Applicability Analysis of New Type of Waterproof and Drainage Partition Theory for Tunnels

Guang Luo, Weizhen Bai and Yun Zhang

1 Guangxi Xianglu Construction Co., Ltd., Nanning, Guangxi, 530029, China
Email: axl15318@hotmail.com, 1450918651.@qq.com, zy3315@163.com

Abstract. Based on the shortcomings of the existing anti-drainage partitioning methods, this paper proposes a new partitioning method with solutions to the shortcomings. Thoroughly waterproofing with a “Shi” type waterstop in the length of one section, partitioning drainage with a sump tank. According to the basic formula of Darcy's law, the calculation formula of the partition length is derived. The calculation of the Yaoshan to Nandan Highway Layi tunnel is carried out. The recommended value of the partition length is given. The numerical simulation is used to verify the applicability of the partitioning method.

1. Introduction
During the construction of highway tunnels in mountainous areas, it is inevitable to cross aquifers. In order to avoid leakage of water in tunnels, more stringent requirements must be put forward for waterproof and drainage technology. Although the current tunnel construction technology in China is quite mature, the waterproofing effect of the whole waterproof and drainage system is not ideal, and the leakage of water in the tunnel is still common[1-2]. Domestic and foreign scholars have made a great deal of research on the design and development of water-proof and drainage materials, and have achieved certain results.

In recent years, many scholars have also changed their thinking on waterproofing and drainage research. The purpose of waterproofing and drainage is achieved by changing the types of waterproofing materials and drainage structures[3]. At present, the concept of partitioned waterproof and drainage has been gradually recognized by scholars at home and abroad. However the current partitioning method is mainly through installing back-mounted water-stop belt on the waterproof board, dividing the groundwater seepage into sections between the secondary lining and the waterproof board, preventing groundwater from channeling between the secondary lining and the waterproof board, achieving the goal of partitioning waterproof, and not draining the water out of the tunnel. The method does not effectively divide the groundwater between the back of waterproof board and the initial support, and still fails to solve the problem of groundwater channeling along the tunnel along the longitudinal direction between waterproof board and the initial support[4]. Therefore, the current partitioned waterproofing and drainage is incomplete. Current drainage systems still have circular and longitudinal drainage pipes behind secondary linings and additional drainage ditches in inverted archs. Once the construction of a certain part of the drainage system is improperly blocked, it will be difficult to clear the entire drainage system. The tunnel will cause water pressure to rise due to poor drainage, which will eventually lead to the leakage of the secondary lining near the damage of the waterproof board[5].

2. New Theory of Partitioned Waterproofing and Drainage
Based on the research results of many scholars, this paper proposes a new partitioned waterproof and
drainage system. First, completely change the tunnel from the perspective of changing the type of waterstop[6]. In this paper, it is proposed to install a new "Shi" type waterstop at the construction joint position (as shown in Fig. 1), and divide the initial support along the longitudinal direction of the tunnel. The concrete installation method is that one end of the water belt is embedded in the initial support of the tunnel, the other end is embedded in the interior of the secondary lining, and the middle part is welded with the waterproof board on both sides of the construction joint. Based on the research ideas of Ming-qing Xiao[7], this paper changes the existing tunnel drainage structure. By adding a catchment trough on the secondary lining, cutting off the waterproof board at the catchment trough position and fixing it inside the catchment trough, groundwater is flowed into the longitudinal drainage pipe through the catchment trough, and then discharged out of the tunnel through the central drainage ditch.

![Installation sketch of new type partitioned waterproof and drainage components](image)

**Figure 1.** Installation sketch of new type partitioned waterproof and drainage components

3. **Advantages of New Partitioned Waterproof and Drainage**

The new partitioning method uses the "Shi" type water stop belt for partitioning. The distance between the two "Shi" type water stop belts is one partition."Shi" type waterproof belt can divide the initial support of tunnel into waterproof board and between waterproof board and secondary lining longitudinally. It can effectively prevent groundwater from channeling along the tunnel longitudinally and truly achieve the goal of waterproof partitioning thoroughly in the tunnel longitudinally. The sump is installed on the secondary lining to replace the conventional circumferential drain pipe, which can ensure the smooth drainage system and avoid the problem of calcium crystallization blockage in the previous three-way pipe. The sump is used for drainage, and the drainage components are easy to be replaced, such as corrosion and aging, so as to facilitate the maintenance of the tunnel during operation.

4. **Determination of Partition Length**

Based on the proposed partitioning method, a simplified model of groundwater distribution in a waterproof and drainage section is shown in Fig. 2. Assuming that the surrounding rock is homogeneous, the highest water level at both ends of the same partition (waterstop partition) is equal to \( h_{\text{max}} \), the head height is 0 at the sump location, and the groundwater distribution law is symmetrically distributed around the sump. Assuming that the surface of the initial shot concrete is flat, and the seepage volume of the groundwater seepage into the tunnel in the surrounding rock is \( q_0 \). The geotextile flows along the pores between the waterproof slab behind the secondary lining and the initial shot concrete to the sump position, and the amount of water discharged is \( q \). A is the cross-
sectional area of the seepage flow is the cross-sectional area of the geotextile drainage layer, and k is the permeability coefficient of the geotextile. The water flow is filled with the gap between the secondary lining and the initial shot concrete along the longitudinal direction of the waterproof board. In order to simplify the analysis without considering the circumferential flow, it is assumed that the motion law obeys Darcy's law.

The symmetrical distribution of groundwater on both sides of the sump in the same area is analyzed with half of the groundwater. According to the basic formula of Darcy's law, it can be obtained that:

\[ x \cdot q = -\lambda \cdot K \frac{dh}{dx} \]  \hspace{1cm} (4.1)

After integrating at both ends, we simplify it:

\[ h = -\frac{q}{2\lambda \cdot K} x^2 + C \]  \hspace{1cm} (4.2)

The resulting equation is introduced into the boundary condition, when \( x=0 \), then \( h=C=h_{\text{max}} \), when \( x=0 \), then \( h=0 \), the formula for calculating the head height is:

\[ h = -\frac{q}{2\lambda \cdot K} x^2 + \frac{q}{2\lambda \cdot K} l^2 \]  \hspace{1cm} (4.3)

The formula for calculating the maximum head height is as follows:

\[ h_{\text{max}} = \frac{q}{2\lambda \cdot K} l^2 \]  \hspace{1cm} (4.4)

Finally, the formula for calculating partition length is obtained as follows:

\[ L = 2l = 2\left(\frac{2\lambda \cdot K \cdot h_{\text{max}}}{q}\right)^{1/2} \]  \hspace{1cm} (4.5)

Figure 2. Simplified model of groundwater distribution in a waterproof and drainage section
5. Examples of Engineering Application

Based on the new formula for calculating the length of waterproof and drainage partitions, this paper applies the formula to the Layi Tunnel of Yaoshan-Nandan Highway and calculates the value of the length of the partitions. The Layi Tunnel of Yaoshan-Nandan Highway is located in Layi Village, Chengguan Town, Nandan County, Hechi City, Guangxi. The tunnel passes through a low mountain body consisting of argillaceous siltstone and limestone with a total length of 632m. According to the preliminary exploration data of the Layi tunnel, the permeability coefficient of the surrounding rock of the tunnel is \( K = 5.46 \times 10^{-5} \text{cm/s} \), the impermeability grade is P8, and the maximum groundwater head height is \( h_{\text{max}} = 148 \text{m} \) of the tunnel is located in the V-class surrounding rock section: K35+400~K35+500. The maximum \( q \) of water inflow calculated from the survey data is 3.07 \( \text{m}^3/(\text{m} \cdot \text{d}) \). The Layi tunnel uses a 1.2mm thick EVA waterproofing membrane and a 350g/m² non-woven geotextile. The total area \( A \) of the geotextile cross-section is 1.52 \( \text{m}^2 \).

Because the maximum water head height of the tunnel is 148m, the maximum hydrostatic pressure of the secondary lining is 1.48MPa (without considering reduction) without drainage, and the maximum hydrostatic pressure of the secondary lining meeting the impermeability requirement is 0.8MPa (i.e. 80m water head height), the drainage pressure of the tunnel should be relieved. According to the derived partition length calculation formula, when the maximum head height on the secondary lining is controlled to be 80m, the tunnel partition length is calculated to be 12.23m. It is recommended that the length of the K35+400~K35+500 section of the Layi Tunnel be 12m.

6. Numerical Simulation

In this paper, MIDAS-GTS finite element analysis software is used. Based on the new theory of waterproof and drainage partitioning, the general situation of the section K35+400~K35+500 of Layi Tunnel is adopted, and the length of the section 12m is calculated.

The full sealing (working condition 1) and the 12m section length (working condition 2) of the 148m head height were respectively established, and the maximum value of the secondary lining water pressure after the partition was analyzed to meet the control standard, thereby verifying the applicability of the partitioning method.

![Image](image_url)

**Figure 3.** Contrast diagram of secondary lining water pressure under two working conditions

It can be seen from Fig. 3(a) that under the undrained condition, the maximum water pressure on the secondary lining surface is 1.487 MPa. It can be seen from Fig. 3(b) that under the condition of 12m section length drainage, the maximum water pressure on the secondary lining surface is 0.786 MPa, and compared with the undrained condition, the water pressure on the secondary lining surface dissipated 52.86%. The analysis results show that the water pressure of the secondary lining surface after the partition can be dissipated to meet the impermeability requirements of the secondary lining concrete (that is, the maximum water...
pressure on the secondary lining after the partition is controlled within 0.8 MPa), thus verifying the new type. The anti-drainage zone method can be applied to the tunnel anti-drainage and pressure relief, which is theoretically feasible.

7. Conclusion
In view of the shortcomings of the current partitioning water-proof and drainage, this paper proposes a new method of water-proof and drainage, using a new type of "Shi" type waterstop for thorough partition waterproofing, using the sump as a water-storing component for partition drainage, overcoming the current partition The shortcomings of water prevention and drainage are more thorough partitioning methods. Based on the basic formula of Darcy's law, a new formula for calculating the length of waterproof and drainage partitions \( L = 2 \left( \frac{2A \cdot K \cdot h_{\text{max}}}{q} \right)^{1/2} \) is derived. In this paper, the Layi tunnel is used as an engineering example, and the derived partition length calculation formula is used to calculate. The recommended value of the partition length of the Layi tunnel is given. Finally, the numerical simulation is used to calculate the new type of zone drainage to effectively reduce the water pressure on the secondary lining. Compared with the two working conditions, the secondary lining water pressure dissipates 52.86%, and the secondary lining water pressure after dissipation is 0.786 MPa. The secondary lining water pressure meets the control value of the impermeability requirement of 0.8 MPa, which proves that the new partition water drainage has theoretical applicability.

8. References
[1] Zhong-xian Ning. Research on Waterproof and Drainage Technology of Expressway Tunnel [D]. Chang'an University, 2007.
[2] Zhan-hui Song. Research on Waterproof and Drainage Technology and Technology of Highway Tunnel[D]. Chang'an University, 2010
[3] Dong-sheng Li. Research on seepage mechanical characteristics and partitioning prevention and drainage of underground tunnels in mining method [D]. Southwest Jiaotong University, 2010.
[4] Yan-jie Yan, Shaohui-He. Waterproof Model Test and Engineering Application Research of Tunnel Partition[J]. Modern Tunnel Technology, 2005, 42(1): 30-37.
[5] Chao-wei Du. Research on water stress and structural stress characteristics of submarine tunnel lining[D]. Beijing Jiaotong University, 2011.
[6] Qing-wen Liu. Research on waterproof technology of subway engineering [D]. Southwest Jiaotong University, 2005.
[7] Ming-qing Xiao. Discussion on Calculation and Control Method of Tunnel Lining Water Pressure[J]. Journal of Railway Engineering Society, 2017, 34(8): 78-82.