Safety Analysis of Shield Tunnel Segment Lining Based on Field Test

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Abstract. During the construction of the Nantanhai Shield Tunnel, some pressure sensors are installed to monitor the formation pressure of the segment lining. Based on the field test of Nantanhai Shield Tunnel, ANSYS software was used to calculate the mechanical model of plane strain according to structure and load pattern. Through the result, we find that the internal force of the lining of the tunnel meets requirements, and then we calculate the safety factor of the shield tunnel segment lining, And proposed the optimization of parameters.

1. Introduction

Based on the field test of Nantanhai Shield Tunnel, this paper uses ANSYS software to analyze the safety factor and optimize the parameters of shield tunnel segment lining. It is of great significance to design the thickness of shield tunnel segment lining.

2. Project Overview

Nantanhai shield tunneling is the dominant engineering of Guangdong Province Natural Gas Pipeline Network Phase II Project Zhuhai LNG Gas Pipeline West Main Line Project. The total length of the crossing section is 1045.57m. According to the engineering geology and hydrogeological conditions of the crossing section, we use slurry shield to lay gas pipeline. Tunnel inner diameter is Φ3.080m, external diameter Φ3.540m, the segment lining is made of thickness of 230mm C50 reinforced concrete. Nantanhai shield tunnel using shield tunneling section of the length is 1009.6m, belonging to the underwater circular section of the single-pipe shield tunnel. The main strata is the artificial fills(Q4m), the crust, the silty clay, the sand, the gravel, and the whole weathered conglomerate, the strong weathered conglomerate and the moderately weathered conglomerate of Cretaceous system.

3. Field Test

During the construction of the Nantanhai Shield Tunnel, in order to understand and master the formation pressure of the segment lining in the river bottom, we set some pressure sensor in the segment lining. The sensor was used to test the formation of the shield tunnel segment lining. And

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analyzes the internal force and safety of the segment lining by the test results, and provides the basis for optimizing the structural design.

The monitoring is carried out using a pressure sensor. With the construction of the Nam Tanhai Shield Tunnel, a pressure sensor is installed on the outside of the shield segment lining. In the river bottom section set up three monitoring sections, respectively, located in the 30th ring, 169th ring, 400th ring. The layout of the test point of the outer side of the shield tunnel is shown in figure.1.

The pressure sensor is mounted on the outside of the segment lining for measuring the pressure applied by the formation to the tunnel. In figure. 1, the pressure box numbers for measuring the pressure of the formation are A_1, B_1, C_1, D_1, E_1, F_1, G_1 and H_1, and the subscript "1" represents the measured cross section. The pressure sensor numbers for the respective measuring points in the second and third monitoring sections are the same. By embedding the pressure sensor, the vibration frequency of each sensor is read by the vibrating wire frequency meter, then compared with the initial frequency, and the pressure value of the measuring point is obtained by calculation

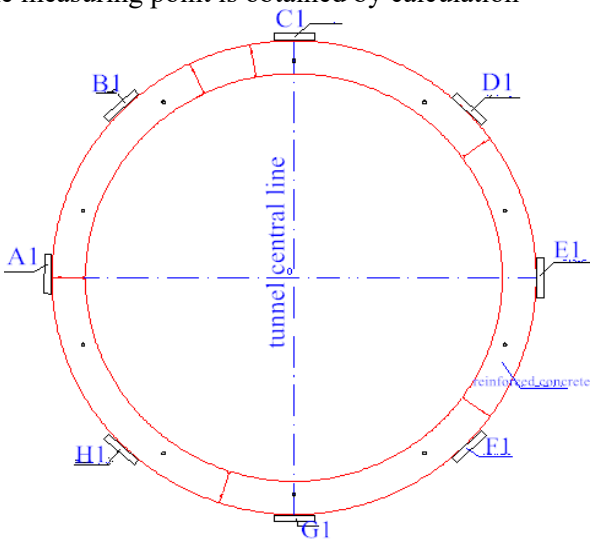


Figure 1. Layout of Segment Lining Pressure Monitoring Point

According to the frequency measured by the vibrating wire pressure sensor in the field, the measured value of the surrounding rock pressure of the shaft structure and the shield tunnel segment can be calculated according to the formula (1). Which is

$$P_i = P_0 + k_j(f_i^2 - f_0^2) \tag{1}$$

Where - P_0 is the pressure box calibration curve of the intercept, usually taken;

- k_j is the calibration factor of the j-th pressure cell, MPa / Hz^2;
- f_0 is the initial frequency reading after the pressure box is buried, Hz,
- f_i is the frequency reading of the i-th test after the pressure box is buried, Hz;
- P_i is the pressure at the i-th observation, MPa.

4. Test Results

By monitoring the formation pressure on the three monitoring sections, the test results are shown in figure. 2, figure. 3 and figure. 4.

For the segment lining of the Nantanhai Shield Tunnel, the formation pressure of the joints in the three sections of the monitoring section is analyzed as the pressure to which they are subjected. The maximum value of the measured point after the value of its pressure distribution is used as the final result. So we can get the pressure distribution of the first monitoring points, which is shown in Figure 5.

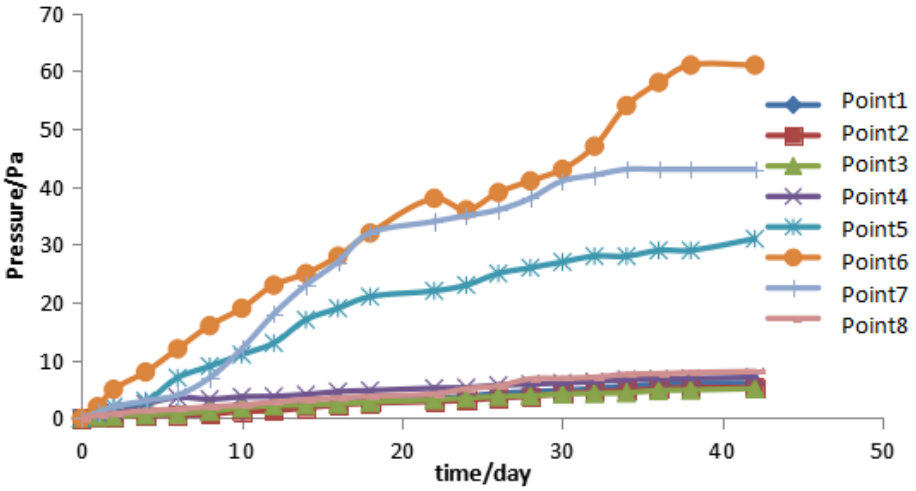


Figure 2. The Velocity Curve of Contact Pressure of the Segment Lining at the 30th Ring

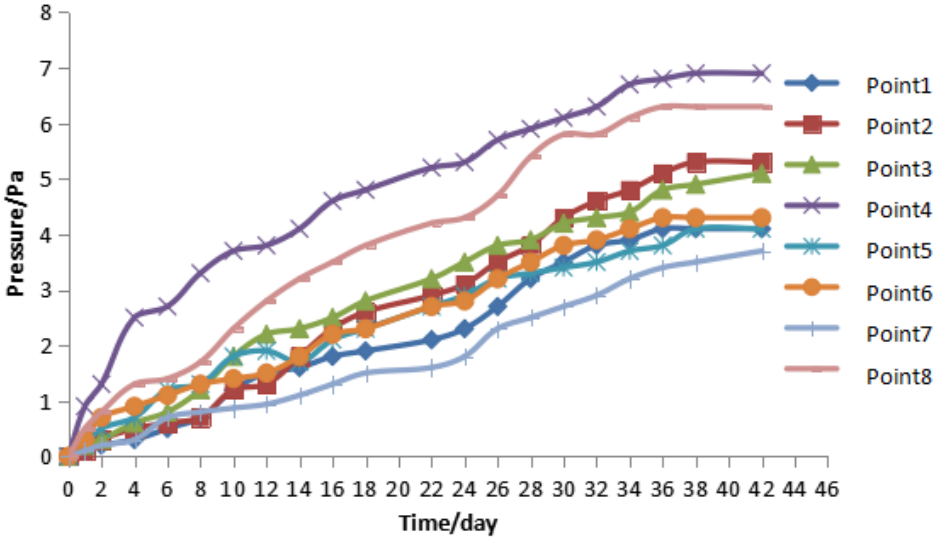


Figure 3. The Velocity Curve of Contact Pressure of the Segment Lining at the 169th Ring

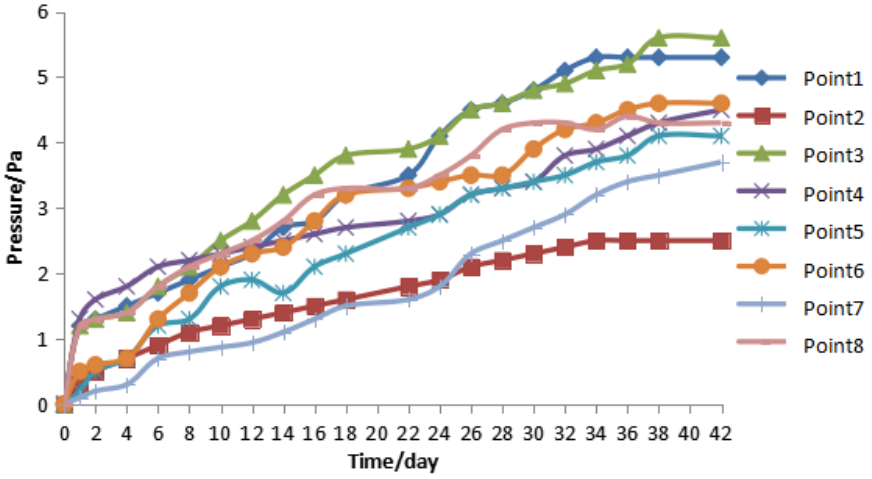


Figure 4. The Velocity Curve of Contact Pressure of the Segment Lining at the 400th Ring

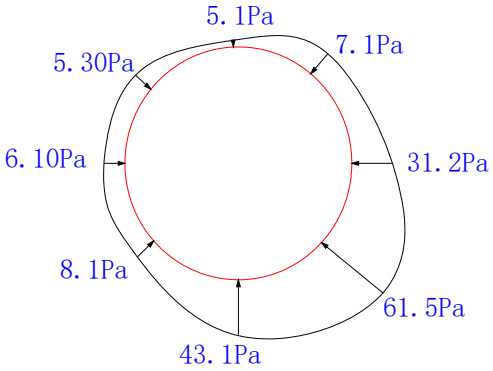


Figure 5. Formation Pressure Distribution of Shield Tunnel Segment Lining

5. Analysis of Internal Force and Safety Factor

According to the formation pressure of the segment received by the field test, ANSYS software is used to carry out the mechanical model of plane strain according to the structure and load pattern. The finite element numerical calculation of the load and structure model shows that the deformation and internal forces of the Nantanhai shield tunnel segment lining under the action of stable formation pressure are shown in figure. 6 to figure.10.

According to figure.6 to figure.10, we can find that the deformation of the segment lining under the test of the formation pressure is small and the radial displacement is at most 0.56×10^{-2} mm. The maximum bending moment of the segment lining structure is 109.7N · m, the maximum axial force is 140.43N, and the maximum shear force is 91.56N.

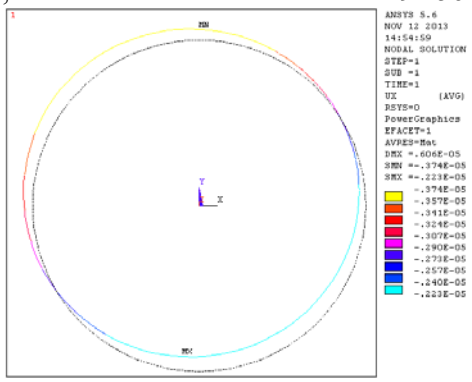


Figure 6. Deformation of X Axial (Unit:m)

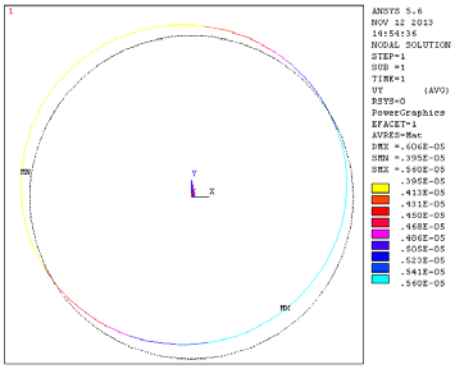


Figure 7. Deformation of Y Axial (Unit:m)

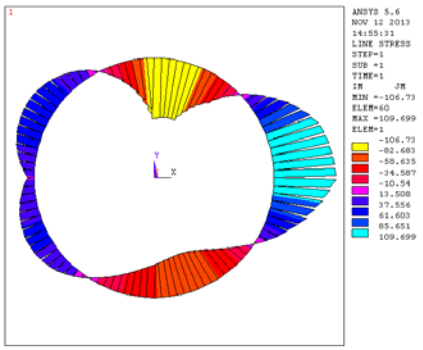


Figure 8. Bending Moment diagram (Unit:N·m)

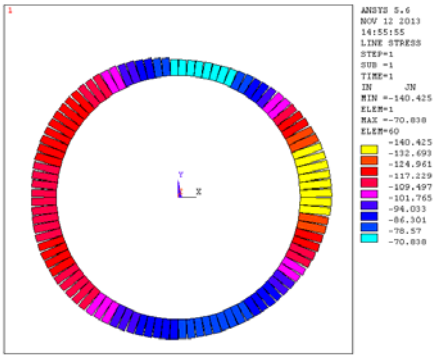


Figure 9. Axial Force Diagram (Unit:N)

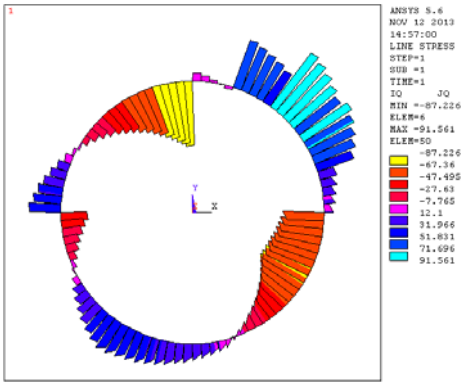


Figure 10. Shearing Force of the Segment Lining (Unit:N)

After obtaining the internal force of the segment lining, the safety of the structure can be calculated according to the load capacity limit state. According to the allowable stress design method to calculate and check the safety factor of the structure. For the rectangular cross section center and eccentric compression members, the compressive and tensile safety factor is

$$K = \varphi \alpha R_a bh / N \tag{2}$$

Where - K is the safety factor, selected according to Table 1, but should be higher than the corresponding specified value;

- R_a is concrete compression limit strength, C30 concrete is 22.5MPa, while the C50 concrete in accordance with the standard to take 36.5;
- N is axial force, kN;
- b is the width of the section;
- h is the thickness of the section;
- φ is the longitudinal bending resistance of the component, for the lining tunnel, Mingdong arch and wall back tight backfill side wall, desirable; for other components, according to the slenderness ratio, in accordance with the railway tunnel design specifications to be selected;
- α is Axial force eccentricity coefficient of influence.

Table 1. Concrete Strength Safety Factor

	Loading Combination	Main Load	Main Load+ Additional Load
Destruction Reason	Ultimate Compression Strength	2.4	2.0
	Ultimate Tensile Strength	3.6	3.0

In the Nantanhai shield tunnel, the segment lining is 230mm C50 reinforced concrete, R_a takes 36.5, the axial force is taken according to Figure 9, φ α are taken according to "Code for design on tunnel of railway" 10.2.1-1 and 10.2.1-3. According to (2), we can calculate the various parts of the safety factor of the segment lining, as it shown in Figure 11.

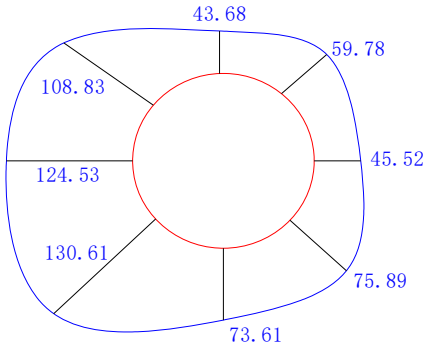


Figure 11. Safety Factor of Shield Tunnel Segment Lining

It can be seen from figure.11 that the safety factor of each part of the shield tunnel segment lining is much larger than the concrete strength safety factor listed in Table 1, the structure is safe and much too safe so that the segment thickness can be optimized.

6. Conclusion and Prospect

According to the Nantanhai Shield Tunnel field test, we get the final stability value of the surrounding rock pressure and take it as the value for caculation. The structural safety factor calculated by the allowable stress design method and plastic stage design method is much larger than that of the concrete structure safety factor listed in table.1. It proves that the thickness of the segment lining has a large space for optimization. However, due to the discrete nature of the field test data, and the number of test data is limited, so the test value does not fully represent the force on the shield tunnel segment lining. So the test value of the surrounding rock pressure may be some certain degree of dispersion and specificity. Therefore, only the analysis of the field test results of the Nantanhai Shield Tunnel can not be used to guide the structural design of the shield tunnel of oil and gas pipelines. And China's 80% of the shield tunnel has no secondary lining, so the segment strength should be part of the surplus and safe reserves. Nevertheless, compared with the design parameters of the shield tunneling lining in the domestic traffic tunnel, the test results of the formation pressure of the Nantanhai Shield Tunneling Tunnel also show that there is further space for further optimization of the design parameters of the tunnel structure segment lining.

Acknowledgments

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