Comparison of GRP (Semi-Steel) Pipes with Steel Pipes in Water Supply Projects

(Case study of Darab water supply project from Rudbal dam by BOT method)

Roozbeh Aghamajidi*[1]

1-Assistant Prof. Department of Civil Engineering, Sep.C, Islamic Azad University, Sepidan, Iran

Corresponding author : roozbeh.aghamajidi@iau.ac.ir

Abstract :

The utilization of pipelines in water supply endeavors has consistently held significant and promising implications. The employment of enclosed conduits for the conveyance of fluids has been particularly crucial in terms of passive defense mechanisms and the preservation of drinking water cleanliness. This research article aims to present a concise comparative analysis between steel pipes and pseudo-steel GRP for water conveyance within the context of the Darab water supply project, delineating the respective merits and advantages of each material and examining the influence of the pipe type on the financial model, culminating in an evaluation of water cost. The rationale behind selecting the Darab water supply initiative originating from the Rudbal Dam stems from the challenging location of the project and its critical significance in addressing water scarcity issues in the arid expanse of Fars province. It is imperative to highlight that within this framework, the latent expenses associated with water supply projects under the Build-Operate-Transfer (BOT) contract methodology have been deliberated upon, with the ultimate projection of the overall project cost factoring in updated construction and operational expenses over a defined timeframe

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Keywords :Darab , GRP, Financial Model, Hidden Cost, BOT, Guaranteed Water Price

introduction

In water supply projects, choosing the right type of pipe material is crucial because it directly impacts the system's efficiency, cost, and lifespan. Two commonly used materials are Glass Reinforced Plastic (GRP) pipes, also known as composite or semi-steel pipes, and steel pipes. Each material has its own advantages and challenges that determine where and how it’s best used.GRP pipes are made from fiberglass and polyester resin, offering corrosion resistance, a high strength-to-weight ratio, and long service life. They’ve become popular in areas where the water supply may have chemicals or be prone to corrosion. On the other hand, steel pipes are known for their strength, durability, and ability to handle high pressures, making them a traditional choice for many water supply systems.This study aims to compare the performance, cost, and environmental impact of GRP and steel pipes in water supply projects. By evaluating their characteristics, this paper provides insights

[1] Department of Civil Engineering, Sep. C., Islamic Azad University, Sep, Iran, email : roozbehaghamajidi1396@gmail.com

due to their corrosion resistance (Liu et al., 2020).

Steel pipes, while cheaper upfront, are heavier and more labor-intensive to install, often requiring special equipment and higher labor costs, particularly for large projects (Richardson & Simmons, 2021). However, steel's strength makes it ideal for installations requiring pipes to endure high mechanical stress, like deep trenches or areas with heavy traffic.

Table 1: Comparison of Installation and Maintenance Costs

Pipe Type	Material Cost (per meter)	Installation Cost	Maintenance Cost
GRP	High	Low	Low
Steel	Medium	High	Medium

Table 1 shows that GRP pipes, while more expensive initially, are cheaper in the long run due to lower installation and maintenance costs. Steel pipes, though less expensive at first, can result in higher overall costs due to more difficult installation and more frequent maintenance needs.

3. Environmental Impact

Sustainability is becoming increasingly important in water supply projects. GRP pipes are generally considered more environmentally friendly than steel because they produce fewer emissions during manufacturing and require less energy to transport and install (Li et al., 2022). Additionally, GRP's resistance to corrosion means they last longer, reducing the need for frequent replacements and lowering waste.

Steel pipes, while fully recyclable, require a lot of energy to produce and emit significant amounts of greenhouse gases during production (Munoz & Garcia, 2016). However, because steel can be recycled, it can be a more sustainable option in the long term if recycling is prioritized (Smith & Tucker, 2020).

into which material may be better suited for specific conditions, helping engineers and decision-makers make more informed choices in water infrastructure development.

Literature Review

The choice between GRP and steel pipes has been widely researched, as each offers unique benefits. This section reviews recent studies on their performance, cost, environmental effects, and longevity.

1. Performance and Durability

A major factor in choosing pipe materials is how well they perform under different conditions like pressure, external loads, and exposure to chemicals. Sablayrolles et al. (2018) highlight that GRP pipes have excellent corrosion resistance, making them ideal for areas where water contains high chloride levels. This resistance extends their lifespan and reduces maintenance needs compared to steel pipes, which are more prone to rust and corrosion (Palmer & Young, 2020).GRP pipes are also flexible, allowing them to absorb shock and resist cracks under heavy loads. In contrast, steel pipes, though strong, can crack in areas where the ground shifts or where external pressure is high (Jha et al., 2017). GRP is often favored in areas with unstable soils or seismic activity.

2. Cost and Installation

Cost is a key consideration, and both GRP and steel have different financial implications in terms of materials and installation. While GRP pipes may have higher material costs, they are much lighter, which reduces transportation and installation expenses (Thomas et al., 2019). Because GRP pipes are easier to install, projects can often be completed faster, resulting in lower labor costs. The long-term maintenance costs for GRP are also lower

Table 3: Hydraulic Efficiency of GRP and Steel Pipes

Pipe Type	Friction Coefficient	Corrosion Impact	Long-Term Efficiency
GRP	Low	None	High
Steel	Medium	High	Medium

Table 3 highlights GRP pipes' hydraulic advantage due to their low friction and corrosion resistance, which helps them maintain long-term efficiency. Steel pipes, while initially efficient, may suffer from reduced efficiency over time as corrosion sets in.In summary, GRP and steel pipes each have distinct strengths that make them suitable for different water supply projects. GRP pipes offer advantages in terms of corrosion resistance, long-term maintenance, and hydraulic efficiency, making them a strong choice for projects where these factors are important. Steel pipes, on the other hand, offer robustness and recyclability, making them valuable in applications requiring high mechanical strength.The decision between GRP and steel should be based on a careful analysis of the specific project conditions, including environmental concerns, budget, and performance requirements. Hybrid solutions that combine the benefits of both materials may also offer future opportunities for optimizing water infrastructure projects.

Table 2: Environmental Impact of GRP vs. Steel Pipes

Environmental Factor	GRP Pipes	Steel Pipes
Carbon Footprint (Production)	Low	High
Energy Consumption (Transport)	Low	High
Recyclability	Limited	High
Lifespan	Long	Medium

Table 2 demonstrates that GRP pipes have a smaller environmental impact than steel pipes, especially when considering carbon emissions and energy use. However, steel's recyclability is an advantage if recycling practices are followed.

4. Hydraulic Efficiency

Hydraulic efficiency is crucial in water supply systems as it affects how easily water moves through the pipes. GRP pipes have smooth internal surfaces, reducing friction and leading to better hydraulic performance (Zhao & Chen, 2017). This is particularly important in long-distance water transmission, where even slight improvements can save a lot of energy over time.Steel pipes, though strong, are more prone to corrosion and scale buildup, which can increase friction and reduce hydraulic efficiency (Hansen & Schmidt, 2018). Over time, this can require more frequent maintenance to keep the pipes running efficiently.

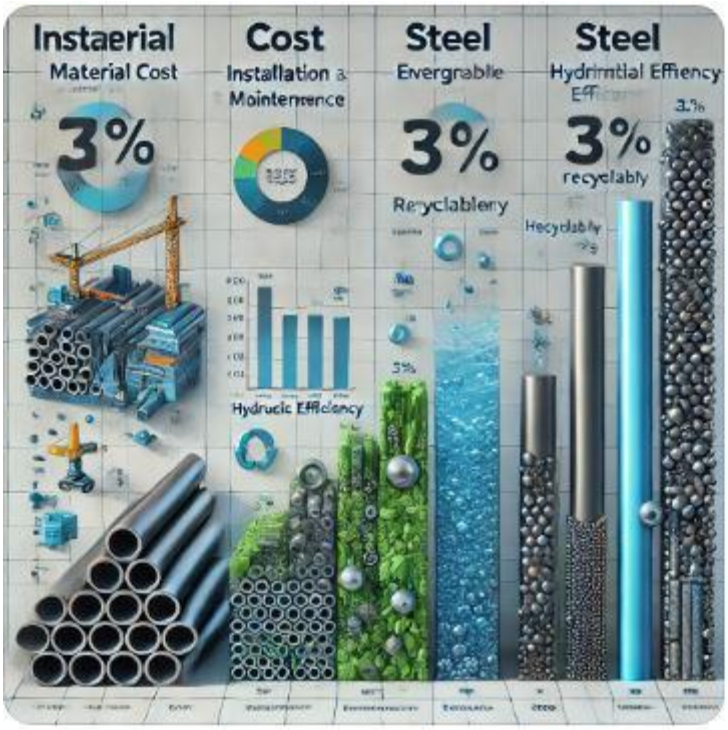


Figure (1) comparing GRP and steel pipes

Here are the three graphs comparing GRP and steel pipes based on installation and maintenance costs, environmental impact, and hydraulic efficiency.

1. **Cost Graph**: It illustrates the initial material cost, installation, and long-term maintenance, highlighting how GRP pipes may have higher upfront costs but lower installation and maintenance expenses compared to steel.
2. **Environmental Impact Graph**: This visual compares the carbon footprint, energy consumption, and recyclability of both pipe materials. GRP pipes have a smaller environmental impact in terms of emissions, while steel benefits from its high recyclability.
3. **Hydraulic Efficiency Graph**: It tracks how GRP pipes maintain a higher hydraulic efficiency over time due to their low friction and corrosion resistance, while steel's efficiency declines due to scale buildup and corrosion.

Figure(2) Cost Comparison: Installation, Maintenance, and Durability

- **Installation Costs**: GRP pipes have lower installation costs due to their lightweight nature, which reduces labor and equipment needs. Steel pipes, being heavier, require more intensive labor and machinery, making installation more expensive.
- **Maintenance Costs**: GRP pipes are corrosion-resistant, leading to lower maintenance costs over time. In contrast, steel pipes are prone to rust and scale buildup, requiring more frequent maintenance.
- **Durability**: GRP pipes have higher long-term durability due to their resistance to environmental factors and chemical exposure. Steel pipes, while strong, can be affected by corrosion, reducing their lifespan.
- **Environmental Impact (Bar Chart)**

- **Carbon Footprint**: GRP pipes have a lower carbon footprint because their manufacturing process emits fewer greenhouse gases compared to steel production, which is energy-intensive.
- **Recyclability**: Steel pipes are highly recyclable, making them advantageous in terms of sustainability if recycling practices are followed. GRP pipes, while durable, have limited recyclability, which can be a downside from an environmental perspective.
- **Hydraulic Performance Over Time (Line Chart)**

- **GRP Pipes**: The graph shows that GRP pipes maintain high and stable hydraulic efficiency over time. Their smooth internal surface minimizes friction, and their resistance to corrosion ensures that the performance does not degrade significantly.
- **Steel Pipes**: Over time, the hydraulic performance of steel pipes declines. This is due to corrosion and the accumulation of scale inside the pipes, which increases friction and reduces efficiency. As a result, steel pipes may require more frequent cleaning or replacement to maintain their flow capacity.

Generalities:

The Rudbal Dam, situated on the Rudbal River in Fars Province, is currently one of the dams being constructed along the Darab-meters of water per year. Geographically, the Rudbal Dam is positioned in close proximity to several cities, with Neyriz and Estahban to the north, Fasa and Jahrom to the west, and Darab city to the south, making it easily accessible from various directions. These cities, located in the vicinity of the dam, benefit significantly from its presence for various purposes related to water resource management and supply.

Estahban road, specifically at the 25th kilometer mark. This particular dam falls under the category of earthen dams, constructed using pebbles with a clay core, and stands tall at an impressive height of 83 meters. The total volume of the Rudbal dam measures up to a substantial 82 million cubic meters. Moreover, the crest length of this dam spans 485 meters while boasting an adjustable capacity of 104 million cubic

Table (4) Dam Specifications:

The river bed at the dam site	**1310 meters above sea level**
The level of the basin to the dam site	910 km2
Average rainfall of the basin (annual)	365 mm/year
Average Annual Yield	110.9 million cubic meters
Tank level at maximum level (2001/4)	27.3 km²
Tank volume at maximum level (2001/4)	95 million cubic meters
Incoming floods to the reservoir with a return period of 100 years	1000 m3/s
Incoming floods to the reservoir with a return period of 1000 years	1950 m3/s
Incoming floods to the reservoir with a return period of 10,000 years	3,100 m3/s

vicinity of the project. Simultaneously, a segment of the water resources is allocated to support the operations of petrochemical industries operating in the project area, contributing to their sustainability and operational efficiency. Furthermore, one of the significant outcomes of these efforts is the generation of hydroelectric power, harnessing the natural resources available in the region to produce clean and renewable energy for various applications and sectors. By integrating these multifaceted approaches, the project aims to not only enhance agricultural practices and water management but also to foster economic growth, environmental sustainability, and social well-being in the region.

Objectives of Dam Construction:

in an effort to enhance agricultural productivity, various strategies are being implemented such as expanding the irrigated lands and establishing orchards, alongside the advancement and encouragement of pressurized irrigation techniques to optimize water usage and conservation. Moreover, a focus is placed on ameliorating the environmental conditions and altering the climatic conditions within the region through innovative methods like utilizing evaporation from the surface of a 270-hectare lake, fostering the growth of plants and aquatic organisms, and creating a recreational ecosystem. Additionally, a crucial aspect of these initiatives involves supplying a portion of the drinking water needs of urban areas situated within the conditions. To address this challenge, the city has historically relied on the drilling of wells. There are currently 13 wells in Darab, each reaching depths of 200 to 250 meters. These wells have been essential in meeting the city's water needs. However, the over-reliance on these wells has led to unsustainable exploitation of the groundwater resources. This overuse has highlighted the urgent need to explore alternative water supply solutions to ensure a sustainable future for Darab.

In response to this pressing issue, authorities have made concerted efforts to address the water scarcity problem. One of the most significant initiatives undertaken is the implementation of a comprehensive water supply plan centered around the Rudbal dam. This strategic project aims to transport water from the Rudbal dam to Darab city and its neighboring urban areas. The project is structured through a Build-Operate-Transfer (BOT) contract, overseen by the Fars Water Organization. This method of project delivery ensures that the private sector is involved in the construction and initial operation phases, which can lead to more efficient project execution and management.

The Rudbal dam water supply project is a critical component of the region's long-term strategy to mitigate water scarcity. By transporting water from the dam, the project aims to provide a reliable and sustainable water source for Darab and surrounding areas. This initiative not only addresses the immediate water needs of the population but also lays the groundwork for future growth and development in the region. The BOT contract structure is particularly advantageous as it involves the private sector in financing, building, and operating the project for a specified period. After this period, the project will be transferred back to the public sector. This approach helps in leveraging private investment and expertise while ensuring that the public ultimately

Image (1) Location of the Rudbal Dam

Darab City: A Historical and Geographical Overview

Darab city, located in the southeastern region of Fars province, is a prominent urban center with a rich history that spans several millennia. It is a significant city within the province, not just for its historical heritage but also for its strategic geographical positioning. In addition to Darab itself, the area includes three other cities: Jannatshahr, Doborji, and Fadami. Darab is situated approximately 240 kilometers from Shiraz, the provincial capital, making it an important settlement both historically and geographically.Based on the 2006 census data, Darab has an estimated population of around 170,000 individuals. The city is divided into four main districts: Rustaq, Forg, and Jannat. This division reflects the city's administrative structure and helps in managing its vast area and diverse population. Geographically, Darab shares borders with several other cities, including Zarrindasht, Estahban, Neyriz, Fasa, Larestan, and even extends to the province of Hormozgan. Covering an extensive area of about 7,500 square kilometers, Darab stands at an elevation of 1,180 meters above sea level. This elevation contributes to its unique topographical characteristics, distinguishing it from surrounding regions.One of the most significant challenges Darab faces is its arid climate. This dry climate has long posed a problem of inadequate water supply, a common issue in many regions with similar environmental infrastructure require significant financial investment and technical expertise. Ensuring the efficient and equitable distribution of water from the Rudbal dam to Darab and its neighboring areas is a complex task that involves careful planning and coordination. Moreover, it is essential to engage the local community and stakeholders throughout the project's lifecycle to ensure its success and sustainability.Community engagement is crucial for fostering a sense of ownership and responsibility among residents, which can contribute to the project's long-term success. By involving the local population in decision-making processes, authorities can ensure that the water supply project meets the needs and expectations of those it is intended to serve.

Water transfer route from Rudbal Dam to Darab Dam:

The water transfer route from Rudbal Dam to Darab encounters numerous challenges stemming from the presence of a rugged and insurmountable terrain, compounded by natural obstacles and resistance from local adversaries. In response to these complexities, a suggestion has been made to employ a steel pipeline equipped with a sanitary casing for the purpose of conveying water from the dam to the treatment facility serving Darab and neighboring urban centers..

Image (2) the view of diifrent soil and enviroment in this project

benefits from the infrastructure.Furthermore, the implementation of the Rudbal dam project reflects a broader commitment to sustainable development in Darab. It underscores the importance of integrating environmental considerations into urban planning and resource management. By reducing reliance on groundwater, the project helps preserve the region's natural resources and promotes the sustainable use of water. Additionally, the project's success could serve as a model for other regions facing similar challenges, demonstrating the effectiveness of integrated water resource management and public-private partnerships.The water supply initiative is not without its challenges. The construction and maintenance of the necessary

In conclusion, Darab city, with its rich historical heritage and strategic geographical location, faces significant challenges related to water scarcity. However, through innovative initiatives like the Rudbal dam water supply project, the city is taking important steps towards securing a sustainable and reliable water source for its future. This project, implemented through a BOT contract, highlights the potential of public-private partnerships in addressing critical infrastructure needs. As Darab continues to grow and develop, the lessons learned from this initiative will be invaluable in guiding future efforts to ensure the sustainable management of its natural resources.

time, ensuring efficient fluid flow and reducing energy costs associated with pumping. The higher Hazen-Williams coefficient of GRP pipes compared to steel pipes means that GRP pipes can achieve the same flow rate with a smaller diameter, resulting in lower material and installation costs.

Transportation and Handling Costs Steel pipes are considerably heavier than GRP pipes, which increases transportation, loading, and handling costs. The high weight of steel pipes also necessitates the use of heavy equipment for installation, particularly for pipelines with large diameters. This requirement adds to the overall cost of projects using steel pipes. In contrast, GRP pipes are lighter and easier to handle, reducing transportation and installation costs. The lower weight of GRP pipes also allows for quicker and more efficient installation, further reducing labor costs and project timelines.

Heat Transfer and Thermal Insulation Steel pipes have a high heat transfer coefficient, which can lead to issues such as freezing in cold climates or temperature increases in drinking water. To prevent freezing, the depth of trench design must be increased, and additional soil slag or thicker pipe walls may be required, further increasing costs. GRP pipes, with their lower heat transfer coefficient, are less prone to these thermal issues, making them more suitable for a wider range of environmental conditions. This characteristic reduces the need for additional insulation and trench modifications, leading to cost savings in both materials and labor.

Structural Integrity and Load Resistance When subjected to excessive loads, steel pipes have a low elastic coefficient and are prone to becoming elliptical, compromising their structural integrity. GRP pipes, with their higher elasticity and flexibility, can withstand greater loads without deforming.

Technical and Economic Comparison of BIAXIAL Pipes and Steel Pipes

When evaluating the use of steel pipes versus GRP (Glass Reinforced Plastic) pipes, several technical and economic factors come into play, highlighting the advantages and disadvantages of each material.

Corrosion Resistance One of the primary drawbacks of steel pipes is their vulnerability to corrosion from environmental factors. This susceptibility necessitates the application of protective coatings and insulation both inside and outside the pipe to extend its lifespan and maintain its integrity. In contrast, GRP pipes are inherently resistant to corrosion, making them a more durable option in environments where corrosion is a concern. This inherent resistance translates into lower maintenance costs and longer service life for GRP pipes compared to steel pipes.

Durability and Longevity Steel pipes, especially when installed underground, tend to have a shorter useful life than GRP pipes due to their susceptibility to corrosion and other environmental factors. This shorter lifespan necessitates frequent replacements or the implementation of protective measures, which can be costly. GRP pipes, on the other hand, offer a significantly longer lifespan, with an expected service life of at least 50 years compared to the 20-year lifespan of steel pipes. This longer lifespan reduces the frequency of replacements and maintenance, leading to lower long-term costs for projects using GRP pipes.

Surface Smoothness and Flow Efficiency The inner surfaces of steel pipes quickly lose their smoothness due to corrosion and sediment build-up, which can hinder fluid flow and increase pumping costs. GRP pipes maintain their smooth inner surfaces over of applications and project conditions. This versatility makes GRP pipes a more adaptable and practical choice for many projects.

Impact of Wave Propagation and Surge Control The speed of wave propagation in steel pipes is three times that of GRP pipes, increasing the risks associated with hydraulic ram impact. This rapid wave propagation requires more immediate and stringent surge control measures in steel pipes. In GRP pipes, the time required for surge control (T=20L/A) is significantly longer, allowing for more effective and manageable control measures. This characteristic enhances the safety and reliability of GRP pipes in applications where surge control is critical.

In summary, GRP pipes offer several advantages over steel pipes in terms of corrosion resistance, durability, flow efficiency, transportation and handling costs, thermal insulation, structural integrity, production and installation time, repair and maintenance, variety of fittings, and surge control. These benefits make GRP pipes a more cost-effective and practical choice for many projects, particularly those requiring long-term reliability and efficiency. The lower overall cost and superior performance of GRP pipes compared to steel pipes highlight their suitability for a wide range of applications, from water supply and wastewater management to industrial and infrastructure projects.

Table (5) Comparison of Mechanical Characteristics of GRP Uni-Axial and GRP Bi Axial Pipes with Metal Pipes

GRP Uni-Axial Pipe PROPERTIES							
pipe density (kg/m3)	poisson ratio hoop/axial	poisson ratio axial/hoop	hoop modulus of elasticity (Mpa)	axial modulus of elasticity (Mpa)	hoop tensile strength (Mpa)	axial tensile strength (Mpa)	thermal expansion coefficient (1/c°)

This characteristic makes GRP pipes more reliable in applications where pipes are subjected to heavy loads or ground movement. The superior load resistance of GRP pipes reduces the risk of damage and the need for costly repairs or replacements.

Production and Execution Time The production and installation of GRP pipes are faster than those of steel pipes. The need for welding in steel pipe installation extends the execution time, requiring skilled labor and increasing project costs. In contrast, GRP pipes can be produced and installed more quickly, reducing labor costs and shortening project timelines. The faster production and execution times of GRP pipes make them a more efficient and cost-effective choice for large-scale projects.

Economic Considerations The overall cost of using GRP pipes is significantly lower than that of steel pipes. The production cost of GRP pipes is about 30 to 35 percent less than that of steel pipes. Additionally, the implementation cost of steel pipes is about 35 to 40 percent higher than that of GRP pipes due to the need for welders and other specialized labor. The lower cost of GRP pipes makes them a more economically viable option for many projects.

Repair and Maintenance Repairing and modifying GRP pipes on-site is relatively straightforward and can be done with minimal time and cost. In contrast, repairs to steel pipes are often time-consuming and expensive, involving specialized labor and equipment. The ease of repairing GRP pipes reduces downtime and maintenance costs, contributing to their overall cost-effectiveness.

Variety of Fittings GRP pipes offer a greater variety of fittings compared to steel pipes, allowing for more flexibility in project design and implementation. The availability of different types of fittings for GRP pipes enables their use in a wider range

$$H_{f(GRP)} = H_{f(steel)} \rightarrow \frac{10.68 \times Q^{1.852} \times L}{C_{GRP}^{1.852} \times D_{GRP}^{4.87}} = \frac{10.68 \times Q^{1.852} \times L}{C_{steel}^{1.852} \times D_{steel}^{4.87}} \rightarrow$$

$$\frac{1}{C_{GRP}^{1.852} \times D_{GRP}^{4.87}} = \frac{1}{C_{steel}^{1.852} \times D_{steel}^{4.87}} \rightarrow \frac{C_{steel}^{1.852}}{D_{GRP}^{4.87}} = \frac{C_{GRP}^{1.852}}{D_{steel}^{4.87}}$$

In the above relationship, the diameter of the GRP pipe is equal to 800 mm and the C coefficient for the GRP pipe is equal to 150 and for the steel pipe is equal to 110:

$$\frac{110^{1.852}}{D^{4.87}} = \frac{150^{1.852}}{0.95_{steel}^{4.87}} \rightarrow D_{GRP} \cong 0.82 \rightarrow D_{GRP} \cong 0.8\text{m}$$

If the C coefficient for GRP pipe is equal to 150 and for steel pipe is equal to 110, the equivalent diameter of a metal pipe with a diameter of 900 mm can be obtained for the GRP pipe , which will be equal to the diameter of 800 mm.

Table (6) General Comparison of Metal Pipes and GRP

Row	Effective Factors	GRP Bi-axial Tubes	Steel Pipes
1	Physical Strength of Pipe and External Load Bearing	Great	Great
2	Roughness of the Interior Wall and Staying Constant Throughout the Design Period	Great	Weak
3	Abrasion Resistance	Great	Medium
4	Shelf Life	Great	Medium
5	Production History in All Required Diameters	Great	Great
6	History of Water Consumption in the World	Great	Optimal
7	History of Consumption in Water Transfer in Iran	Optimal	Optimal
8	Production Speed	Great	Optimal
9	Speed and Ease of Installation	Great	Optimal
10	Ease of Branching Out	Great	Great
11	Ease of Operation	Great	Great
12	Ease of Maintenance	Great	Optimal
13	Transmission and Shipping Speed	Great	Optimal
14	Hydraulic Pressure Drop per 1000 Meters	Great	Optimal
15	Hygienic in Drinking Consumption	Great	Optimal
16	Availability of Raw Materials in the Country	Medium	Great
17	No Need for External Insulation	Great	Medium
18	No Need for Internal Coating and Corrosion Resistance	Great	Medium
19	Experience, Skills, and Equipment Necessary for Implementation	Great	Great
20	Ability to Store in the Open Space	Great	Medium
21	Ability to Be Used at High Pressures	Great	Great
22	Weight Loss in High Diameters	Great	Medium

- Loss and Damage Caused by Changing the Roughness of Steel Pipes Over Time

1872	0.3	0.16	20100	8400	300	34.8	21 x 10 -6

GRP Bi-Axial Pipe PROPERTIES							
pipe density (kg/m3)	poisson ratio hoop/axial	poisson ratio axial/hoop	hoop modulus of elasticity (Mpa)	axial modulus of elasticity (Mpa)	hoop tensile strength (Mpa)	axial tensile strength (Mpa)	thermal expansion coefficient (1/c°)
1872	0.3	0.16	26715	12570	385	117.5	21 x 10 -6

CARBON STEEL PROPERTIES				
pipe density (kg/m3)	poisson ratio	modulus of elasticity (Mpa)	yeild strength (Mpa)	thermal expansion coefficient (1/c°)
7830	0.292	203000	240	11 x 10 -6

. As discussed in the technical discussions of GRP pipes. These pipes, due to their high Hazen-Williams coefficient and very low friction drop capability, make it possible to provide the required flow rate and pressure with lower diameters. For example, according to the hydraulic calculations, the 800 mm GRP pipe is almost equal to the 900 mm metal pipe in terms of flow rate and pressure. It is equal to 150 and for steel pipes it is equal to 110.

$$H_f = \frac{10.68 \times Q^{1.852} \times L}{C^{1.852} \times D^{4.87}}$$

In this regard:

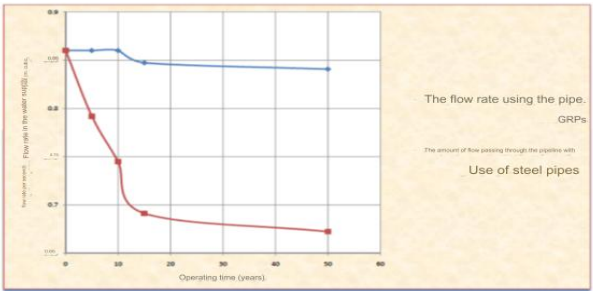
L represents the length of the path in meters.
D represents the diameter of the pipe in meters.
Q represents the flow rate in cubic meters per second.
Considering the constant flow rate in both pipes, it can be concluded as follows:

$$H_{f(GRP)} = \frac{10.68 \times Q^{1.852} \times L}{C_{GRP}^{1.852} \times D_{GRP}^{4.87}} \qquad H_{f(steel)} = \frac{10.68 \times Q^{1.852} \times L}{C_{steel}^{1.852} \times D_{steel}^{4.87}}$$

years that the pipes have been in use, ranging from 0 to 20 years.

GRP Pipe: Represented by blue circles and a linear trendline, the GRP pipe exhibits minimal degradation in hydraulic efficiency over time. The regression equation C=−0.24T+151C = -0.24T + 151C=−0.24T+151 (where TTT is time in years) shows a very slow decline, with an R2R^2R2 value of 0.75, indicating a moderately strong correlation between time and decreasing efficiency. After 20 years, the hydraulic coefficient remains around 145.

Steel Pipe: Represented by red squares, the steel pipe shows a more significant decrease in hydraulic efficiency over time. The regression equation C=−1.5T+138.5C = -1.5T + 138.5C=−1.5T+138.5 indicates a faster decline compared to GRP pipes. The R2R^2R2 value of 0.986 suggests a very strong correlation between time and the reduction in efficiency. After 20 years, the hydraulic coefficient drops to approximately 110, a much larger decrease compared to the GRP pipe.In summary, GRP pipes maintain higher and more consistent hydraulic efficiency over time compared to steel pipes, which degrade more rapidly.



As steel pipes age, their roughness increases, which impacts water transmission systems that rely on gravity and pressure. This increase in roughness inevitably leads to a reduction in the available discharge over time. Calculations reveal that within a 5-year span, the discharge capacity of these systems is expected to decline by approximately 6%. This trend is illustrated in the accompanying graph, which shows the changes in roughness for both steel pipes and GRP BIAXIAL pipes. The graph highlights how the roughness of steel pipes escalates over time compared to GRP BIAXIAL pipes, demonstrating a significant impact on the system's efficiency and discharge capabilities as the pipes degrade.

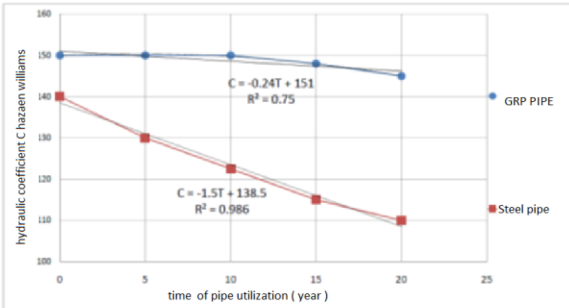


Diagram (1) Changes in Roughness Coefficient for Steel Pipes and GRP During 20 Years of Operation

This graph illustrates the relationship between the hydraulic coefficient (C) based on the Hazen-Williams equation and the time of pipe utilization for two types of pipes: Glass Reinforced Plastic (GRP) and Steel pipes, over a period of 20 years.

Y-axis (Hydraulic Coefficient - Hazen Williams C): The Hazen-Williams hydraulic coefficient, which is a measure of the smoothness of a pipe's interior surface and its ability to carry water efficiently, is plotted on the vertical axis. Higher values indicate smoother pipe surfaces with better hydraulic performance.

X-axis (Time of Pipe Utilization - years): The horizontal axis represents the number of similar project using steel pipes would require at least 3 years.Additionally, the lighter weight of GRP pipes eliminates the need for heavy machinery to transport the pipes within the trench, reducing logistical challenges and associated costs. This not only lowers the overall cost of pipe production and project implementation but also minimizes water wastage, making the project more economically viable.Figure 4 outlines the investment costs and the hidden costs related to lost water sales during the implementation period, considering an inflation rate of 18.2%. These costs are compared for GRP and steel pipes in the water supply project for Darab and its neighboring cities. It is crucial to update the implementation costs during the project using the cost equalization formula: P=P0×(1+i)nP = P_0 \times (1 + i)^nP=P0 ×(1+i)n, where PPP is the updated cost, P0P_0P0 is the initial cost, iii is the inflation rate, and nnn is the number of years.In summary, GRP pipes not only facilitate faster and more cost-effective project completion but also help prevent significant water loss, ensuring a more sustainable and economically sound water supply project.

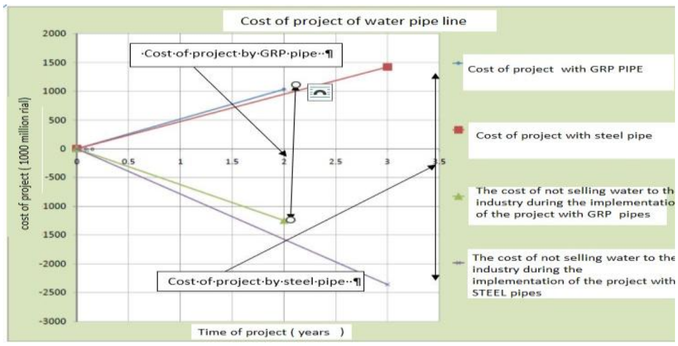


Figure (4) Estimation of the Obvious and Hidden Cost of Implementing Darab Water Supply Project with (Using GRP Pipes and Steel Pipes)

Based on the calculated costs and also considering the hidden cost (due to not selling water during the implementation period), the estimated cost of implementing

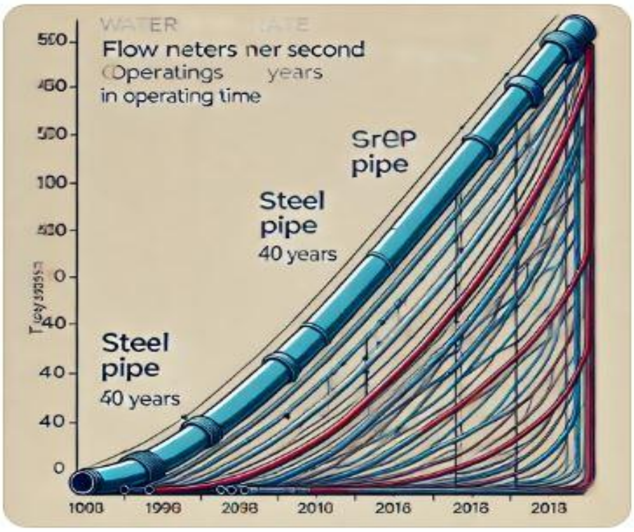


Figure (2) Reduction of discharge throughput during operation based on changes in roughness coefficient in steel pipes and GRP (Darab 9 water supply project)

This graph shows the flow rate of water through GRP and steel pipes over time. The GRP pipe (blue) maintains a relatively stable flow rate with minimal decline over 50 years. In contrast, the steel pipe (red) exhibits a steep reduction in flow rate within the first 10 years, continuing to decrease sharply until it levels out around 40 years.

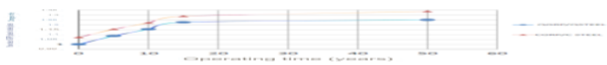


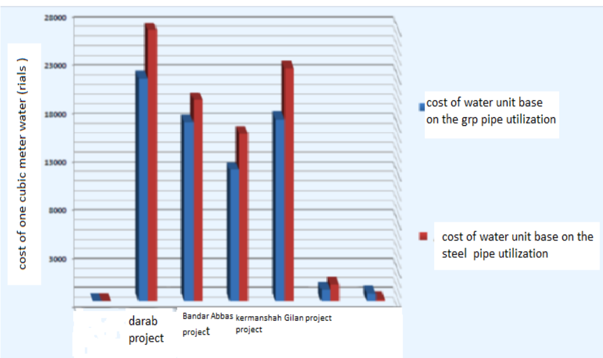
Figure (3) Dimensionless Relationship of Discharge Changes in GRP and Steel Pipes with Respect to Operation Time

Based on the provided diagrams, it is evident that the long-term use of steel pipes will diminish discharge rates and consequently increase the final water price in BOT projects by at least 35%. Conversely, GRP pipes offer several advantages in this context. One significant benefit is the higher speed and ease of installation compared to steel pipes. Due to their lower weight, GRP pipes allow for the connection of 100 to 200 meters of pipe daily within the trench. This efficiency means that a project using GRP pipes can be completed in 2 years, while a

Long-Term Project Cost	Lower due to reduced maintenance	Higher due to ongoing maintenance
Installation Time	Faster due to lightweight	Slower due to heavier weight
Cost of Not Selling Water During Installation	Lower (shorter installation time)	Higher (longer installation time)
Maintenance Requirements	Low (corrosion-resistant)	High (prone to corrosion)
Impact on Industries (Water Downtime Losses)	Minimal due to quicker installation	Significant due to longer downtime

The cost of implementing steel piping vs. the cost of implementing GRP pipe

The implementation costs of steel pipes are significantly higher compared to GRP pipes, not only due to the increased time required but also because of the greater material costs. To illustrate this difference, we can examine the cost estimates for steel and GRP pipes based on cubic meters of water for the Darab water supply project, as well as several other water supply projects across various provinces. The results are detailed in the following diagram.The comparison shows that while steel pipes involve a larger financial investment and extended project timelines, GRP pipes offer a more economical and efficient alternative. This is largely due to GRP pipes' lower material costs and easier, quicker installation. The diagram provides a visual representation of these cost differences, highlighting the economic advantages of opting for GRP pipes in water supply projects.



the project using steel pipes is equal to 3780 billion Rials and the total overt and hidden cost of implementing the project with GRP pipe is equal to 2281 billion Rials and their difference is equal to 1499 billion Rials. This will be equal to supplying theThe graph illustrates the cost comparison for a water pipeline project using GRP and steel pipes over time, measured in years. The primary focus is on the total project cost and the additional cost of not selling water to industries during the implementation of the project. The graph shows that while the initial costs for both GRP and steel pipe installations are similar, the long-term project cost for GRP pipes remains relatively stable, indicating lower maintenance and operational costs. In contrast, the cost of the project with steel pipes rises steeply, reflecting higher ongoing expenses. Additionally, the cost of not selling water to industries during the installation period is also accounted for, which is a factor that affects the total financial impact.

The sharp decline in the lower curves highlights the significant losses industries face due to water unavailability during the pipeline project. The cost of not selling water during the implementation period is higher for steel pipes, as the installation process for steel pipes tends to take longer due to their heavier weight and more complex installation. GRP pipes, being lighter and quicker to install, minimize the time industries face disruptions, making them a more financially viable option in projects where downtime directly impacts revenue. This analysis emphasizes the cost-efficiency of GRP pipes not only in material and installation costs but also in minimizing losses related to project implementation time.

Comparison Criteria	GRP Pipes	Steel Pipes
Initial Project Cost	Medium (Similar to Steel)	Medium (Similar to GRP)

Table (7) The results of sensitivity analysis related to the effect of different parameters on the cost of water in BOT methods during implementation and fixed operation time (Darab case study)

Impact Percentage	*Why is it important?*	*Description*	*Row*
22.5	1	The price of pipes and fittings	*1*
18.8	2	Type of piping route	*2*
12.5	3	Volume of excavation and embankment	*3*
11.8	4	Type and dimensions of the operation building	*4*
10	5	Overhaul Cost	*5*
24.4	6	Other parameters	*6*

According to these factors, the cost of water has been calculated as a dimensionless parameter considering the equilibrium and unbalanced cost.

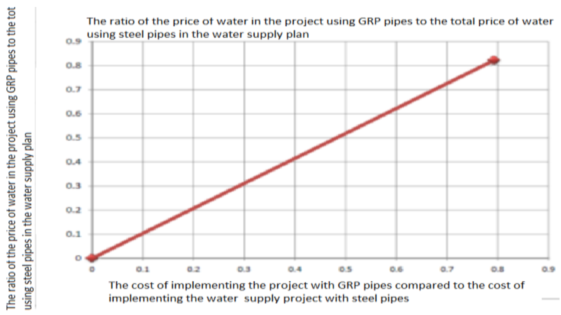


Figure (5) Dimensionless Diagram of Estimating the Cost of Water Using GRP Pipes in Relation to the Cost of One Cubic Meter of Water Using Steel Pipes:

Conclusion

Over a span of 50 years, the increase in the roughness coefficient of steel pipes significantly diminishes their discharge power. In contrast, GRP (Glass Reinforced Plastic) pipes maintain a more consistent performance, resulting in a 35% higher discharge throughput compared to steel pipes over the same period. This difference in efficiency underscores the superior long-

Figure (6) Diagram of estimation of water cost using GRP pipes compared to the cost of one cubic meter of water using steel pipes in different project (year 2012)

In developing a financial model to estimate the cost of delivering one cubic meter of water, several critical factors must be considered. These include the costs associated with pipes and valves, the type and price of connectors, and the route specifications. Additionally, the costs of pumping stations and operational buildings, the anticipated discharge rate throughout the project's duration, and the inflation rate over the operational period are all vital components. Other important factors include the tax rate and the bank interest rate.To accurately calculate the cost per cubic meter of water in BOT (Build-Operate-Transfer) projects, a sensitivity analysis is performed to identify the most impactful parameters. This analysis helps pinpoint which factors have the greatest influence on cost fluctuations. Key parameters typically include the price of pipes and valves, which directly affect material costs, and the inflation rate, which impacts overall project expenses over time. Additionally, the type and cost of pumping stations and operational buildings contribute significantly to the total expenditure. Understanding these variables and their sensitivity allows for more precise budgeting and financial planning, ensuring that the cost of water delivery is both realistic and manageable within the project's financial framework.

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term performance of GRP pipes.Additionally, the initial cost of purchasing GRP pipes, which possess physical strength comparable to steel pipes, is 18% lower. This cost advantage makes GRP pipes a more economical choice from the outset.When considering both overt and hidden costs, the overall expenditure for implementing a project with steel pipes is significantly higher than with GRP pipes. The total cost difference is equivalent to the price of water supplied for 18 months within the project. This calculation highlights the substantial financial benefits of opting for GRP pipes in long-term projects.Furthermore, in a Build-Operate-Transfer (BOT) contract with a fixed implementation and operation duration, the cost of pipes emerges as the most influential factor affecting the cost per cubic meter of water. This is due to the direct impact of pipe prices on the overall project budget. By choosing GRP pipes, projects can achieve considerable cost savings and operational efficiency. In summary, the adoption of GRP pipes over steel pipes for long-term projects offers multiple advantages: a significant increase in discharge power, lower initial costs, reduced total project expenditure, and more cost-effective water pricing in BOT contracts. These benefits make GRP pipes a superior choice for sustainable and economical water supply solutions.

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