



Key Technologies for Crossing Bridge Laying and Utility Tunnel Connection Design of Water Supply Pipelines

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Abstract. Aiming at the technical problems of water supply pipelines in coastal hilly areas, such as insufficient deformation adaptability, easy leakage at joints, high requirements for coastal corrosion protection, and limited laying space in the crossing-bridge laying and utility tunnel connection, this paper takes the water supply project of Yudonggenjiang Bridge section of Jingangjiang Shugang (Qinhai) Avenue as an example to study the key technologies including overhead layout of crossing-bridge pipelines, staggered exhaust design, flexible transition between bridge and ground, node connection between utility tunnel and directly buried section, and collaborative design of corrosion protection and seismic resistance. The project adopts 4 DN400 steel pipes laid overhead on both sides of the bridge, 6m-spacing sliding supports in the utility tunnel, staggered exhaust valves, rubber flexible joints and a graded corrosion protection system, which effectively adapt to the complex geological and bridge deformation conditions in coastal areas, and solve the practical problems of pipeline crossing-bridge operation, utility tunnel connection sealing and corrosion protection. The practice shows that the qualification rate of pipeline pressure test and disinfection is 100%, there is no leakage or air blockage during operation, and the seismic and corrosion protection performance meets the design service requirements. The research results can provide engineering reference for the composite laying design of urban road water supply pipelines in coastal hilly areas.

Keywords: water supply pipeline; crossing-bridge laying; utility tunnel; connection node; coastal hilly area; corrosion protection and seismic resistance

1 Introduction

At present, the construction of urban water supply networks is gradually developing towards cross-regional laying and integrated utility tunnel. The crossing-bridge laying and utility tunnel connection of water supply pipelines have become an important part of urban water supply system layout. Foreign countries have formed a relatively mature technical system for stress analysis of overhead pipelines, flexible joint adaptation and long-term protection in the design of water supply pipeline crossing bridges. The technologies such as support layout and branch lead-out of water supply pipelines in utility

tunnels have been standardized, focusing on pipeline deformation absorption and operation stability[1~4]. Domestic scholars have carried out a large number of engineering practices around the crossing-bridge laying of urban water supply pipelines and the design of water supply systems for utility tunnels, and clarified the basic design principles such as pipe material selection, buttress setting and valve arrangement. The relevant specification system has been continuously improved.

However, existing domestic and international design standards and guidelines mainly target single laying forms of water supply pipelines (overhead crossing-bridge, direct burial, or utility tunnel internal laying), and lack systematic design clauses for the full-chain connection of "crossing-bridge laying - directly buried section - utility tunnel" in coastal hilly areas. These standards insufficiently consider the coupling challenges of large topographic relief, strong corrosive groundwater, complex cross-river bridge deformation and limited laying space, resulting in poor adaptability of conventional design methods to coastal hilly geological and environmental conditions. Conventional technologies such as centralized exhaust, rigid bridge-ground connection, and single-layer corrosion protection cannot simultaneously meet the requirements of deformation adaptation, operational stability, and long-term durability in complex coastal environments.[5~8].

Relying on the water supply project of Jingangjiang Shugang Avenue, this paper takes the crossing-bridge laying and utility tunnel connection of water supply pipelines as the research core, carries out key technology optimization and practical analysis combined with engineering geological, hydrological and laying conditions, and provides technical reference for the design of similar water supply projects in coastal areas.

2 Project Overview

2.1 Basic Project Conditions

The water supply project of Yudonggenjiang Bridge section of Jingangjiang Shugang (Qinhai) Avenue has a total road length of 0.88km, with the stake number ranging from K2+330 to K3+210. The scope of the water supply project is consistent with that of the road project, and the design content includes water supply pipelines and ancillary facilities. The project is located in Qinzhou District, Qinzhou City, in the triangular area where the inland waterways of Qinzhou Port, Longmen Port and the main stream of Jingangjiang River cross. It crosses Yudonggenjiang River and belongs to the coastal ridge-like hilly-gully combination landform. The original terrain has large fluctuations, with the height difference between hilltops and valley bottoms ranging from 20m to 45m and the slope ranging from 15° to 30°, resulting in relatively complex engineering construction conditions.

2.2 Geological and Hydrological Characteristics

The site stratum is composed of Quaternary fill, silt, gravel sand, angular gravel and underlying Silurian argillaceous sandstone. The main type of groundwater is bedrock fissure water with poor water volume, and the hydraulic connection between surface

water and groundwater is close. The water quality corrosion test results show that surface water is weakly corrosive to concrete structures and strongly corrosive to steel structures; groundwater is weakly corrosive to concrete structures and strongly corrosive to steel bars under alternate wet and dry conditions. The site seismic intensity is VI degree, the basic seismic peak acceleration is 0.05g, the site is basically stable, and the engineering construction suitability is relatively suitable.

2.3 Overall Laying Scheme of Water Supply Pipelines

The project adopts water supply pipelines with diameters ranging from DN400 to DN800, which are divided into three parts according to laying conditions: directly buried section, bridge-following laying section and utility tunnel section. The segmented laying parameters are shown in Table 1.

Table 1. Segmented Laying Parameters of Water Supply Pipelines

Laying Section	Stake Range	Pipe Diameter	Laying Position	Pipe Material Selection
Directly Buried Section	K2+330~K2+385, K2+880~K2+930	DN600~DN800	Under non-motor vehicle lane on the east side	Grade K9 ductile iron pipe
Bridge-following Laying Section	K2+385~K2+880	4 DN400	Under sidewalk slabs on both sides of the bridge	Q235B steel pipe
Utility Tunnel Section	K2+930~K3+210	DN800	Inside the utility tunnel in the green belt on the east side	Grade K9 ductile iron pipe

3 Key Technologies for Crossing-bridge Laying of Water Supply Pipelines

Affected by bridge deformation, height difference change, wind load and coastal environment, the bridge-following laying section is the key control node of the project's water supply system. The design focuses on solving four technical problems: pipeline layout, exhaust, joint and fixation.

3.1 Pipe Material Selection and Spatial Layout for Crossing-bridge Laying

There is no underground laying space in the bridge section, and it is necessary to adapt to the longitudinal deformation and vibration of the bridge. Q235B steel pipe with a

pressure resistance grade of 1.0MPa and wall thickness of 5~8mm is selected to meet the strength and deformation requirements of overhead laying. The design adopts 4 DN400 steel pipes symmetrically arranged on both sides, laid under the sidewalk slabs on both sides of the bridge. The two pipes on each side are staggered vertically to avoid mutual interference and disperse the additional load on the bridge.

For the longitudinal section layout of the crossing-bridge pipeline, the bridge entry point is K2+385, the west bridge exit point is K2+837 and the east one is K2+875. After landing, the pipelines are merged into DN600 directly buried pipelines to realize smooth connection between bridge and ground.

3.2 Optimization Design of Staggered Exhaust Valves

Air is easy to accumulate at the high points of overhead pipelines, affecting the stability of water supply. Conventional centralized exhaust valves are prone to air blockage and cannot fully exhaust multi-pipeline systems. This project adopts staggered exhaust layout to overcome such defects: The project adopts staggered exhaust valve layout: the west exhaust valve is set at K2+504 and the east one at K2+506. The high points of the two DN400 pipelines are staggered vertically, and the exhaust tees are staggered horizontally. The exhaust function is realized by reversely installing drain tees, and the exhaust valves are fixed on the outside of the bridge guardrail. This layout can improve the reliability of exhaust without affecting bridge traffic and landscape effect.

3.3 Flexible Joint Technology for Bridge-ground Connection

Conventional rigid connection cannot adapt to uneven settlement between bridge and subgrade, easily causing joint damage. Therefore, rubber flexible joints are set at the junction of the bridge overhead section and the buried section to absorb vertical and axial displacement. The pipelines under the bridge section are fixed with pipe clamps with a spacing of 3m. After landing, the pipelines are merged into DN600 directly buried pipelines through reducers to ensure smooth flow transition.

3.4 Buttress and Fixation Design of Crossing-bridge Pipelines

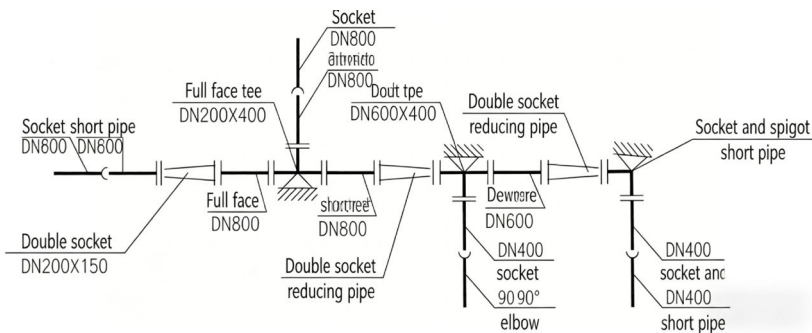


Fig. 1. Detail Drawing of Water Supply Pipeline Node Fittings

Concrete buttresses are set at pipeline bends, tees and valves in accordance with *Buttresses for Flexible Joint Water Supply Pipelines* (10S505), and selected according to the parameters of groundwater existence, 0.8MPa pressure and 2m soil cover above the pipe top. The pipelines laid along the bridge are fixed with C5 non-insulated pipe clamps with a spacing of 3m to ensure the stability of pipelines under wind load and vibration, as shown in Fig. 1.

4 Key Technologies for Connection Design Between Water Supply Pipelines and Utility Tunnels

The utility tunnel section is the core laying area of the main water supply pipeline. The connection between the pipeline in the utility tunnel and the external directly buried section and household branch pipes is the design focus, which needs to solve the problems of space adaptation, waterproof sealing and maintenance convenience[9~10].

4.1 Support Layout of Pipelines in Utility Tunnels

The utility tunnel has a size of 3200mm×3500mm, and DN800 water supply pipelines are laid along the side wall of the utility tunnel, adopting a combination of fixed supports and sliding supports. The spacing of sliding supports in the straight section is 6m, and buttresses are added at pipeline bends, tees and valves. The support design parameters are shown in Table 2.

Table 2. Design Parameters of Pipeline Supports in Utility Tunnels

Support Type	Spacing	Applicable Position	Fixation Method
Sliding Support	6m	Straight section	Welding with embedded steel plates on utility tunnel side walls
Fixed Support	Sectional nodes	Pipeline maintenance sections	Expansion bolt fixation
Buttress	Bends/Tees	Pipeline node positions	Cast-in-place concrete

4.2 Node Design for Utility Tunnel-Directly Buried Section Connection

The DN800 main pipeline in the utility tunnel leads out DN200~DN300 reserved branch pipes through the branch well, which are directly buried to 2m outside the road red line. The connection nodes adopt the center-aligned connection method, and soft-seal gate valves are set on the branch pipes.

4.3 Waterproof Sealing Design of Connection Section

Waterproof sleeves are set at the lead-out position of branch pipes on the utility tunnel side wall, and the gap between the sleeves and pipelines is filled with waterproof

sealant. The pipeline joints are sealed with T-type rubber rings. The allowable rotation angle for curved installation of pipelines with diameter DN600 and below is $\leq 3^\circ$, which adapts to the small deformation of the utility tunnel and directly buried section and ensures the sealing performance of the connection section.

5 Collaborative Design Technology of Corrosion Protection and Seismic Resistance in Coastal Environment

5.1 Graded Corrosion Protection System Design

Conventional single corrosion protection cannot adapt to the strong corrosive coastal environment. This project adopts graded corrosion protection for different pipe materials and laying environments, and the coating parameters are shown in Table 3.

Table 3. Parameters of Anticorrosive Coatings for Water Supply Pipelines

Pipe Material	Laying Position	Anticorrosive Form	Coating Index	Derusting Grade
Q235B Steel Pipe	Buried	Four-oil-one-cloth epoxy coal asphalt	Dry film thickness $\geq 0.4\text{mm}$	Sa2.5
Q235B Steel Pipe	Overhead	Polymer anticorrosive coating (two primers and two topcoats)	80~100 μm	St3
Q235B Steel Pipe	Inner Wall	8710-2B drinking water anticorrosive coating	Dry film thickness $\geq 200\mu\text{m}$	Food grade
Ductile Iron Pipe	Utility tunnel/Buried	Zinc layer + epoxy coal asphalt paint	Zinc layer $\geq 150\text{g/m}^2$, paint layer $\geq 70\mu\text{m}$	Grade K9

5.2 Pipeline Seismic Checking Calculation

In accordance with *General Code for Seismic Design of Building and Municipal Engineering* (GB55002-2021), the horizontal seismic displacement checking formula for buried pipelines is adopted as Formula (1):

$$\gamma_{EHP} \Delta_{pl,k} \leq \lambda_e \sum_{i=1}^n [u_n]_i \quad (1)$$

Where: γ_{EHP} is the horizontal seismic action partial coefficient, taken as 1.2; $\Delta_{pl,k}$ is the standard value of axial displacement of the pipeline within half the apparent wavelength caused by the propagation of shear waves; λ_e is the coordination coefficient of pipeline joints within half the apparent wavelength, taken as 0.64; $[u_n]_i$ is the design allowable displacement of a single pipeline joint; n is the total number of pipeline joints within half the apparent wavelength. The checking calculation shows that the allowable displacement of pipelines and joints of the project meets the seismic design requirements.

The complete seismic checking calculation parameters and results are supplemented in Table 4. The checking calculation shows that the calculated displacement is less than the total allowable displacement, so the allowable displacement of pipelines and joints meets the seismic design requirements.

Table 4. Seismic Checking Calculation Parameters and Results

Calculation Parameter	Value	Description
γ_{EHP}	1.2	Horizontal seismic action partial coefficient
$\Delta_{pl,k}$	12.5 mm	Standard axial displacement
λ_e	0.64	Joint coordination coefficient
$[u_n]_i$	8.0 mm	Single joint allowable displacement
n	4	Number of joints
$\lambda_e \sum_{i=1}^n [u_n]_i$	20.48 mm	Total allowable displacement
$\gamma_{EHP} \Delta_{pl,k}$	15.0 mm	Calculated seismic displacement
Result	Meet requirements	15.0 mm < 20.48 mm

6 Key Technologies for Construction and Quality Control

6.1 Trench Excavation and Backfilling

(1) The trench foundation pit has a safety level of Grade III, with an excavation depth of 0.9~2.0m. It is excavated at a slope of 1:0.75, the slope surface is protected with geotextile, a drainage ditch is set at the slope top, and a 10cm gravel cushion is laid at the pit bottom. The dewatering adopts the open sump drainage method to lower the water level to 0.5m below the foundation pit bottom.

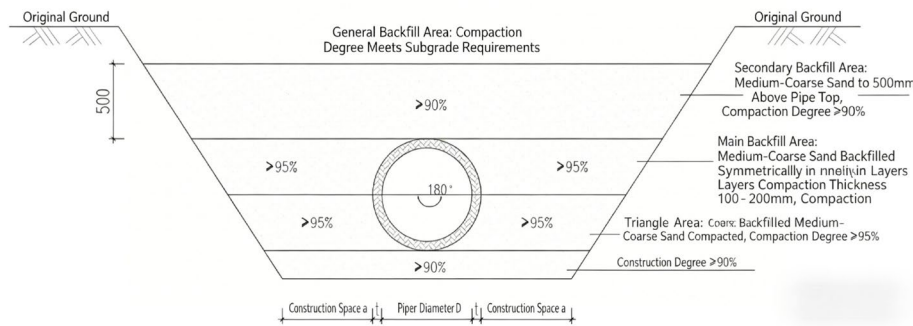


Fig. 2. Pipeline Trench Backfilling Drawing

(2) Layered compaction is adopted for backfilling: medium-coarse sand is used for backfilling on both sides of the pipe and 50cm above the pipe top, with a compaction coefficient ≥ 0.95 ; gravel soil is used for backfilling from 50cm above the pipe top to the designed subgrade top to meet the compaction requirements of road subgrade. When the soil cover above the pipe is less than 1.0m, concrete full-encasement reinforcement shall be carried out in accordance with Fig. 2.

6.2 Pipeline Pressure Test and Disinfection

(1) The working pressure of ductile iron pipes is 0.6MPa, and the test pressure is 1.1MPa. In the pre-test stage, after boosting to the working pressure and checking no leakage, boost to the test pressure and keep constant pressure for 30min. In the main test stage, stabilize the pressure for 15min, and the pressure drop ≤ 0.03 MPa is qualified.

(2) Pipeline flushing shall be carried out continuously with a flow rate not greater than 1m/s for 4~6 hours. It is qualified when the water color and transparency at the outlet are consistent with those at the inlet. After flushing, the pipeline is disinfected by pouring chlorine water with 20~30mg/L free chlorine, and the chlorine water stays in the pipeline for more than 24 hours, then flushed with domestic drinking water until the water quality test is qualified.

6.3 Welding and Installation Quality Control

(1) E4303 welding rod is adopted for steel pipe welding, with V-groove (angle 60° , gap 2mm, blunt edge 1.5mm). The inner wall misalignment is ≤ 0.5 mm, and the non-destructive testing ratio of welds is not less than 5%. When welding at ambient temperature below 0°C , preheat the pipeline to $100\sim 200^\circ\text{C}$ with a preheating width not less than 40mm.

(2) The installation of ductile iron pipes is guided by the manufacturer's technicians on site. The push-in depth of the joint reaches the mark ring, and the allowable rotation angle for curved installation of pipelines with diameter DN600 and below is $\leq 3^\circ$ to ensure the sealing performance of the joint.

7 Engineering Application Effect

The design scheme of crossing-bridge laying and utility tunnel connection of water supply pipelines in this project has been verified by construction, and all indicators meet the design and specification requirements:

(1) The exhaust system of crossing-bridge pipelines operates stably without air blockage;

(2) There is no leakage at the bridge-ground flexible joints and utility tunnel connection nodes, which can adapt to bridge deformation and uneven subgrade settlement;

(3) The graded corrosion protection system can adapt to the coastal corrosive environment and ensure pipeline durability;

(4) The qualification rate of pipeline pressure test and disinfection is 100%, and the seismic performance meets the specification requirements.

8 Conclusions

(1) The adoption of 4 DN400 steel pipes overhead on both sides, staggered exhaust and rubber flexible joints for crossing-bridge laying of water supply pipelines in coastal hilly areas can effectively adapt to bridge deformation and improve the operation stability of overhead pipelines.

(2) The connection between utility tunnel and directly buried section adopts 6m-spacing support combination, center-aligned connection and waterproof sleeve sealing design, which can realize smooth connection between the main pipeline in the utility tunnel and external branch pipes, and ensure waterproof sealing and maintenance convenience.

(3) The collaborative design of graded corrosion protection and seismic checking calculation in coastal environment can simultaneously meet the requirements of corrosion protection and seismic safety, and adapt to the complex geological and hydrological conditions in coastal areas.

(4) Limitations: This study is based on the coastal hilly area with seismic intensity VI degree; the adaptability to higher seismic intensity, stronger corrosion or larger terrain relief needs further verification. Long-term monitoring data over 5 years is insufficient to evaluate durability. The scheme is applicable to DN400–DN800 pipelines, and needs optimization for large-diameter pipelines.

(5) Future work: Establish a parametric design model for different coastal conditions; integrate intelligent sensing to realize real-time monitoring; carry out full-life cycle performance and cost-benefit analysis.

The key technologies for crossing-bridge laying and utility tunnel connection formed in this study are optimized based on actual engineering, with strong pertinence, and can provide reference for the design of similar urban road water supply projects in coastal hilly areas.

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