

Analysis of safety factors of embankment pipeline

ABSTRACT

With the rapid development of the modern economy, the safety of the embankment of the pipeline through the embankment is particularly important. Combining the construction method of the pipeline, the location of the pipeline crossing with the exit and entry points, the burial depth of the pipeline below the riverbed with the scouring depth of the riverbed, the permeability coefficient of the embankment and the stratum, the initial water level on the waterward side and the backwater side of the embankment, and other factors are analyzed to provide a theoretical basis for the future implementation of the project.

Keywords: dike crossing pipeline; crossing location; permeability coefficient

Introduction

1 Type of construction of a pipeline through the embankment

1.1 Excavation method construction

The pipeline will hurt the embankment during construction, for example, the directional drilling construction process will make the presence of boreholes in the riverbed, if the boreholes are not backfilled or the backfill quality is not high, the seepage diameter will be reduced, which may form a concentrated seepage under the action of high head, along the wall of the pipe, is prone to contact leakage.

Pipelines are mainly used to cross rivers by the following methods: bare crossing method, shallowly buried crossing method, horizontal directional drilling method, tunneling method (which also includes drill

and blast method, pipe jacking method, immersed pipe method, shield method, etc.). The impact of the crossing project on the river and embankment mainly occurs during the construction and operation phases, and the impact of the crossing project on the river embankment will be different due to different construction methods. The construction method of a pipeline through the embankment can be divided into excavation construction method and non-excavation construction^[1], Excavation method construction mainly includes bare laying, trench burial laying, blasting method, etc. Non-excavation method construction includes directional drilling method construction, pipe jacking method construction, shield method construction, tunneling method construction, drill and blast method construction, etc.



Figure 1 Excavation construction method

Generally, when the excavation method is used, it will affect the environment around the pipeline. Jilin Province, the Qingtie line through the river pipeline project, including the second river, seven doors through the project is the use of excavation method of construction, a certain degree of damage to their embankments and shore protection, after the completion of construction to restore the embankment, and often meet the existing standards, try to control the damage to the embankment, to ensure the safety of embankment operation, the final remedial measures", in addition to the water Construction using the excavation method, its workload is very large, accept the reason of shallow depth, river scouring, sand dredging, road navigation ship throwing drill, etc. is easy to impede navigation.

(1) Bare paving

The direct laying of the pipe on the riverbed is called bare set, the method is generally not easy to excavate the hard riverbed stratum or easy to scour the soil, which does not guarantee that the pipeline has sufficient depth, and bare laying force situation is extremely complex, safety can not be guaranteed, must also do a series of protective measures, but according to this method of laying is not easy to affect navigation and river dredging, boat anchor is not easy to damage the pipeline, excavation underwater The trench does not need to be used in the laying method, construction equipment, and technology can be easily applied^[2].

(2) Trench buried laying

Construction of cofferdams, diversion

channels, and other temporary construction buildings, if the use of a large excavation ditch buried method of construction, these buildings will impede the overflow area, obstructing the river flooding, play if you can work in the flood season, will certainly have a greater impact. And some projects need to break ground in the embankment construction, which will cause great danger to the river and the embankment on both sides.

(3) Blasting method

The explosives are arranged in the cross-section through the river bottom to each blast to blow out the submerged pipe trench, at first the blasting method was only applied to the bare blasting method, and finally gradually developed into the chamber planting pile blasting. The blasting method is generally more in the stone riverbed, and China has also used this method in the soil and stone riverbed to implement the pipeline crossing, such as the 1980s are using the blasting method, completed three crossings of the Yellow River, three crossings of the Liao River and Lotus River, which crossed the riverbed including pebbles sand, sand, and powder soil, but the results achieved is not very good, can not meet the burial depth requirements , However, the construction method also has shortcomings, such as the depth of the excavated pipe trench is uneven and cannot meet the burial depth requirements, the construction must be cleared with facilities such as pulling shovel, the embankment, buildings on both sides and shipping will be affected by the vibration of the blasting method, and also affect the flora and fauna in the water body, in recent years the blasting method has been unused.

(4) Trenching and plowing method construction U.S. Archie Brown used to use high-powered mechanical traction heavy trenching type, the pipeline in the seabed for

open technology trenching plow method can also be used in the river crossing, but the method can generally only dig out about 2m digging more.

1.2 Non-excavation construction

If the buried pipeline is constructed by non-excavation technology, because its advantage is that the pipeline can be buried very deep, avoiding the river washing the pipeline to cause bare outside, so it can make the pipeline run very safely, the ground building is affected by the non-excavation construction method is very small, the impact on the river bed and the slope are also very small, to the natural environment, hydrogeological conditions are very favorable. There is no need to excavate the pipe trench so that the amount of earthwork can reach the minimum, but also regardless of the season, year-round construction, short construction period, and fast progress is generally only about 2 to 4 weeks to complete, unnecessary to place the reinforced concrete shell above and below the pipe, will not cause navigation and river dredging obstruction, etc.^[3]. Meanwhile, the non-excavation method is used for crossing, and the pipeline can be buried 5~15m below the riverbed under different soil and terrain. Non-excavation crossing construction methods are generally used for sand and clay layers. There are two most common methods for the non-excavation construction of pipelines through rivers, namely the curve jacking method and directional drilling method, of which the directional drilling crossing method is the fastest growing in China, and the non-excavation construction method for pipelines through embankments has progressed rapidly in recent years, and the common non-excavation construction methods also include drill and blast

tunneling method, shield construction method, etc. Pipeline crossing in large rivers, should not choose a large number of workers in the water, and will also impede navigation underwater excavation method, but should choose low-disturbance non-excavation construction methods.

(1) Directional drilling method

When horizontal directional drilling is used for construction, the location of the entry and exit points of the pipeline will be affected by the construction pressure during construction, which will cause greater damage. Construction disturbance is likely to change the contact surface of the river and embankment penetration project and the soil layer, which may make infiltration damage occur on the contact surface of the pipe wall and the soil, resulting in infiltration damage, which is not conducive to ensuring the stability and safety of the embankment.

The advantage of using the directional drilling method for crossing is that: there is enough burial depth to easily meet the burial requirements, fast construction speed, labor saving, construction covers little ground, does not affect the natural environment and river navigation, different hydrological conditions almost do not effect on the directional drilling method, and the project cost is small. The disadvantage is that: geological conditions have a greater impact on directional drilling, not suitable for traversing within the pebble layer, drift stone layer, and hard rock layer, In addition to the traversing length of the pipeline and the diameter of the pipeline, will be limited by the limited torsional resistance of the drilling rig for long distances.

The main points of horizontal directional drilling construction are drilling guide hole → expansion hole → pipeline back dragging, and directional drilling construction intention as shown in Figure 2 - Figure 4.

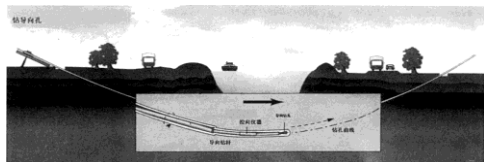


Figure 2 Drilling pilot hole

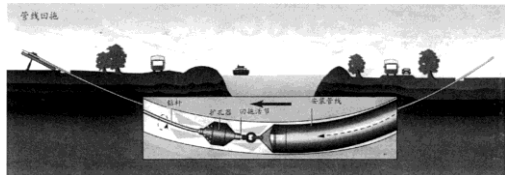


Figure 3 Reaming

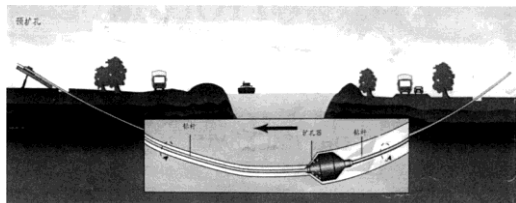


Figure 4 Pipeline back dragging

2 Pipeline burial depth and riverbed scour depth analysis



Figure 5 Pipe burial depth

During the construction of the pipeline, it is easy to collapse and collapse pits in the shallow part of the pipeline burial depth, and with the extension of time and the action of high water level, new collapse pits may appear, and even if there are no collapse pits, the soil will be loosened in a certain range, which is extremely unfavorable to the embankment stability and seepage resistance.

From 1971 to 1975, there were four accidents in the former Soviet Union caused by the insufficient depth of burial of pipelines, and after the mandatory deepening of pipeline burial protocols, the

possibility of pipeline deformation or floating was reduced, and only one such accident occurred in 1975-1990, which shows that the depth of burial of pipelines may cause safety problems.

To determine the reasonable burial depth of the pipeline and the engineering measures to stabilize the pipeline, it is necessary to analyze the scour change of the crossing section and calculate the maximum scour depth of the riverbed. The safety of the buried pipeline through the river is directly affected by the change of the riverbed and the magnitude of the change, while the safety of the embankment will also be affected by the pipeline through the river^[6].

When the northwest Mahuining pipeline crossed the Yellow River, the pipeline crossed 33.5km near Qingtongxia Reservoir, the pipeline should have at least 4m depth of reasoning according to the requirements, but in reality, the burial depth of the pipeline did not meet the design requirements, causing most sections of the pipeline to be scoured and exposed during the flood season, plus the influence of backwater from Qingtongxia Reservoir, and the upstream river artificially and indiscriminately set In 1988, the pipeline of the project was scoured by the flood, which eventually led to the rupture of the pipeline, resulting in significant property damage and serious social impact.^[4]

From here, it can be seen that the burial depth of the pipeline can save the pipeline from the risk of being exposed by scouring if it is buried a little deeper so that the depth of the pipeline exceeds the scouring depth of the river, which can also show that the burial depth of the pipeline can have an impact on safety.



Figure 6 Severe exposure of an oil pipeline through a dike in the northeast (1997 situation)

The burial depth of the pipeline through the embankment is mainly influenced by the following factors.

(1) Streambed evolution, usually refers to a series of changes in streambed morphology when it is artificially disturbed by natural conditions. These changes include scour and siltation of the riverbed in the vertical direction, displacement in the horizontal direction, and changes in the morphology and dimensions of the riverbed planes.

(2) river planning and later river regulation, the planning line of the river, the river bottom planning elevation, planning channel level, and later river regulation is an important considerations for the burial depth of the pipeline through the river.

(3)Corresponding to the navigational requirements under the river grade, according to the provisions of the Inland Waterway Navigation Standards, the burial depth of the river crossing pipeline navigational requirements need to consider the following factors: 1, the channel depth required for the planned channel grade, 2, the design minimum navigable water level, 3, the rich value of the Inland Waterway Navigation Standards on the burial of underwater river crossing structures, 4, the depth of the anchor body into the ground when the ship is anchored in an emergency, etc.

3 seismic analysis theory of overbank pipelines

3.1 Static force theory

Earlier studies simplified the underground pipeline as a beam on an elastic foundation, then its equations of motion in the transverse and axial directions, respectively

$$\rho A_0 \frac{\partial^2 w}{\partial t^2} + EI \frac{\partial^4 w}{\partial x^4} + k_b w = k_b w_g(x, t) \quad (1)$$

$$\rho A_0 \frac{\partial^2 u}{\partial t^2} - EA_0 \frac{\partial^4 u}{\partial x^4} + ku = ku_g(x, t) \quad (2)$$

Where w, E, A_0, I is the material density, modulus of elasticity, pipe cross-sectional area, and moment of inertia of the pipe,

respectively; k_b and k are the spring coefficients of the foundation over the length of the transverse and axial pipe units, respectively; w and u are the transverse and axial displacements of the pipe, respectively,

w_g and u_g are the deformations of the foundation in the corresponding directions.

To solve the above two equations, we obtain:

$$w(x, t) = \frac{1}{D_b} w_g(x, t) \quad (3)$$

$$u(x, t) = \frac{1}{D_u} u_g(x, t) \quad (4)$$

Eq.

$$D_b = 1 + \left(\frac{w}{w_0} \right)^2 \left(\frac{v_b}{v} \right)^4 - \left(\frac{w}{w_0} \right)^2 \quad (5)$$

$$D_u = 1 + \left(\frac{w}{w_0} \right) \left(\frac{v_p}{v} \right)^2 - \left(\frac{w}{w_0} \right)^2 \quad (6)$$

Where $w_0 = \sqrt{k / \rho A_0}$ is the self-oscillation frequency of the pipe on elastic support

$v_b = \sqrt[4]{EIw^2 / \rho A_0}$ is the bending wave velocity

propagated by the pipe; $v_p = \sqrt{E / \rho}$ is the

longitudinal wave velocity propagated by the pipe.

Since in general, the rigid self-oscillation frequency of the underground pipe w_0 is much larger than the frequency of ground vibration w (especially in the soft ground), i.e. $(w/w_0) \ll 1$, the damping of the soil around

the pipe is very large, so the dynamic action can be ignored and only the static action is considered, and the results of the so-called quasi-static analysis are obtained.

$$D_b = 1 + \left(\frac{EI}{k_b} \right)^2 \left(\frac{2\pi}{L} \right)^4 \quad (7)$$

$$D_u = 1 + \left(\frac{EA_0}{k} \right) \left(\frac{2\pi}{L} \right)^2 \quad (8)$$

$$L = vT(2 - 4c) \quad (9)$$

$$T = \frac{2\pi}{w} \quad (10)$$

Where, v is the velocity of seismic wave propagation along the axial direction of the pipe, and T is the ground vibration period?

From this, the bending and axial strains in the pipe due to foundation deformation are

$$\varepsilon_b = \left(\frac{2\pi}{L} \right) \frac{1}{D_b} u_0 r_0 \quad (11) \text{ (Bending strain)}$$

$$\varepsilon = \left(\frac{2\pi}{L} \right)^2 \frac{1}{D_b} u_0 r_0 \quad (12) \text{ (Axial strain)}$$

$$u_0 = \frac{a_{\max}}{w^2} = \frac{a_{\max}}{4\pi^4} \quad (13)$$

Where, u_0 is the displacement amplitude of the foundation vibration, a_{\max} is the corresponding acceleration amplitude, and r_0 is the outer radius of the pipe. The above two equations can also be written as the

ratio of pipe-to-foundation displacement R_b and R as follows.

$$R_b = \frac{k_b / (EI)}{\left(\frac{2\pi}{L} \right)^4 + k_b / (EI)} = \frac{1}{D_b} \quad (14)$$

$$R = \frac{k / (EA_0)}{\left(\frac{2\pi}{L} \right)^4 + k / (EA_0)} = \frac{1}{D_u} \quad (15)$$

When the pipeline is thin and long, $D_w = 1$,

$D_u = 1$. Therefore, the final simplified bending strain and axial strain are:

$$\varepsilon_b = \left(\frac{2\pi}{L} \right)^2 u_0 r_0 \text{ or } R_b \approx 1 \quad (16)$$

$$\varepsilon = \frac{2\pi}{L} u_0 \text{ or } R \approx 1 \quad (17)$$

This means that the displacement of the pipe is equal to the displacement of the

C_c foundation, i.e. the static theory.

By simply assuming that the pipe strain is equal to the foundation strain, the underground pipe strain can be represented by the parameter of ground vibration only. As a result, the axial strain along the pipe ε ,

the curvature strain ε_b / r_0 , the relative displacement deformation between the

nodes ε_L , and the relative corner

deformation of the nodes ε are

$$\varepsilon = \frac{\dot{u}}{v_p} = \frac{2\pi u_0}{vT} = \frac{2\pi u_0}{L} \quad (18)$$

$$\varepsilon_b / r_0 = \frac{\ddot{u}}{v_s^2} = \left(\frac{2\pi}{T} \right)^2 \frac{u_0}{v_s^2} = \left(\frac{2\pi}{T} \right)^2 u_0 \quad (19)$$

$$\varepsilon_L = \varepsilon L \quad (20)$$

$$\varepsilon_g = \varepsilon_b L \quad (21)$$

Where, \dot{u}, \ddot{u} are the mass velocity and acceleration of ground vibration, respectively, and L is the length between two nodes. The axial strain of the pipe is inversely proportional to the propagation velocity v of the seismic wave along the pipe and proportional to the mass vibration^[8]. Since v is small and u is large in soft ground, the strain of the pipe is also large, and the seismic damage is also large; in addition, this relationship shows that the axial strain is independent of the amplitude of the maximum acceleration, which is also consistent with the seismic response observations^{[9][10]}.

3.2 Elastic foundation beam theory

In 1975, *parmelee, Ludtke* proposed a semi-elastic foundation volume theory to analyze soil-pipe interactions in underground pipes. They assumed that there is an underground pipe with radius r0 at h below the surface of the semi-infinite elastic foundation, and the dynamic response of the soil-pipe common system can be replaced by a static displacement u generated by a horizontal concentrated force at the pipe, which gives the equation of motion of the system as

$$M \frac{\partial^2 u}{\partial t^2} + C \frac{\partial u}{\partial t} + k u = -M \frac{\partial^2 u_g}{\partial t^2} \quad (22)$$

where k represents the elastic resistance at unit relative displacement in the pipe, $M = M_p + M_s$ is the sum of the pipe mass M_p and the effective mass of the soil M_s , C is the damping effect of the soil-pipe interaction, u is the displacement of the pipe concerning for to the soil, and u_g is the displacement of the pipe due to ground shaking. Conclusions are drawn.

$$k = c_k(a) E_s \quad (23)$$

$$M_s = C_M(a) \rho_s \quad (24)$$

$$C = \frac{C_s L}{A r_0^2} C_c(a) \quad (25)$$

where C_K, C_M , and C_c are functions of the ratio $a = h / r_0$; E_s, ρ_s and C_s are the modulus of elasticity, mass density, and damping coefficient measured on the soil of length L and cross-sectional area A, respectively. With these parameters, the dynamic properties and seismic response of the pipeline can be studied^[5]. It turns out that the relative displacement u between the pipe and the foundation is small, which indicates that the pipe is moving almost co-moving with the foundation soil rather than moving through the soil. However, there are limitations of this theory: first, the Poisson's ratio is taken in this theory $\nu = 0.5$ to simplify the Mindlin equation, and for many soils, this is its upper limit; second, the assumption of a uniform semi-infinite elastic space, which is not consistent with reality; third, buckling instability is not considered and cannot be used for rupture analysis, and beam theory obviously cannot be used to analyze shell theory.

3.3 Nonlinear Friction Theory

The Japanese scholar Takada proposed a nonlinear friction theory for underground pipeline analysis in 1977. He used experimental. The method determines the nonlinear static and dynamic friction of the pipe in the soil. The static friction is.

$$F_t = A \cdot E \cdot \varepsilon \quad (26)$$

where E is the pipe modulus of elasticity and A is the pipe area. The dynamic friction

force is also a linear function of the axial strain, which is about 2/3 of the static friction force. ε The test also shows that the friction force is independent of the vibration frequency, and the frequency has no effect on the hysteresis^[11].

For the analytical solution of the relative displacement between the pipe and the foundation^[7], assuming the restoring force $F = k \cdot ua$, the solution yields the amplitude of the strain as

$$\varepsilon = \left[\left(\frac{\dot{u}}{v_{ph}} \right) - \frac{2k}{EA} - \frac{1}{1+a} u^{1+a} \right]^{\frac{1}{2}} \quad (27)$$

Where, u is the ground vibration velocity amplitude, and v_{ph} is the seismic body variable phase velocity?

3.4 Shell Theory

The shell theory was proposed in 1979 by Muleski and Ariman . This theory assumes that the pipe is an elastic isotropic thin cylindrical shell in a viscoelastic medium, and this theory can be used to study not only the instability and rupture problems but also other displacements caused by a curvature of the pipe. If the deformation of the pipe along the axial direction is simple harmonic, the amplitude ratios of the radial

displacement ε_r and axial displacement

ε_u to the axial displacement ε_s of the

foundation are $R_w = \varepsilon_r / \varepsilon_s$ or $R_u = \varepsilon_u / \varepsilon_s$,

$$R_w = \frac{-v\varepsilon w^3 - \frac{2v}{1-v}\varepsilon^2 w}{(1-v^2)w^4 + (2v+3)\varepsilon w^2 + \frac{2}{1-v}\varepsilon^2} \quad (28)$$

$$R_u = \frac{vw^3 R_w + \left(\frac{2v}{1-v} w r_w + w^2 \right) \varepsilon + \frac{2}{1-v} \varepsilon^2}{w^4 + \frac{3-v}{1-v} \varepsilon w^2 + \frac{2}{1-v} \varepsilon^2} \quad (29)$$

where W is proportional to the wavelength of ground deformation; and is dimensionless parameter. Proportional to the ratio of soil stiffness and pipe tensile stiffness ν is the Poisson's ratio.

4 The impact of crossing location and foundation permeability coefficient on the safety of the rapids

The burial depth of the pipe through the embankment has a small effect on the maximum permeability slope drop, while the permeability coefficient of the crossing location and the stratum has a significant effect on the permeability slope drop. The farther the crossing location is and the smaller the permeability coefficient is, the smaller the maximum permeability slope drop of the model will be; on the contrary, the maximum permeability slope drop of the model will be larger, which will have a certain impact on the embankment safety.

The burial depth of the pipeline has little effect on the infiltration slope drop, while the crossing location and infiltration coefficient has a large effect on the infiltration slope drop. The closer the crossing position of the pipe through the embankment is to the foot of the embankment, and the larger the permeability coefficient of the stratum, the larger the infiltration slope drop will be, and conversely, the maximum infiltration slope drop of the seepage field will be larger^[12].

If it is not possible to avoid the stratum with easy leakage, it is necessary to find a

way to ensure that the top permeability coefficient of the stratum is smaller than the permeability coefficient of the embankment. And the crossing location should be as far away from the embankment as possible, not less than 50m, preferably 70m away from the backwater side of the embankment.

5 Conclusion

Through the analysis of the above influencing factors, it is known that the construction method of the pipeline, the burial depth of the pipeline below the riverbed with the scouring depth of the riverbed and the crossing position of the pipeline, the embankment as well as the permeability coefficient of the strata, the initial water level on the waterward and backward sides of the embankment, etc., may adversely affect the safety of the embankment.

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