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The Proposal and Leakage Test of the Round Culvert with Tensile Performance and Mechanical Connection Function

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Abstract

In view of the existing trenchless technology, which cannot realize the pipe dragging construction of reinforced concrete round culverts, a round culvert with tensile performance and mechanical connection function is proposed. And the infiltration test and exfiltration test are carried out for the existing round culvert interface and sealing mode to determine the interface and sealing form that is most suitable for the new round culvert. The results show that the leakage situation of the sealing form using only the gasket is relatively serious, and the leakage rates of the sealant and the sealant + gasket are relatively small; the average exfiltration and infiltration rates of the all-encompassing sealant connection are the smallest and are more suitable for the new round culvert; and the leakage coefficients in the Darcy model and the Torricelli model under various situations of different interfaces and sealing methods are obtained through experiments.

Keywords

Reinforced Concrete Round Culvert; Pipe Dragging Construction; Pipe Interface; Leakage Rate; Torricelli Model.Wetland; Ecosystem; Ecological Restoration.

1. Introduction

By 2022, the country will have 913508 km of drains, 2,894 Sewage Treatment and 6389707 m3 of sewage, and 1102976 km of water supply lines, the total annual water supply is 6744063 million cubic metres, and has been increasing by 10-20% annually since 2016[1]

The existing underground pipeline laying scheme is divided into excavation and non-excavation[2]

Open cut method of excavation[3]: First, excavate the foundation pit or trench from the surface downwards, using plate-type support, ordinary steel sheet piles, or Larsen-type steel sheet piles for temporary support. After the construction is completed, these supports will be removed. Following the installation of the pipeline, backfill the earthwork, and finally restore the road surface to complete the construction.2.Trenchless Construction Technology[4]: It refers to the construction techniques that utilize various rock and soil drilling equipment and technological means to lay or replace various underground pipelines without excavating trenches on the surface. This includes methods such as pipe jacking, microtunneling, shield tunneling, and mining methods.① Tow tube method[5]: The basic principle is to use a directional drilling rig as shown in Fig.2 to drill directly from the surface at a small angle at the surface, drill from the other end of the surface and then pull the pipe back to the design position, its process is roughly construction preparation, pilot hole construction, anti-stretch reaming, hole, traction pipe, masonry inspection wells, acceptance, clearance.② Pipe jacking method[6]: The basic principle is to push the tool pipe or roadheader from the working pit through the soil layer to the receiving pit by means of the thrust between the main top cylinder and the relay between the pipes, as shown in Fig. 1. At the same time, the pipe following the tool pipe or the tunnel boring machine is buried between the two pits.③ Shield method[7]:The principle is to work by using

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a shield machine. The shield machine keeps digging the tunnel by moving forward and installing the lining at the same time to keep the tunnel stable as shown in Fig. 3.

Fig. 1 Jacking cylinder and relay

Fig. 2 Horizontal Directional Drilling

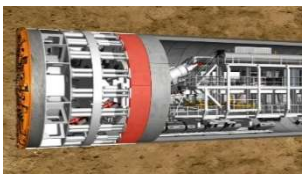

Fig. 3 Shield machine

In today's water supply and drainage fields, open cut method, towed pipe method and pipe jacking method are the main methods. Although there are many technical schemes for pipe laying, however, each scheme has its own unique characteristics, applicable conditions and problems. Open cut method: direct, simple and crude, mainly applicable to shallow buried projects, large and complex plane size of the project, other non-excavation programs are all invalid, but its shortcomings are also more significant. ① There are requirements for the surrounding environment, the need for support space on both sides of the pipeline, pipe piling construction above the space.② Additional technical processing[8],The clay soil can not be used for the backfill of the foundation trench, but the sand or gravel soil can be used, but the uneven settlement will still occur in the later stage.③ The impact on the surrounding environment and traffic,The impact of open-cut construction on traffic and the environment can not be avoided. Its essence is the infringement of the interests of other groups, such as the infringement of the traffic rights of vehicles and pedestrians, and the infringement of the right to operate shops around the road, the consequences of these violations are in fact borne by society. Dragging pipe method: quick construction, long distance underground curve layout, little influence on the ground, low construction cost. Widely used in water, gas, electricity, telecommunications, natural gas, oil and other pipeline laying construction projects, suitable for steel pipes and PE pipes with pipe diameters of 300 ~ 1200 mm, the pipe must be weldable or weldable, but it still has many disadvantages.① High requirements for pipe, pipe tensile performance is very good, and easy to weld or weld, then the cement pipe and bellows can not be connected as a whole can not be managed by construction;② It needs a certain distance of auxiliary inclined section and a sufficient length of pipe to connect the site as a whole. There are still requirements for the surrounding construction environment, but compared with the open excavation method, the influence of the dragging pipe method on the surrounding environment is very small.

Pipe jacking method:Small disturbance to the ground, low construction noise, various jacking methods, suitable for all kinds of complex strata, suitable for places where surface traffic can not be

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interrupted or excavation construction can not be carried out; The conventional pipe jacking method is suitable for buried depth greater than 3 meters and pipe diameter not less than 0.8 meters. For reinforced concrete pipe, ductile iron pipe and other non-connection, and good compressive properties of the pipe, but there are still many shortcomings of pipe jacking. ① Special working and receiving wells are required[9]High cost, long preparation time as shown in Fig. 4 ②The situation in front of the jacking can not be directly perceived. Once geological changes or other accidents occur, only reasoning can be used to analyze the causes and take countermeasures. ③ When it comes to large and dangerous projects, the risk is relatively large and requires special demonstration.

2. New Type of Round Culvert

2.1 Defects of Existing Round Culverts

A circular culvert refers to a circular pipe made of reinforced concrete, used for water supply and drainage pipelines.① Ordinary reinforced concrete precast round culverts are prone to leakage and collapse. Due to the only splicing of each segment, they can not be effectively connected closely. When the geological environment changes, the segments are easy to slip and fall off, resulting in cracks and leakage, then make the sand flow into the pipe, causing the pipeline and ground collapse, serious loss of water function. The key to leakage is the tight and effective connection between tube joints.② Reinforced concrete round culvert pipe sections are connected together. When the Pipe Foundation is deformed and collapsed, the round culvert pipe will also be deformed and collapsed. In municipal engineering, it can only be used for drainage, and can not be used for tap water pipes with higher requirements, if the round culvert pipe has tensile and bending resistance performance as a whole, it can be used as tap water pipe to realize close mechanical connection between pipe joints. ③ The common circular culvert pipe joint can not transmit tensile force and has no tensile performance itself. It can only be used by open-cut splicing or pushing forward technology, and can not be towed. Although there are new technologies for towed pipe construction, special auxiliary devices are needed, implementation is cumbersome and difficult to achieve.

2.2 Tensile Properties and Mechanical Connection Function

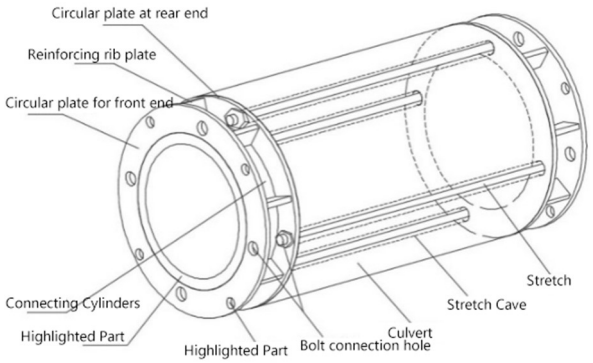

Fig. 4 Perspective view of the new round culvert

The new circular culvert has two connecting mechanisms, a pipe body made of reinforced concrete and a lacing bar. The two connecting mechanisms are arranged at both ends of the circular culvert pipe body. It has three characteristics: ① The reinforced concrete pipe body includes the cylinder section, the convex parts at both ends and the reserved tension holes through the cylinder wall. The two ends of the reinforced concrete pipe body are tightly contacted and wrapped by the connecting mechanism. ② The lacing tendon is through the lacing tendon hole through the whole round culvert pipe body, the lacing tendon hole and the round culvert pipe body reserve the hole center of the lacing tendon hole, the hole center is located on the same axis, and the inner diameter is the same. ③ The connecting mechanism comprises a front-end annular plate, a rear-end annular plate and a connecting

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cylinder. The reinforcing rib plate is used to connect the front-end annular plate, the rear-end annular plate and the connecting cylinder as shown in Fig. 4.

The new circular culvert can be tightly connected by using the bolt connection holes reserved on the circular plate at the front end of the adjacent two sections, and the whole pipe section can be a long string as a whole. The sealing rubber gasket is added between the front circular plates of two adjacent sections to ensure the air tightness of a long string of pipe sections, so that the whole pipe section can meet the water pressure standard of the water supply pipe when it is used, so that the reinforced concrete circular culvert can be used as a water supply pipe, expanded its use.

The reinforced concrete pipe body of the new circular culvert comprises at least 2 tie bars, which run through the circular culvert as force-bearing bars. When the first section of a long pipeline is subjected to tension, the tension can be transmitted to the subsequent pipe section in turn by the tie bar and the connecting device as shown in Fig. 5, which not only ensures that each section of the pipeline moves forward under the tension, but also avoids the tensile damage of the reinforced concrete pipe body. In this way, the horizontal directional drilling rig is used to directly carry out the underground dragging construction of the circular culvert without the aid of auxiliary devices and without the destruction of the circular culvert, which greatly saves the construction cost of pipeline laying.

When the tie bar does not need to run through multiple circular culverts, it can be directly bolted to the back-end circular plate. When multiple circular culverts need to be connected in a string, one tie bar can be used to run through the tie bar holes of multiple circular culverts as shown in Fig. 6, the multi-section new round culvert can be mechanically connected into a whole, and the lacing bar runs through the round culvert, which can bear the internal tensile stress of the pipe wall and improve the integrity and mechanical properties of the round culvert. When local settlement or collapse occurs in the soil of the pipeline foundation, the integrity and mechanical properties of the pipeline are greatly improved, which can effectively avoid the separation of the circular culvert section or the tensile damage of the pipe body, so that the pipeline acts like a bridge span, reducing the cost of pipeline failure and post-repair.

Fig. 5 The overall connection of a pair of new round culverts

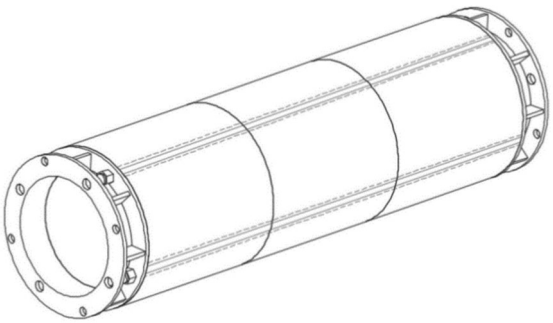

Fig. 6 Three-dimensional schematic diagram of the multi-segment of the new round culvert

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3. Design of Leakage Test

3.1 Raw Materials

①The diameter of the new round culvert is selected according to the code for construction and acceptance of water supply and drainage pipeline engineering. In practical engineering, the minimum pipe diameter is 150 mm The casting was carried out in the laboratory with a 3d-printed membrane as shown in Fig. 7, in which the lacing holes were pre-embedded and molded when they were cast through a stainless steel tube with a diameter of 6 mm. The concrete was selected as C40 and added with an impermeability agent, and then cured for 28 days.

②According to“Steel Flange, Part 1: PN Series”, there are three kinds of flange connectors: flat type, socket type and full package type.

Fig. 7 Membrane components and physical images.

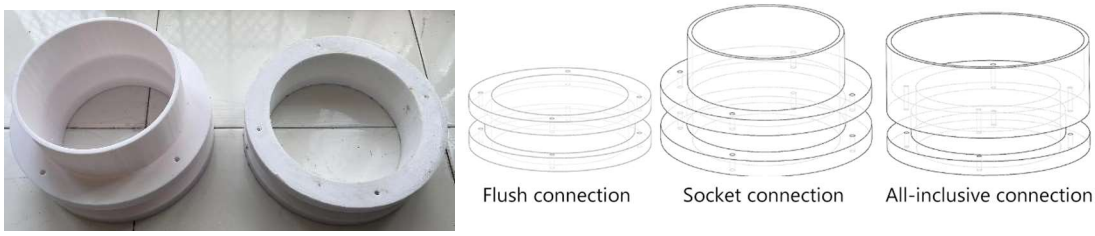

Fig. 8 Model diagram and physical diagram

③The 3D printer uses Tuozhu a 1bambu Lab, the maximum size of the platform is 256 * 256 * 256 MM3, the 3D printing consumables use R3DPETG, and the slicing software is simplify3d; the consumables parameters and 3D printing setting parameters are as in Table 1

④The cement is produced by Southern Cement Co. , Ltd. . O42. Ordinary Portland cement sand, ISO standard sand produced by Xiamen esio Standard Sand Co. , Ltd. and sodium bentonite produced by Guangzhou Yifeng Chemical Technology Co. , Ltd. .

⑤Gasket Xiangchen new material production of foam silicone gasket, thickness 5 mm, conventional hardness 25-30 Shaw a; sealant seal production of polyurethane sealant.

⑥Tank size 500 mm x 450 mm x 400 mm

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Table 1. Consumable parameters and 3D printing setting parameters.

Consumable Parameters			
Printing temperature	Printing panel temperature	Deformation temperature of hot bed	Diameter
230-280℃	65-90℃	70℃	1.75mm
Tensile strength	Bending Strength	Density	Printing speed
50±4MPA	75±4MPA	1.25±0.05/cm3	50-300mm/s
Print setup parameters			
Floor height	Back cover	Filling Rate	Overlap rate
0.1400mm	6	60%	10%
Fill pattern	Support Filling Rate	Support Filling Type	Spacing between supports
Rectilinear	20%	Normal	0.2mm
Printing speed	X/Y axis velocity	Z axis velocity	Reduction ratio
5300mm/min	4800mm/min	1000mm/min	80%

3.2 Pipeline Preprocessing

The pipeline and the flange are closely connected by lacing tendons, and two groups of sealant and gasket are respectively used at the joints, and the joints are left for 3 days. The ratio of cement, water and sand on one side of the flange is 1:0. 5: 3 of the plugging, followed by 7 d curing, and then sealed with sealant in the water plugging place, standing 3 d, as shown in Fig. 8. According to different pipe joints and sealing methods, the test samples are divided into six groups, as shown in Table 2

Table 2. Sample number

Infiltration Number	Interface type	Type of interface seal	Leakage Number
RM1	Flat connection	Sealant	CM1
RM2	Socket	Sealant	CM2
RM3	All inclusive	Sealant	CM3
RD1	Flat connection	Gaskets	CD1
RD2	Socket	Gaskets	CD2
RD3	All inclusive	Gaskets	CD3
RDM1	Flat connection	Sealant + Gasket	CDM1
RDM2	Socket	Sealant + Gasket	CDM2
RDM3	All inclusive	Sealant + Gasket	CDM3

3.3 Test Methods

3.3.1 Simulation Experiment of Drainage Pipeline Leakage

The new culvert leakage test is divided into infiltration test and seepage test as shown in fig. 10. The infiltration test is to observe the infiltration of different joints and sealing methods under the condition of large earth pressure after the construction of the new culvert pipe, the leakage of different joints and sealing methods in the connection of the new culvert pipe can be used to select the most suitable connection method for the actual construction.

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The assembled culvert pipe is immersed in the water tank for one day in advance to make the concrete fully absorb water and take out. The connection between the water tank and the culvert pipe is sealed by foaming sealant, and then it is left for half a day after sealing, wait for the Styrofoam to set. The water enters the upper water tank, Raise the water tank by 10m and enters the test water tank through the automatic water supply valve. The automatic water control valve will ensure that the test water tank is always at the same water level and will not change due to the leakage of the culvert pipe. Each group was tested separately, and the right seepage volume was recorded every 15 min for 2 h after 5 min. . In each group of numbered tests, three groups of the same samples were carried out at the same time to avoid the data differences caused by artificial connection errors. Finally, the average seepage and infiltration leakage rates of the new type of culvert pipe under no pressure were obtained.

Two methods were used to measure the actual leakage rate in this experiment: ① Based on the scale in the upper tank, the water reduction is calculated every 15 minutes, and then the leakage rate is calculated. ② To the right side of the box outlet after the water evenly, weighing every 15 minutes of the water weight. Then the leakage rate can be obtained.

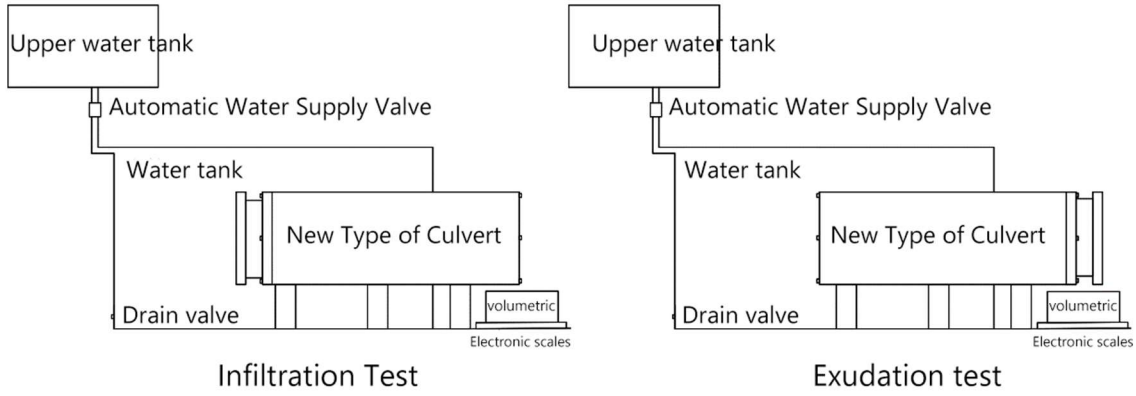

Fig. 9 Schematic diagram of the leakage simulation test device for the new culvert

3.3.2 A New Leakage Model of Circular Culvert

The research model of leakage patterns focuses on two key aspects: the Darcy model[10] and Torricelli model[11] .The Torricelli model takes into account the water level difference, the resistance at the leakage location and the leakage area. Darcy Model model is mainly applied to the seepage law in the pores of rock and soil, and also takes into account the effect of leakage path on leakage.

Darcy model:

$$Q = KA \bullet hl^{-1} \tag{1}$$

In the formula: Q ---Rate of leakage,m^3 / s; K ---Coefficient of leakage,m^3 / s ; A ---Leakage area,m^2; h ---Liquid level difference,m; l ---Leakage path distance,m.

Torricelli model:

$$Q = CA \cdot (2gh)^{0.5} \tag{2}$$

In the formula: Q ---Rate of leakage,m^3 / s; C ---Dimensionless discharge coefficient; A ---Leakage area,m^2 ; g ---Gravitational acceleration,m/ s^2; h ---Liquid level difference,m.

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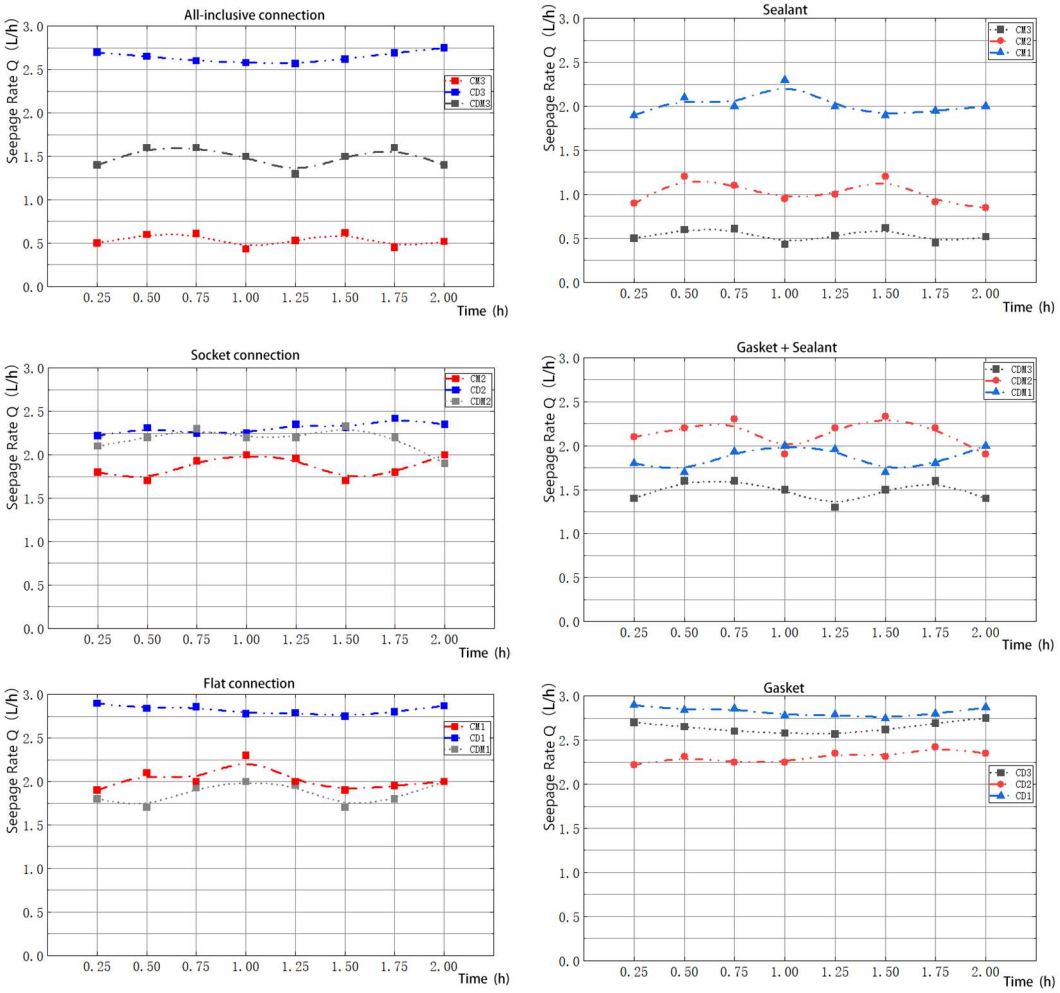
4. Results and Discussion

4.1 Analysis of Test Results of Seepage and Infiltration

According to the difference of the interface and the sealing mode, the experimental data are grouped and compared.

4.1.1 Effects of Interface Differences on Exudation and Infiltration Rates



(a)Interface Form Grouping (b)Sealed Form Grouping

Fig. 10 Exudation experiment

Figs 10(a) and 11(a) categorize the experimental data based on different test interfaces. It can be observed from the figures that as time progresses, the leakage rates of the new circular culverts with different interfaces and sealing forms remain stable. From Fig 10(a), it is noted that the average minimum outflow rate for the CM3 sealing adhesive fully wrapped interface test group is 0.532 L/h, while the average maximum outflow rate for the CD1 gasket flat connection test group is 2.823 L/h. From Fig 11(a), it is noted that the average minimum infiltration rate for the RM3 sealing adhesive fully wrapped interface test group is 0.233 L/h, while the average maximum infiltration rate for the RD1 gasket flat connection test group is 2.344 L/h. ① In the full package interface test group, the sealing performance of the sealant is far superior to the other two sealing forms. The addition of the gasket will increase the leakage rate and the sealing performance will become worse. There is a big difference in the results of the infiltration test of the sealing Gasket + Gasket test group, and the results of the infiltration test are much smaller than the results of the infiltration test. ② In the socket joint test group, the leakage rate of the sealant group was 1.861 L/h for outflow and 1.254 L/h for inflow, indicating that its sealing performance was slightly better than the other two forms. The outflow

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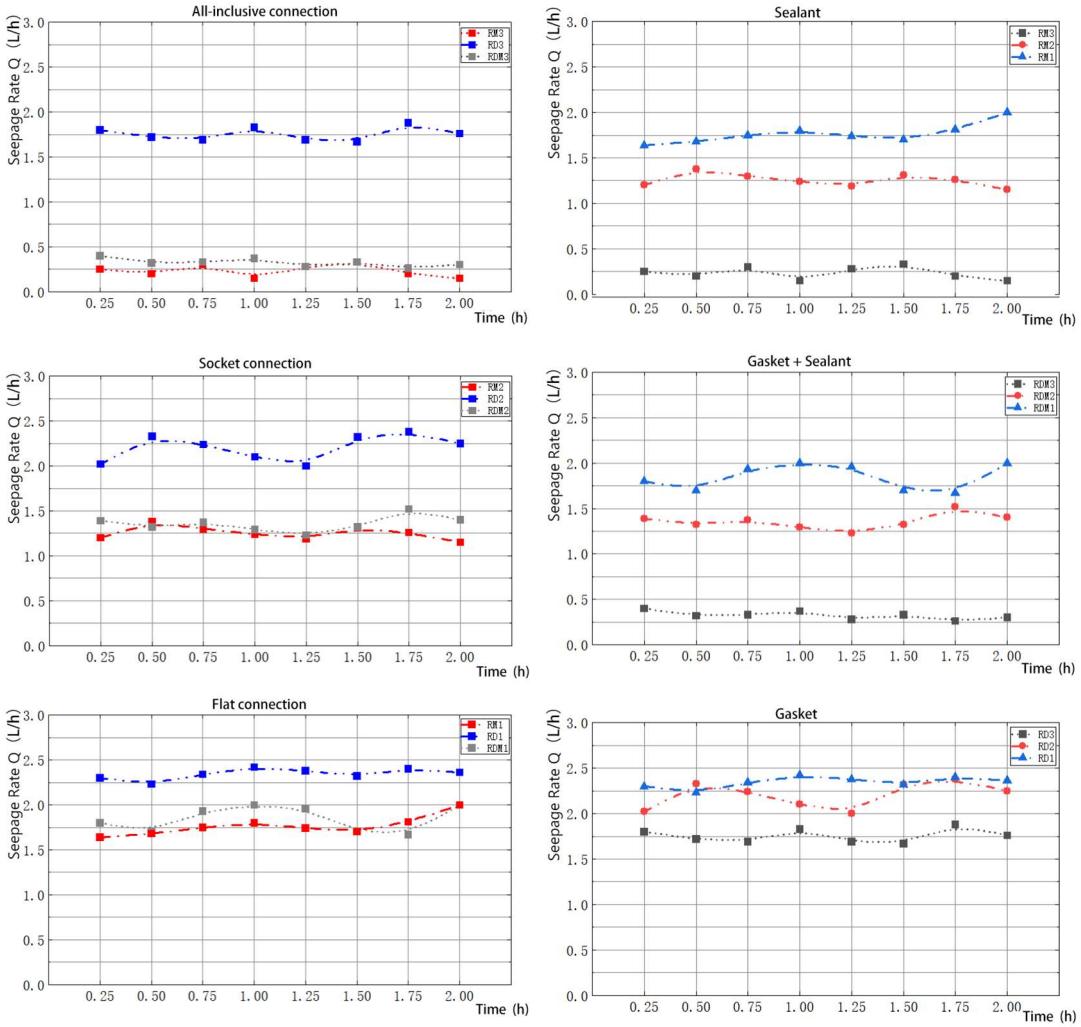
leakage rates for the gasket and gasket + sealant groups were similar, at 2.310 L/h and 2.181 L/h, respectively, but there was a significant difference in the inflow leakage rates, which were 2.205 L/h and 1.355 L/h, respectively. The addition of sealant did not significantly enhance the outflow sealing performance of the gasket at the socket pipe joint, but it greatly improved the inflow sealing performance. ③ In the flat joint interface test group, unlike the previous two groups, the sealing performance of the sealant + gasket test group is slightly better than that of the sealant test group, with leakage rates of 1.861 L/h and 2.018 L/h, respectively. Moreover, the addition of the gasket reduces the leakage rate and enhances the sealing performance[12].

According to Fig. 10(a), the outflow rates of the three different interface forms are roughly ranked as fully wrapped ≤ socket ≤ flat connection; according to Fig. 11(a), the infiltration rates of the three different interface forms are also roughly ranked as fully wrapped ≤ socketed ≤ flat connection, which is similar to the outflow results. The fully wrapped interface test group has the lowest outflow and infiltration rates. However, within the fully wrapped test group, changes in the sealing form can lead to significant differences in leakage rates, while in the other two test groups, changes in the sealing form do not result in substantial differences in leakage rates.

4.1.2 Effects of Interface Seal Type Differences on Exudation and Infiltration Rates



(a)Interface Form Grouping (b)Sealed Form Grouping

Fig. 11 Infiltration experiment

Fig. 11(b) groups the experimental data according to the different types of sealing interfaces. ① In the sealant test group, the average seepage rate of the three sealing forms was 1.893 L/h, 1.013 L/h,

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0.532 L/h, and the average infiltration rate was 1.76 L/h, 1.25gvbh L/h, 0.233 L/h, the leakage rate of the flat interface is the largest, and its sealing performance is greatly related to the interface form ② In the Gasket + sealant test group, the average seepage rates of the three sealing forms were 1.861 L/h, 2.141 L/h, 1.487 L/h, and the infiltration rates were 1.845 L/h, 1.355 L/h, 0.324 L/h, respectively, the leakage rate of full-envelope interface is the smallest, the leakage rate of socket interface is close to that of flat interface, and the sealing performance is less related to the interface form. ③ In the gasket test group, the average leakage rates of the three sealing forms were 2.823 L/h, 2.307 L/h, 2.645 L/h, and the infiltration rates were 2.344 L/h, 2.205 L/H, and 1.755 L/h, and the leakage rates of the three interfaces were relatively close, moreover, the leakage rate of the gasket test group with three sealing forms is close to each other over time, and its line chart curve is relatively smooth, which is different from the fluctuation of the other two groups.

According to the three different sealing forms in fig. 10(b) , the leakage sealing performance is roughly ranked as sealant ≥ sealant + gasket ≥ gasket; according to the three different sealing forms in Fig. 11(b) , the order of infiltration and sealing performance is sealant ≥ seal + rubber gasket ≥ gasket, and the results of infiltration and infiltration experiments are similar. The sealing performance of the gasket is the worst, but the pipeline interface form has a great influence on the sealing performance of the sealant group. In the Gasket Test Group, the sealing performance is poor in the three sealing forms, and the three groups of data are close.

Table 3. New leakage coefficient of circular culvert

Number of infiltration test	Average rate of leakage(L/h)	K (m/s2)	C
RM1	1.765	4.626E-04	6.270E-06
RM2	1.254	3.287E-04	4.455E-06
RM3	0.233	6.107E-05	8.277E-07
RD1	2.344	6.144E-04	8.327E-06
RD2	2.205	5.780E-04	7.833E-06
RD3	1.755	4.600E-04	6.234E-06
RDM1	1.845	4.836E-04	6.554E-06
RDM2	1.355	3.552E-04	4.813E-06
RDM3	0.324	8.493E-05	1.151E-06
CM1	2.019	5.292E-04	7.172E-06
CM2	1.014	2.658E-04	3.602E-06
CM3	0.533	1.397E-04	1.893E-06
CD1	2.824	7.402E-04	1.003E-05
CD2	2.308	6.050E-04	8.199E-06
CD3	2.645	6.933E-04	9.396E-06
CDM1	1.861	4.878E-04	6.611E-06
CDM2	2.141	5.612E-04	7.606E-06
CDM3	1.488	3.900E-04	5.286E-06

4.2 Prediction of Experimental Results of Pressure Leakage

Two models are used to predict the results of exfiltration and infiltration. In the non-pressure test, the distance between the upper tank and the experimental tank is 1m, that is, H = 1 for both models, K for Darcy's model and C for Evangelista Torricelli model , as shown in table 3. The distance between the above water tank and the experimental water tank is the ABSCISSA i. e. the water level pressure, and the leakage rate is the ordinate in fig. 12,13. The predicted results show that the seepage and

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infiltration of the full-package sealant joint still have good sealing performance when the water level pressure is high, and the seepage rate changes little with the water level pressure The leakage rate of the gasket test group is the largest when the water level pressure is large, so the gasket is not suitable for the connection and sealing of the new circular culvert

From the predicted results, it can be clearly found that the relationship between the infiltration and exfiltration rates and the water level pressure of the drainage pipe interface under the same interface material conforms to the Evangelista Torricelli model. This is because the experimental research point is the pipeline interface, mainly considering the sewage seepage out of the pipeline or groundwater infiltration, the pipeline leakage path (i.e. , the lateral distance of the pipe joint) has little effect on infiltration and exfiltration, and the pipeline leakage path (i.e. , the lateral distance of the pipe joint) has little effect on infiltration and exfiltration, therefore, it is more suitable for the Torricelli model, while there will be some errors when using the Darcy model.

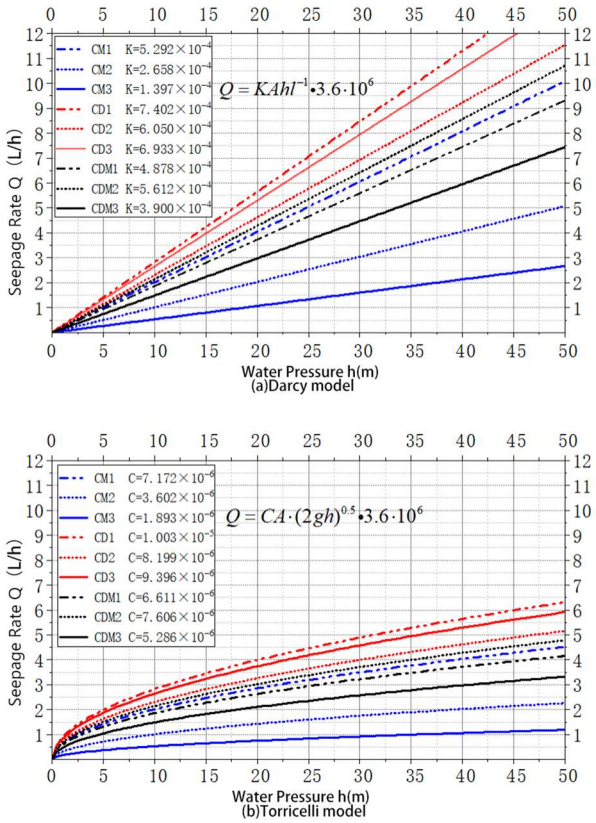

Fig. 12 Exfiltration experiment

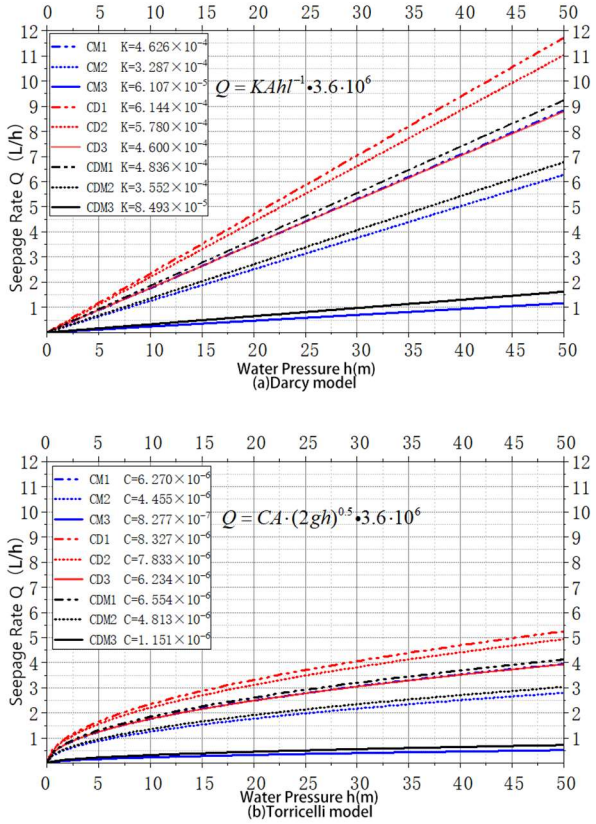

Fig. 13 Infiltration experiment

5. Summary and Analysis

(1) in view of the use of clear water for the test, during the time of the test, the effect of clear water on the interface is only dominated by the water pressure, the results of the test show that with the extension of time, under the same water pressure conditions, the infiltration rate and the exfiltration rate of the pipe joints remain constant. In the actual pipes, the sewage pipes are filled with odorous gases or sewage containing a large amount of organic matter is deposited at the joints, storm sewers often have airborne and ground-level contaminants deposited, which can cause the rate of leakage to change over time.

(2) because this test mainly tests the leakage law of the new round culvert with different types of joints and sealing methods, three kinds of joints and three sealing methods are selected for research, it is necessary to meet certain conditions such as site, water pressure and measuring instruments, and the device is not covered with soil, that is, the soil resistance factor near the sewage seepage inlet and outlet interface is not considered, in the later stage, Wang Fuming et al [13] .used a variety of software

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to simulate the flow, load and position on the mechanical response of the concrete socket pipe interfaceAnd Zhai et al[14]. analyzed the force and rotation angle of the prestressed concrete cylinder tube joint under the conditions of additional load, load position, coverage depth and internal pressure, further, there is soiling in the pipe[15].The leakage law of different types of interface is studied under the condition of.

(3) Due to the use of 3D printing to connect flanges, although it can replace plastic flange plates for testing, there may be differences in sealing performance between steel flange plates and plastic flange plates. In the later stage, comparative tests can be conducted with steel flange plates to determine the most suitable flange interface, materials, and sealing methods for the new type of circular culvert.

(4) Since this experiment only conducted infiltration and exfiltration tests at a water level of 10m to obtain its leakage coefficient, predictions for other water levels were made using two models. In the future, actual tests at different water levels can refer to the works of Chen Shengbing [16] and Li Ruohan from Tsinghua University [17] to improve the accuracy of the leakage coefficient.

6. Conclusion and Outlook

In this paper, the effects of different joints and sealing methods on the seepage and infiltration of the new circular culvert under the premise of pure water are studied. The main conclusions are as follows

through the study of different interfaces and connection methods. In the case of using only gasket sealing, the leakage rate of either joint is large, which is not suitable for the new circular culvert, the average seepage rate and average infiltration rate of the full package sealant and gasket are 0.324 L/H and 1.488 L/h, respectively. The leakage rate of these two connections is relatively small, so the angle lifting test of the new circular culvert is mainly based on this interface.

It is found that the leakage rate remains stable with the increase of time. The leakage coefficients in Darcy's model and Evangelista Torricelli's model under nine conditions of different interfaces and sealing methods are obtained, it provides the basis for the follow-up pressure leakage test.

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