Study on the Theoretical and Experimental in Leakage Characteristics of New Type Prestressed Pipe Seal

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Abstract. Based on the leakage rate analysis theory, a new type of prestressed porous rubber sealing device is invented. The compressive force and stress variation of the device are calculated by numerical simulation. The sealing coefficient of device is obtained and verified by outdoor experiments. The results show that the compressive stress is proported to the elastic modulus of the sealing ring, curvature angle of the transition section and the friction coefficient. The device of prestressed pore sealing can effectively solve the leakage problem of splicing construction, which is a simple seal structure.

1. Introduction

Compared with the long-line method, the short-line method is of high working efficiency and transportation areconvenient. However, for the large numbers of segment, the assembling process is more complicated and the complete is weaker. The sealing between prestressed concrete pipe(PCP) is particular difficult. Aiming at this problem, the "road bridge and culvert construction technical specifications" (JTG/T F50-2011) provides the rang of units vacuum [1] [2]. For the ruling applies to the continuous channel system, and there is a large difference between the practical value and theoretical value, which is limited by the sealing technique. and How it influences the assembled segments remains to be established. With the assembled segments widely used in domestic project, most of the sealing schedule still uses the closed loop to connect the prestressed holes.Based on this method, Gao Mingchang[3] recommendated to use closed-cell foam polyethylene gasket. However, it did not solve the problem of seamless connection between sealing device and prestressing pipeline.Zhang Fenglin [4] proposed an assessment method of hole quality for prestressed pipes, which only refers to the sponge washers in series adjacent prestressed holes, and the sealing effect remains to be determined. Sui Guosong[5] recommended to adopt expanded polyethylene without grooved. In the mathematic analysis, most of the research achievements on contact-sealing was based on the A. Roth theory. Li Bin [6] studied the leakage rate of the double rubber ring seal structure in the vacuum environment on the basis of other researchers' test work. Xiao Qing [7] researched the application of large diameter O-ring seal in vacuum equipment, and calculated the leakage rate of the seal ring. Wang Guangzhen[8] studied the factors of leakage rate on O-ring by the method of experiment. In the research of stress distribution on rubber sealing ring, Sun Jian [9] analyzed the deformation and stress variation of special section rubber ring in the rectangular groove by axisymmetric finite element analysis model. Tan Jing [10] established the influence of initial compression ratio and the liquid pressure on the deformation. For the value of compression amount is small, it will causes the leakage for large gap. At the same time, the friction of O-ring is large, and the sealing effect is not ideal, which can only control the leakage below censes value. It need to install protective ring and dust circle in some occasions, and add lubricants in the air pressure and water pressure sealing process [11]. Therefore, it is necessary to develop a new sealing structured to improve the sealing effect of the channel.

This paper first elaborated the related theory of rubber sealing, then it was numerically simulated by renault equation, and the influence curves of the sealing coefficient, transition gradient and influence coefficient of the rubber-PVC friction coefficient on the extrusion force μ are drawn. The research production can provide a reference for rapid construction by short line method.

2. Calculation of Leakage Rate

2.1. Mechanism of Sealing Device

According to the composition of the sealing structure, the force gasket puts on the sealing surface reduces, which lead to the micro-crack formation, and the inner pressure of medium may leak through the micro-crack. By analysis and comparison, for the open-sealing, the size of closed loop is much larger than the groove of flange, the sealing effect is mainly depending on the interactive compression of the rubber material and sealing facet of flange.

2.2. Analysis in Leakage Rate of Sealing Device

According to A. Roth theory, leakage of gas can be calculated as follows.

$$Q = C\Delta_P \approx 4\sqrt{\frac{T}{M}} \cdot \Lambda^2 \cdot \frac{L}{\omega} \cdot \exp\left(-\frac{3F}{L\omega R}\right) \cdot \Delta_P , \qquad (1)$$

Where, C is the flow conductance of all the leaky channels on the sealing surface, Δ_p is the differential gas pressure across the sealing surface; T is the absolute temperature of the gas (K); M is the molecular weight of the gas; Λ is the flange surface roughness; L is the sealing surface length; w is the sealing surface width; F is the sealing surface of the total compression force, R is sealing coeffic.

Eq. (1) demonstrates that the leakage quantity Q of device only relateds to the calculation parameters Δ_p, T, M, L, w, F and R, and other are negligible. Obviously, in addition to the parameter R, others are the inherent properties of structural materials. Once the type and size of materials are determined,these parameters are constant value. The only parameter need to be calculated is R. A. Roth only gives the chloroprene rubber value of 5 ~ 30kg/cm^2. In order to obtain the sealing factor of the sealed package, the empirical coefficient method is used. The specific method is:

Gravure applied compressive stress P, the sealing ring gradually is pressed into the cone body. When the average compressive stress in the model is equal to the average contact stress of the seal, the seal coefficient R should be the seal factor that eing sought, ie

$$R = -P\ln\left(A_x / A\right) \qquad (2)$$

Eq. (2) shows that sealing material is penetration depth Ax and the surface roughness value of the flange A.

2.3. New Type of Sealing Device for PCP

The new type of sealing device mainly consists of five parts: cylindrical part, locating ring, sealing ring, push ring and buckle hat, as shown in Figure 1. Compared with the friction of O-ring, the sealing effect of device is entirely depend on the gap between PVC and seal ring. The process of the device is that under the pressure of the automatic, the deformation of the ring will adjustment the gap of seal ring and PVC. The gap decreases with the increase of pressure.

Fig. 1 New type of sealing device for PCP

The new type of sealing device has the good elasticity and watertightness, which can effectively improve the tightness of pipe and reduce the occurrence of the pulp leakage. The extrusion process and the docking completion state are shown as Fig. 2.

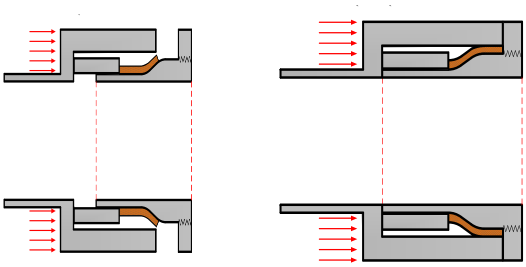

Fig.2 Schematic diagram of pushing

3. Experimental on Seal Leakage of Device

When the value of pressure is -0.09 MPa, which means the PCP has a good closure. To test the sealing effect of new device, two sets of pieces are selected, and the applicability of materials and size are tested by using the new type of closed device. According to the size of pipeline sealing device, selected test specimens for the length 70cm, width 45cm, 45cm high rectangular section of the concrete block, a total of two sets of six test pieces. Specimen of the concrete material used C50, prestressed steel wire standard strength of 1860MPa.Comparison of test specimens shown two groups the test program in Table 1. he text of your paper should be formatted as follows:

Table 1. Comparison test program

Number	Test device	Test content
A	new type of sealing device	vacuum degree
B	traditional sealing device	vacuum degree

3.1. Seal Device Performance Test Steps

According to the requirements of the experimental, the specimens fall into two groups, which are named group A and group B, which are shown as Fig. 3. The process of the test is:

Group A: Three concrete blocks are placed according to the assembled position. the sealing ring are mounted on the root of the first cylinder section, then connect the pushing ring with the seal ring.

Group B: use O’ring to prevent the leakage. The O’ring is epoxy-bonded to the concrete block.

- The cylinder part of the latter girder is inserted into the buckle hat, and then finishes the work of PCP.
- The PCP is drawn at single end.
- Test the hermeticity performance of pip, and read the vacuum degree.

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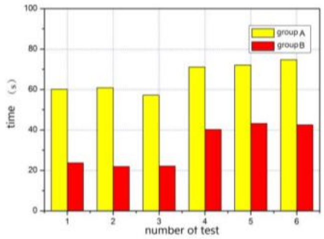
(a) Test specimen of group A (b) Test specimen of group B
Fig.3 leakage test of sealing device

The results of test are shown in Fig.4 and Fig.5



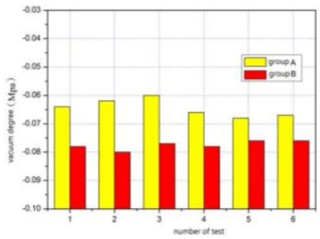


Fig 4. result of leak proofness test Fig 5. result of pressure-continuous test

The test results show that:

- Sealability. Through the comparison of the test results, it shows that the maximum vacuum of of the traditional sealing device is -0.068Mpa. but to the new seal device, the sealing vacuum more than -0.08Mpa, it is close to the vacuum of limit, which proves that the new sealing device is better to ensure the sealing effect at the joint connection;
- Holding pressure. For the rubber sealing gasket, the maximum time of holding pressure is about 43s, and the maximum time for new seal device is up to 75s, which increased about 74%.

4. Seal leakage characteristics analysis

It takes the infinitesimal element *ds* of the sealed rubber ring as the study object. In the extrusion process, the pressure distribution of element can be described as Fig 6. The initial state of element named State I and the radius is r_1. The state of moment named the State II. At this time, the curvature angle of element is θ, the radius is r_2, the pressure of the element is N, and the friction is f.

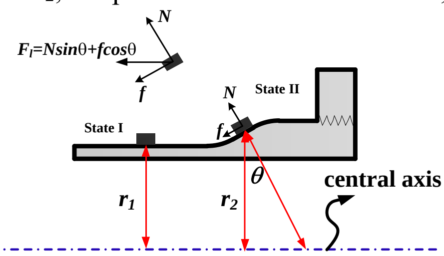


Fig 6. stress analysis of rubber infinitesimal

Suppose that the rubber elastic modulus of the seal ring is Er, we can see that the circumferential strain and stress of the infinitesimal through analysis the initial state (State I) and the strain state (State II),

$$\varepsilon_h = \frac{\Delta l}{l} = \frac{2\pi r_2 - 2\pi r_1}{2\pi r_1} = \frac{r_2 - r_1}{r_1}$$
$$\sigma_h = E_r \varepsilon_h = E_r \frac{r_2 - r_1}{r_1} \qquad (3)$$

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Figure 7 shows the space truss of transverse section drawing. Supposing that the thickness of the infinitesimal is h, and the strength evenly. The normal compressive stress p is

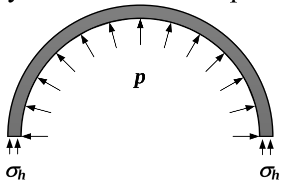


Fig 7. Analysis of force for rubber ring

$$2\sigma_h h=\int_0^{\pi} pr_2 \sin\theta d\theta = 2pr_2 \Rightarrow p = \frac{\sigma_h h}{r_2} \qquad (4)$$

The The normal pressure of infinitesimal is N=2pr_2ds. Suppose that the friction coefficient between rubber and PVC is μ, the tangential friction force of infinitesimal is f=N=2pr_2ds. The horizontal stress component of infinitesimal is:

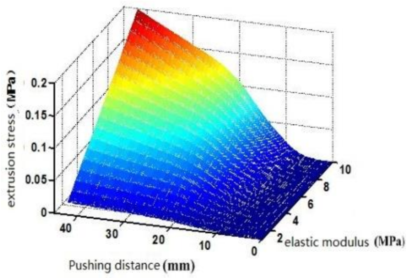
$$\begin{aligned} F_l &= N\sin\theta + f\cos\theta = N(\sin\theta + \mu\cos\theta) \\ &= 2(\sin\theta + \mu\cos\theta)p\pi r_2 ds = 2(\sin\theta + \mu\cos\theta)\pi h\sigma_h ds \\ &= 2\frac{r_2 - r_1}{r_1}(\sin\theta + \mu\cos\theta)E_r\pi hds \end{aligned} \qquad (5)$$

The minimum pushing force F is applied by integrating the rubber ring at any position during the process along the contact surface.

$$F = \int_{0\to l} F_l = \int_{0\to l} 2\frac{r_2 - r_1}{r_1}(\sin\theta + \mu\cos\theta)E_r\pi hds \qquad (6)$$

4.1. Influence of elastic modulus on pushing force

A typical gasket ring that the length of infinitesimal is 0.1mm, transition of slope is 30 degree, friction coefficient between rubber and PVC is 0.6. In order to facilitate to do comparison and analysis of elastic modulus, Fig.8 and Fig.9 have shown the effect of different elastic modulus of seal ring rubber on extrusion stress curve. It can be seen from the figure that when the thrust distance is less than 10mm, the sealing force increases slowly with the increase of elastic modulus. When more than 10mm, the growth trend of force increases drastically and the difference of elastic modulus tends to be apparent. The elastic modulus of 4~7MPa for rubber material are suggested.



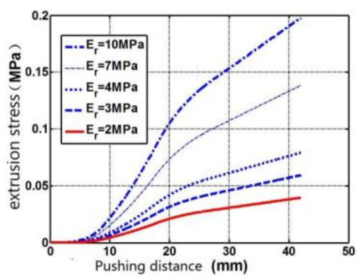
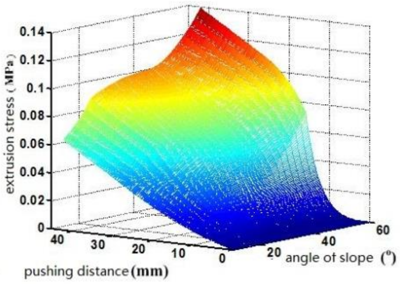


Fig 8. stress surfaces for the transition zone   Fig 9. Extrusion stress curves under different elasticmodulus

4.2. Influence of Transition Slope on the Extrusion Force

In order to analyze the influence of transition slope on the extrusion force, the length of infinitesimal is 0.1mm, friction coefficient between rubber and PVC is 0.6. The elastic modulus of the rubber ring is 5MPa, and transition of slope is 30°. The squeezing force under the working conditions is shown in Fig. 10 and Fig.11. It shows that when the distance is less than 10mm, the slope of transition zone is larger, the growth rate of the sealing pressure is lagging behind the small slope, but with the pushing distance greater than 10mm, the growth trend of large slope specimen is rising dramatically. So, The angle of 30 ~ 45 degree for slope design are suggested.



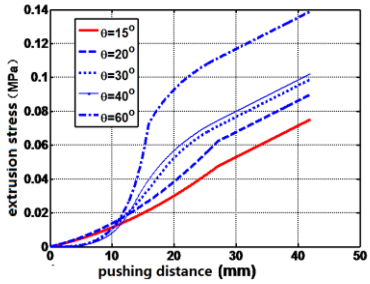
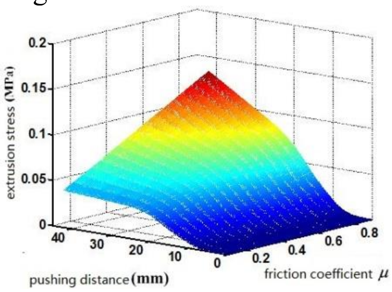


Fig 10. stress surfaces for the transition zone Fig 11. Extrusion stress curves under different slope gradient

4.3. Influence of Friction Coefficient on the Extrusion Force

In order to analyze The slope design for the transition zone is also affected by the friction coefficient. the length of infinitesimal is 0.1mm, The elastic modulus of the rubber ring is 5MPa, the transition angle of cylindrical part is 30 degree, and the pressing force under different working conditions is analyzed by changing the friction coefficient between rubber and PVC. The calculation result is shown in Fig. 12 and Fig 13.



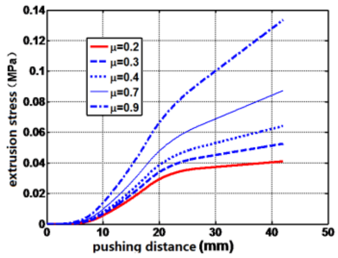


Fig12. Stress surfaces of transition zone Fig13. Extrusion stress curves under different coefficient

It shows that the friction coefficient of rubber-PVC has a significant effect on the extrusion force. With the friction coefficient growing, the minimum pressing force increases sharply. If the transition zone of cylindrical part is too large, the demand for minimum extrusion force will increases.

5. Conclusion

1) The new type of sealing device is entirely dependent on the gap between PVC and seal ring to ensure its closeness. For the compression deformation of seal ring, the device could adjust the gap automatically under the pressure between seal ring and PVC.

2) The new type of sealing device can improve the sealing effect, which effectively solve the leakage problems for short-line matching method on connection. The sealing device is proved to be simple and practical

3) The relation of nonlinear coefficient a in proportion to the voltage at grain boundary was induced theoretically the compressive stress change is proportional to the elastic modulus of the sealing ring.

Acknowledgments

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