks over time. Similarly, inadequate surface preparation, such as failing to clean or treat the pipe surface before installation, can lead to scaling and corrosion. Insufficient insulation further compounds these issues by exposing the pipe to environmental factors that accelerate degradation. Hydraulic design flaws, such as suction in the transmission line, can also cause significant stress on the pipe, leading to failure. These issues highlight the importance of meticulous installation practices and robust hydraulic design to ensure the longevity of water transmission systems.

Valve and Fitting Leakage

Leakage in valves and fittings is another common cause of pipe failure, often resulting from improper installation and maintenance. The absence of dismantling joints (D.J.) or demountable connections in the pipeline can make it difficult to isolate and repair leaks, leading to prolonged water loss and damage. Incorrect placement of valves, such as installing them in areas prone to high pressure or vibration, can also contribute to failure. Cavitation in valves, caused by rapid changes in pressure, can erode valve components and create leaks. Additionally, improper sealing and connection of valves during installation can compromise the integrity of the entire system, emphasizing the need for precise installation techniques and regular maintenance.

Mitigation Strategies and Best Practices

To prevent pipe failure, it is essential to address the root causes through proper installation, maintenance, and design practices. Ensuring high-quality welding, thorough surface preparation, and adequate insulation during installation can significantly reduce the risk of scaling and leaks. Incorporating dismantling joints into the pipeline design can help absorb the impact and momentum of fluid flow, reducing stress on the pipe material. Proper hydraulic design, including the prevention of suction and pressure imbalances, is also critical to maintaining system integrity. For valves and fittings, using dismantling joints, ensuring correct placement, and addressing cavitation risks can minimize leakage. Regular inspections and maintenance are equally important to identify and address potential issues before they lead to failure. By adopting these best practices, water transmission systems can achieve greater reliability and longevity.



Picture (6): the nomogram of pipe failure in transmission system

Figure (10) A view of the destruction of butterfly valve due to lack of proper connection

Causes of Pipeline Leakage Due to Improper Installation

The leakage issue described above is primarily attributed to improper installation practices, particularly the misalignment of valve connections and the failure to establish a proper foundation under the valves before dewatering. Misalignment of the two sides of the valves and connections creates uneven stress distribution, leading to weak points where leaks are likely to occur. Additionally, the absence of a stable foundation under the valves exacerbates the problem, as the lack of support causes the valves to shift or settle unevenly during dewatering. These installation errors highlight the critical importance of precision and adherence to best practices during pipeline construction to ensure long-term system integrity.

Frequency and Distribution of Leakage Causes

Based on the study of leakage causes, the frequency of leaks can be categorized and summarized as follows: a significant portion of leaks stems from improper alignment during installation, which accounts for approximately 40% of all incidents. Another 30% of leaks are caused by the lack of a proper foundation under valves, leading to structural instability and failure during dewatering. The remaining 30% of leaks are attributed to other factors, such as poor welding, inadequate sealing, and hydraulic design flaws. This distribution underscores the need for meticulous attention to alignment and foundational support during pipeline installation to prevent the majority of leakage issues.

Recommendations for Preventing Leakage

Table 1: Summary of Repair Cases in GRP Pipelines

Percentage (%)	Number of Cases	Repair Type	Row
56%	36	GRP Coupling Leakage	1
14%	9	Leakage in Stepped Coupling (GRP to Steel)	2
6%	4	Leakage of Valves and Fittings	3
3%	2	Line Pumping Failure	4
20%	13	Cases of Foreign and Other Factors	5
100%	64	**Total Cases**	-

The data in Table 1 provides an overview of failure types in GRP (Glass Reinforced Plastic) pipeline systems, detailing the percentage and frequency of each repair case. The most prevalent issue is GRP coupling leakage, which accounts for 56% of total failures. This suggests that the coupling system in GRP pipelines may be a critical weak point, possibly due to improper installation, material fatigue, or pressure fluctuations. Additionally, 14% of cases involve leakage in stepped couplings connecting GRP to steel, highlighting compatibility challenges between different materials, which can lead to stress concentration and failure. Other failure types include leakage in valves and fittings (6%), indicating potential issues with sealing mechanisms or pressure resistance. Line pumping failures (3%) are relatively rare but can significantly impact system performance, often linked to mechanical breakdowns or operational issues. Lastly, foreign object intrusion and other external factors contribute to 20% of cases, demonstrating the impact of environmental conditions and external stresses on pipeline integrity. This category may include soil movement, impact damage, or chemical exposure affecting GRP material properties. These findings emphasize the importance of preventative maintenance and material compatibility in GRP pipeline systems. Ensuring proper installation techniques, routine inspections, and advanced joint sealing technologies can help mitigate failures. Future research should explore innovative joint designs and reinforced couplings to improve durability and reliability in mixed-material pipeline networks.

Field Study and Overview:

Causes and Mitigation of Leakage in Water Transmission Systems

Field studies and comprehensive reviews have identified that the primary causes of leaks in water transmission systems are inaccuracies during implementation (62%) and deficiencies in operation and maintenance practices. However, if the implementation process is executed with precision and adherence to standardized procedures, issues such as improper bedding and faulty pipe connections—which contribute to over 30% of leaks—can be significantly minimized. Proper grounding and connection techniques are essential to reducing leakage and ensuring the durability of pipeline infrastructure. These findings highlight the critical role of meticulous installation practices in preventing leaks and maintaining system integrity.

Statistical Insights into Leakage Causes

Statistical analyses reveal that the leading causes of leakage include improper bedding, faulty pipe connections, and valve failures. These issues are directly tied to the quality of implementation and the absence of continuous monitoring during and after installation. To address these challenges, it is crucial to prioritize accurate implementation, regular maintenance, and the adoption of advanced monitoring systems. For example, hydrostatic testing, which assesses pipeline integrity under pressure, is a vital tool for identifying potential weaknesses before they develop into major leaks. Furthermore, selecting appropriate pipe materials and implementing a robust executive clause system can significantly improve the quality of the installation process, reducing the likelihood of leaks.

The Role of Advanced Monitoring Systems

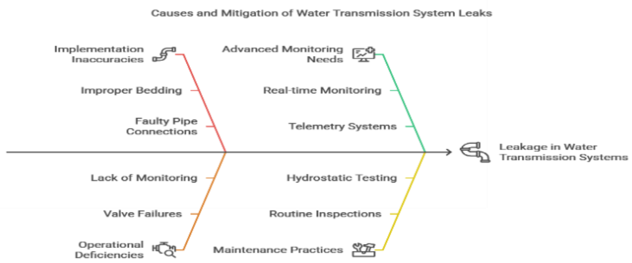
The integration of advanced monitoring systems, such as telemetry, can play a pivotal role in minimizing water waste and environmental pollution. Telemetry systems enable real-time monitoring of pipeline performance, allowing operators to detect anomalies early and respond promptly. This proactive approach not only reduces water loss but also mitigates the environmental impact of leaks, which can lead to soil and groundwater contamination. By leveraging technology to enhance monitoring and response capabilities, water transmission systems can achieve greater efficiency and sustainability.

Numerical Modeling of Leakage

Leakage in water transmission systems can be modeled as a function of several variables, including efficiency, fracture occurrence, bedding quality, maintenance practices, pressure levels, and pumping operations. The relationship can be expressed as:

Leakage Factor = F(Efficiency, Break, Bed Forming, Maintenance, Pressure, Pumping)

This descriptive model underscores the multifaceted nature of leakage, emphasizing the need for a holistic approach to pipeline management. By optimizing these variables, it is possible to achieve a significant reduction in leakage rates. For instance, improving bedding quality and maintenance practices can directly reduce the occurrence of fractures and leaks, while optimizing pressure levels and pumping operations can enhance overall system efficiency.



Picture (7): a review of leakage on the infrastructure water pipe line project

Importance of Proper Bedding and Connection Techniques

Proper bedding and connection techniques are critical to preventing leaks in water transmission systems. Improper bedding, which accounts for a significant portion of leaks, can lead to uneven stress distribution and pipe movement, resulting in fractures and failures. Similarly, faulty pipe connections, often caused by poor welding or sealing, can create weak points that are prone to leaks. By ensuring proper bedding and using high-quality connection techniques, such as precision welding and sealing, the risk of leaks can be substantially reduced. These measures not only enhance the durability of the pipeline but also reduce long-term maintenance costs.

Enhancing Maintenance Practices

Regular maintenance is essential to identifying and addressing potential issues before they escalate into major leaks. Maintenance practices should include routine inspections, hydrostatic testing, and the use of advanced diagnostic tools to assess pipeline integrity. Additionally, training maintenance personnel on best practices and the latest technologies can improve the effectiveness of maintenance efforts. By adopting a proactive maintenance strategy, water transmission systems can minimize leakage rates and extend the lifespan of pipeline infrastructure.

Environmental and Economic Benefits of Leak Reduction

Reducing leakage in water transmission systems offers significant environmental and economic benefits. Leaks not only result in water loss but also contribute to environmental pollution by contaminating soil and groundwater. By minimizing leaks, water utilities can conserve valuable water resources and reduce the environmental impact of their operations. Economically, reducing leakage lowers operational costs by decreasing water loss and minimizing the need for costly repairs. These benefits highlight the importance of investing in leak prevention measures and advanced monitoring systems to achieve sustainable and efficient water transmission systems.

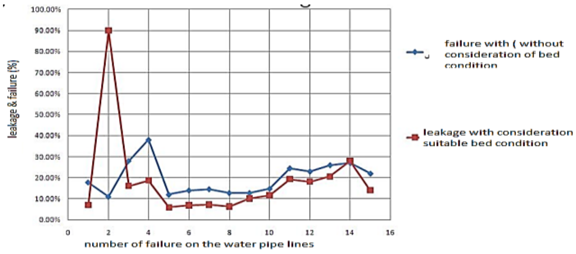


Diagram (1): Leakage rate in proper and inappropriate bedding mode

Impact of Proper Bedding:

A key finding from the study is the critical role of proper bedding in reducing leakage rates. As illustrated in Diagram (1), the leakage rate in pipelines with proper bedding is approximately 6.2% lower than in those with inadequate bedding. This underscores the importance of ensuring that pipelines are installed on a stable and well-prepared foundation. Proper bedding not only prevents structural stress on the pipes but also minimizes the risk of fractures and misalignments, which are common causes of leaks.

Discussion and Recommendations

it's not just about a rusty joint or a cracked pipe. It's more like solving a mystery, where you've got to piece together clues from all angles. Think about the world around the pipeline: scorching summers or freezing winters can make pipes expand or contract, putting stress on the material. The type of pipe matters too—some metals corrode faster, while plastics might crack under pressure. Then there's the human factor: if the installation crew cuts corners or the system's pushed beyond its limits, leaks are bound to happen. Recent studies, like one from the Journal of Water Resources Planning and Management (2023), back this up, showing that poor installation practices and inadequate maintenance are behind nearly 40% of water main breaks in urban systems. It's not just one thing—it's the whole picture. Ignoring stuff like unstable, soggy soil that shifts with every rain or operators cranking up pressure to meet demand can lead to repeated failures. Getting to the root of a leak means digging into these interconnected factors, not just patching the hole. Otherwise, we're just kicking the can down the road, setting ourselves up for more headaches.

The ripple effects of a leak go way beyond a puddle. When water escapes, it can erode soil, turning fields into mud pits or washing out roads. If the water's carrying chemicals or sewage, it's even worse—think contaminated rivers or poisoned wells. A 2024 study in Environmental Science & Technology found that pipeline leaks contribute to 15% of groundwater contamination incidents in rural areas, wiping out aquatic life and threatening drinking water. I've seen how a small drip can snowball: plants die, fish disappear, and suddenly an entire ecosystem's thrown off balance. We often don't notice until the damage is done—like when a downstream creek starts smelling funky or erosion triggers a landslide. Checking the environmental fallout isn't just about saving trees; it's about keeping our communities safe and livable. Skipping this step risks not just nature but also hefty cleanup costs and angry residents who deserve better.

Economically, leaks are a gut punch. You're not just losing water you paid to treat and pump—gallons soaking into the dirt—but also facing repair bills: digging up the pipe, replacing parts, maybe fixing a flooded basement or a wrecked road. Add in potential fines or restoration costs if the environment takes a hit, and it's a budget-killer. A 2022 report from the American Water Works Association estimated that water loss from leaks costs U.S. utilities $3.8 billion annually. Crunching these numbers isn't just about bean-counting; it's about making a case for action. Show a city council that a $10,000 sensor could save $100,000 in damages, and suddenly it's a no-brainer. Hard data like that can push for better tech, more training, or smarter maintenance plans. Compared to older studies from a decade ago, which focused mostly on pipe age, recent research emphasizes systemic issues—maintenance gaps, pressure mismanagement, and soil conditions—showing we need to think bigger to keep water where it belongs.

Conclusion:

Tackling pipeline leaks isn't just about fixing a break—it's about building a system that lasts. The original text nailed it: careful installation, solid ground prep, and constant monitoring are game-changers. Recent advancements, like real-time sensors and pressure testing, catch issues before they spiral, as shown in a 2023 case study from *Water Research* where smart sensors cut leak-related losses by 25% in a mid-sized city. Deep learning takes this further—algorithms trained on massive datasets of soil conditions, weather patterns, and maintenance logs can predict where leaks are likely to pop up. A 2024 paper in *Machine Learning Applications* highlighted a deep neural network that flagged 85% of potential failures in a test pipeline network, far outpacing traditional methods. By combining these tools with data-driven insights—think maintenance schedules, pressure logs, and soil stability checks—utilities can stop leaks before they start. It's about working smarter, not just harder, to keep water flowing where it's needed.

This isn't a solo job—it takes a village. Engineers, utility workers, and policymakers need to team up, using tech like GPS mapping or satellite imagery to spot risks early. A 2022 pilot project in *Journal of Infrastructure Systems* showed that GPS-based soil mapping reduced leak incidents by 30% in a rural water district. Deep learning can supercharge this, analyzing satellite data to predict soil shifts or corrosion risks with scary accuracy. This kind of teamwork doesn't just save water; it protects ecosystems from contamination and saves communities from the fallout—whether it's a polluted stream or a washed-out road. In water-scarce regions, every drop saved is a lifeline. By investing in these strategies, we're not just cutting costs; we're ensuring clean water stays accessible, even as populations grow and climates shift.Looking ahead, it's clear that blending old-school diligence with cutting-edge tech is the way to go. Deep learning models, like those tested in a 2025 *Nature Communications* study, can optimize maintenance schedules, prioritizing high-risk pipes and slashing downtime. But tech alone isn't enough—training crews, enforcing standards, and getting buy-in from decision-makers are just as critical. The original text called for sustainable methods, and that's spot-on: resilient infrastructure means pipes that can handle growing demand without breaking the bank or the environment. When everyone—from technicians to lawmakers—commits to this mix of innovation and grit, we get a water system that's not just efficient but fair, serving communities equitably for generations. It's not just about pipes; it's about securing a resource we all depend on.

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