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STUDY ON THE INFLUENCE OF BOLT ANCHORED CATENARY ON TUNNEL LINING UNDER THE AERODYNAMIC LOAD

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ABSTRACT

In order to study the influence of Bolt anchored catenary on tunnel lining under the aerodynamic load, the paper takes a tunnel on Qinhuangdao -Shenyang Railway as an example.The force of lining structure is studied using numerical simulation based on the research and analysis of relevant theory and model test results. Firstly, the variation of the air pressure in the tunnel was calculated caused by the train when it is passing through the tunnel at different speeds (200 ~ 400km/h). Then, by ANSYS the aerodynamic load calculated by FLUENT is applied to the simplified catenary suspension. The main results are as follows: 1. The maximum normal stress of tunnel lining with train speed according to the power law, and maximum normal stress with train speed according to quadratic function relation; 2. Tunnel lining is subjected to push-pull stress because the magnitude and direction of aerodynamic loads change with the advance of the train; 3. The lining structure is mainly subjected to the stress of the Y direction, and this stress should not be neglected when design the structure of tunnel secondary lining. 4. The load spectrum of the lining structure under different train speed is given. The research results of this paper are of great significance to the optimization design of tunnel lining structure.

KEYWORDS

High–speed train, Tunnel lining, Aerodynamics load, Suspended ancillary facilities, Tension and compression cycle

1. INTRODUCTION

It is expected that in 2020, China's high-speed railway mileage will reach 30,000 km, at the same time; the high-speed railway tunnel construction scale will increase with the increasing mileage of high-speed rail in mountainous China. With the increase of the train speed, the aerodynamic effect of the tunnel is more and more obvious, and out of the consideration of the comfort of high-speed railway train, the tunnel construction and the economy of the vehicle manufacturing, many experts in domestic and overseas have conducted a series of numerical simulations, model tests and field experiments on tunnel aerodynamics. For example: Miyachi T and Ozawa S [1], Cross D and Hughes B [2], Luo Jianjun [3-4] Ma Weibin et al. [5-7] improved the computational theory of tunnel aerodynamics further through the numerical simulation study.

In order to ensure the normal operation of the train, the catenary fittings are essential as part of power supply facilities. When the train passes through the tunnel, catenary suspension will also be affected by the aerodynamic effect of the tunnel. Shi Chenghua, Yang Weichao, Wang Zhaowei [8-11] et al. found that long-term aerodynamic loads will accelerate the damage of the attachment fixtures. As for the current situation of railway tunnel design in our country, during the design of the lining structure, the influence of the catenary on the lining under the action of aerodynamic load is not considered. With the increase of railway tunnels in recent years, the problems are more and more serious. The authors have found that the connection between the auxiliary facilities and the tunnel lining is where the lining cracks begin to form in many tunnels.

In this paper, the bolt anchored catenary in a tunnel of Qinhuangdao -Shenyang railway is studied. Firstly, the ICEM CFD is used to establish a high-speed railway tunnel model whose length is1000m and blocking ratio is 0.1102 (The train model is CRH_{380A}, the cross sectional area of the tunnel is 100m^2). Secondly, the air pressure in tunnel will be acquired by FLUENT when the train speed is 200km / h, 250km / h, 300km / h, 350km / h, 380km / h and 400km / h. Then the ANSYS is used to establish the simplified catenary suspension model and the influence of the catenary on tunnel lining under the action of aerodynamic load is also studied. Last but not least, the load spectrum of the lining structure under different train speed is given, and the load should be considered in combination with the passage frequency of the tunnel when design the secondary lining. The research results of this paper will make a great significance to the design or partial strength of the high-speed railway tunnel lining.

2. AERODYNAMIC LOAD CALCULATION BASED ON FLUENT

Firstly, a numerical model is established according to the data provided by the relevant scholars of Central South University. In order to make the calculated aerodynamic load close to reality, the aerodynamic load calculation model is verified and related calculation parameters is adjusted by comparing with the model test data in the laboratory. Linearity reduced scale of this model test is 1/17.6. The train model is CRH380A and the length of it is 2.92m. The length and sectional area of tunnel are 28m and 0.258 m2 respectively. The speed of train is 55.98m/s, the measure point is about 14.2m away from the entrance of tunnel. In order to make the results as accurate as possible，calculate time step size is 0.0005s. Figure 1 shows the test and calculated value.

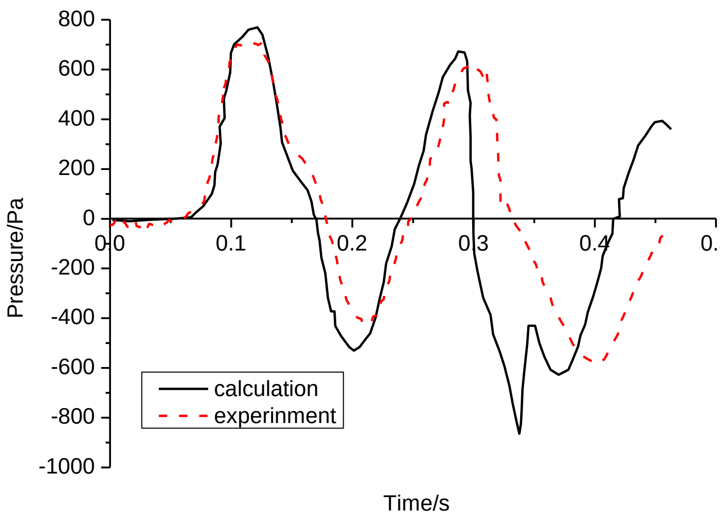

Fig. 1 - Comparison between the test value and the calculated value

As we can see from Figure 1, the difference between the maximum positive pressure obtained from numerical simulation and the model test result is less than 5%. It shows that the parameter setting and the model of numerical simulation are in accord with the actual situation.

Then, the aerodynamic load of CRH_{A380} train caused when going through the tunnel whose cross section is 100m^2 at different speeds is analyzed by the numerical simulating calculation. According to the results of real vehicle test and numerical simulation, the maximum aerodynamic load is obtained within the range of 100m ～150m from the tunnel entrance. Taking the most unfavorable situation into account, in this paper, the measuring point of aerodynamic load is set at 120m from the entrance in the tunnel, the calculated results are as shown in Figure 2.

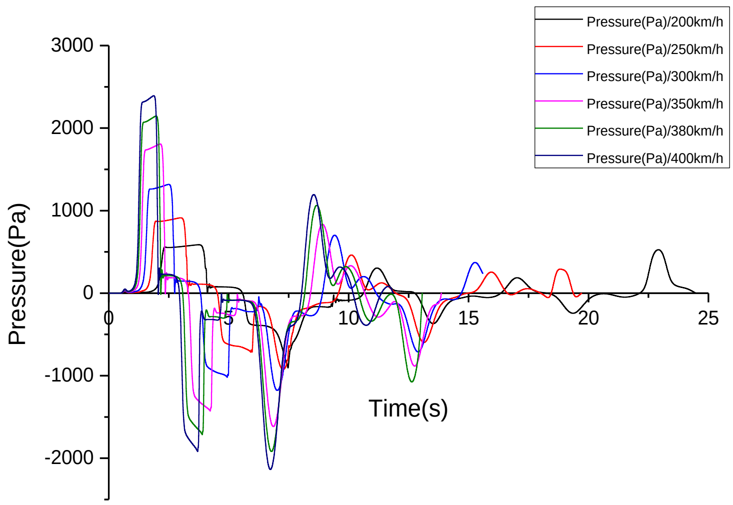

Fig. 2 - Calculation results of aerodynamic loads at different speeds

3. ANSYS COMPUTING MODEL

3.1 Stress analysis of lining

When the tunnel is opened to traffic，the lining structure will be interacted with external loads, such as the surrounding rock pressure, water force and so on, and form a stable tertiary stress field. The bolt anchored catenary is directly fixed on the secondary lining structure by bolts, as shown in Figure 3.

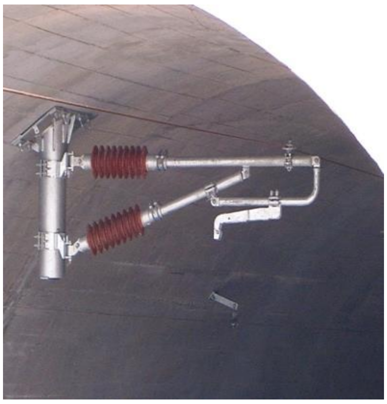

Fig. 3 - Bolt type contact net hanger after installation

Due to the limited space inside the tunnel and the compressibility of air, when high speed train passing through the tunnel, catenary becomes obstacles to train wind, therefore, it will be affected by the aerodynamic load, and all these forces are eventually passed on to the tunnel lining. For the lining structure, the stress direction of the lining structure is along the tunnel axial (X direction) and perpendicular to the tunnel axial (Y direction). This force is only applied to the lining when the train passes, and the size and the direction change with the time. In order to make statistic more convenient, this study determines the positive direction of x and y are as shown in Figure 4, that is, when the y-direction stress is positive, the lining structure is subjected to tensile stress.

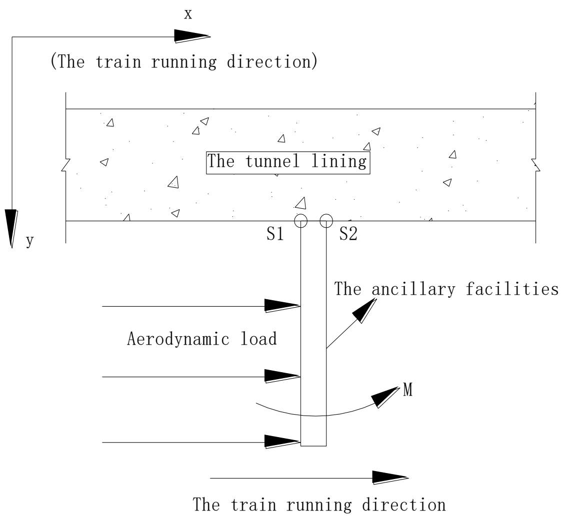

Fig. 4 - Force analysis and measuring point position of bolt anchored catenary under aerodynamic load

3.2 ANSYS APDL simulation implementation process

After making a force analysis of the bolt anchored catenary, the model is established and the grid is divided by ANSYS Parametric Design Language. PLANE42 is used for the unit type of Lining structure and Bolt anchored catenary.The lining concrete is C35 concrete, the density is 2425kg/m^3, Elastic modulus is 2.83.15×104MPa, Poisson's ratio is 0.2, material of bolt anchored catenary is Q335. In order to facilitate the calculation, the connection between the tunnel lining and the suspension is set to perfect contact. [9]

Then, the aerodynamic load caused by the train are calculated by FLUENT. The calculated aerodynamic load is applied as a force varying with time to catenary by means of transient analysis, in order to analyze the stress of secondary lining and monitor the stress at the connection point between the lining and catenary. The simplified model and the numerical simulation of the stress distribution of the bolt anchored catenary are shown in Figure 4.

The length of bolt anchored catenary is 500mm in Qinhuangdao-Shenyang Railway. From the current research on the railway tunnel disease(), the lining structure is prone to crack where the suspension is located. The measuring points are as shown in Figure 4 (S1 and S2). The simplified two-dimensional model is established to monitor the X-direction and Y-direction stresses.

4. ANALYSIS OF NUMERICAL SIMULATION RESULTS

4.1 Basic law analysis

Using ANSYS APDL to simulate the X-direction and Y-direction's stress at the two measuring points, it is found that the magnitude of the stress at S1 and S2 are of small differences and are opposite in direction, so just monitor the stress at S1, and, the tunnel lining structure caused by bolt anchored catenary in the aerodynamic loads the directional change of stress is consistent with the aerodynamic loads. In order to save the length of the paper, taking the stress of the tunnel lining as an example at the train speed of 400km/h, the stress distribution of the lining structure is analyzed. The stresses in the tunnel structure are shown in Figures 5 and 6, the magnitude of the stress and its relation to the aerodynamic load are shown in Table 1.

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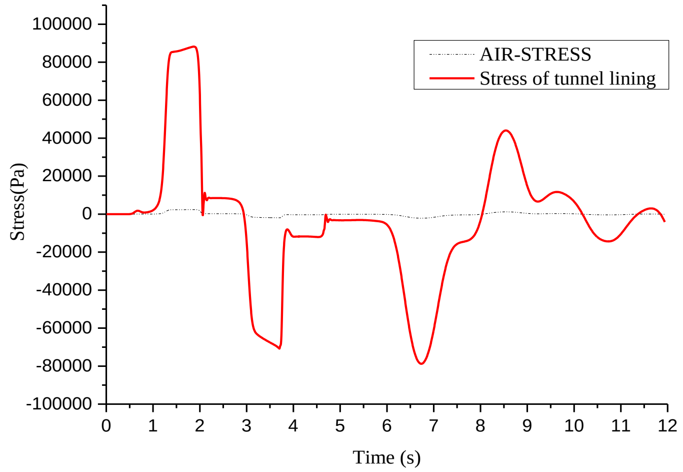

Fig. 5 - The stress of X direction when the train peed is 400km/h

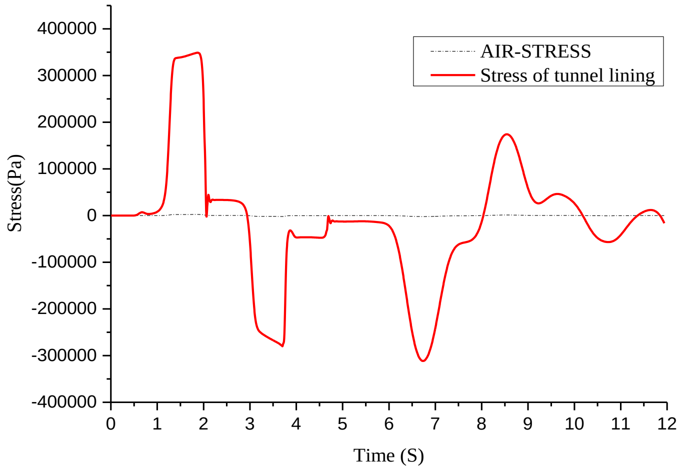

Fig. 6 - The stress of Y direction when the train peed is 400km/h

Tab. 1 - Peak stress of tunnel lining when the train speed is 400km/h

Time/s	AIR-STRESSAIR/ Pa	Stress direction	Peak stress	The relationship
1.87	2392	X	88215	P=37* AIR-STRESS
		Y	348901	P=146* AIR-STRESS
6.735	-2136	X	-78768	P=37* AIR-STRESS
		Y	-311537	P=146* AIR-STRESS

From Figure 5, 6 and Table 1, we can draw the following conclusions:

(1) When the speed is 400km / h, the aerodynamic load in the tunnel reaches the maximum positive pressure (AIR-STRESS = 2392Pa) when t = 1.87s. At this time, the tunnel lining structure is subjected to the maximum horizontal force to the right and maximum pulling force under the action of aerodynamic load;

(2) When t = 6.735s, the aerodynamic load in the tunnel reaches the maximum negative stress (AIR-STRESS = -2136 Pa). At this time, the tunnel lining structure is subjected to the maximum horizontal force to the left and maximum upward pressure under the action of aerodynamic load;
(3) As shown in Figures 5 and 6, the stress of the lining structure caused by the passing of the train is a cycle of tension, compression and tension;
(4) The X and Y directional stresses of the tunnel lining reach 37 times and 146 times of the aerodynamic load, respectively.

4.2 Analysis of lining stress without working condition

As shown in Figure 7 to 10, the maximum positive pressure and the maximum negative pressure curve of tunnel lining structure in the direction of X and Y are summarized.

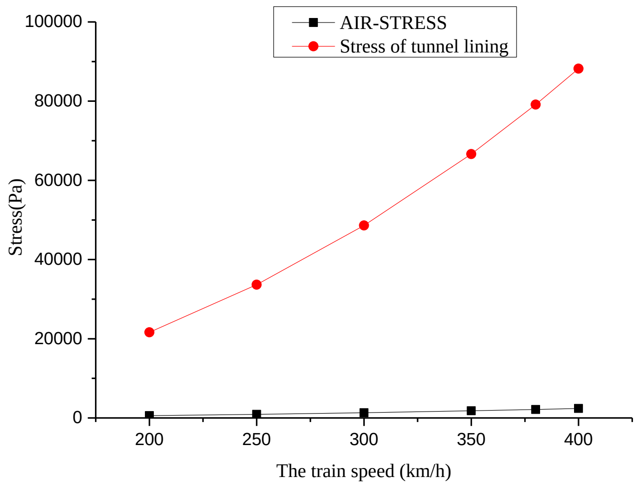

Fig. 7 - Maximum positive pressure in X direction of tunnel lining structure

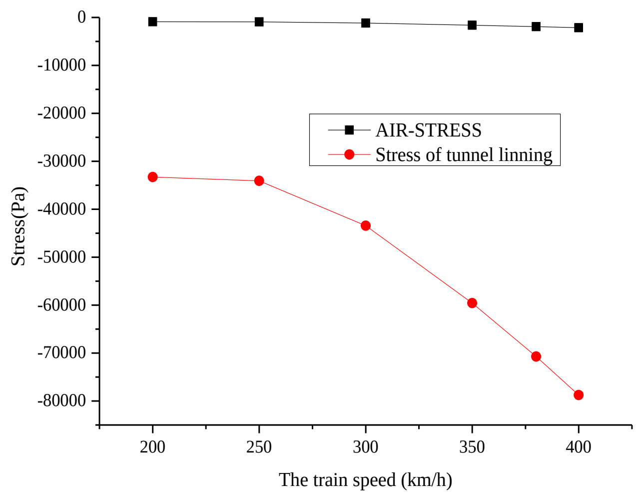

Fig. 8 - Maximum negative pressures in X direction of tunnel lining structure

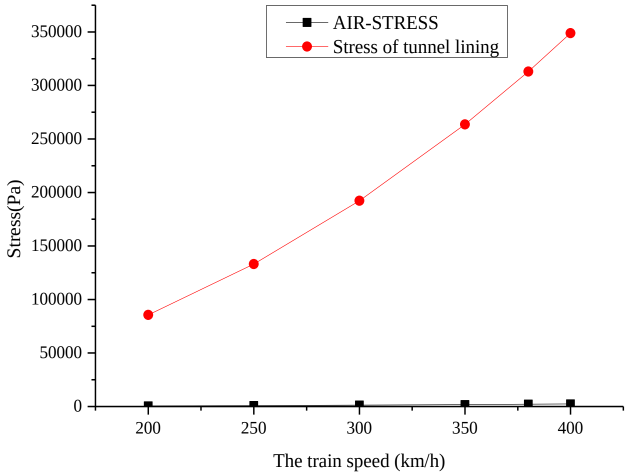

Fig. 9 - Maximum positive pressure in Y direction of tunnel lining structure

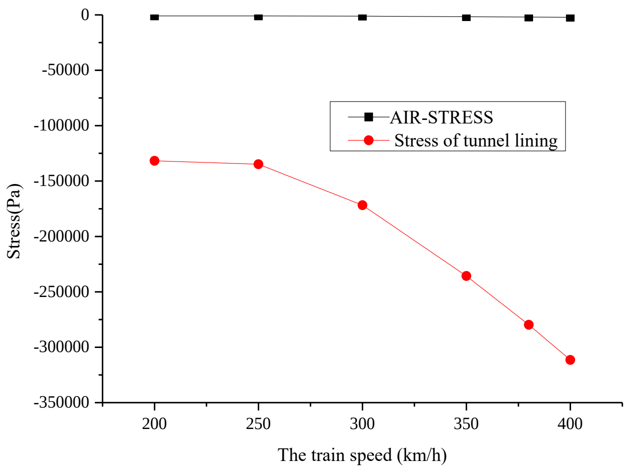

Fig. 10 - Maximum negative pressure in Y direction of tunnel lining structure

As shown in Figure 7 and Figure 10, we can see that the stress value of the tunnel lining has a great relationship with the operation speed of the train, and the size and increasing rate of stress increase with the increase of train speed. The relation between the stress of the lining structure and the train speed is summarized as follows in Table 2.

Tab. 2 - Relationship between the stress of lining structure and train speed

Maximum positive stress in X direction	$P=0.4661*x^{2.027}$
Maximum negative stress in X direction	$P=-1.2515x^2+516.87x-86067$
Maximum positive stress in Y direction	$P=1.8432*x^{2.027}$
Maximum negative stress in Y direction	$P=-4.9499x^2+2044.3x-340407$

The load spectrum of the tunnel lining structure due to the suspension under different speed is shown in Table 3. The load should be considered in combination with the passage frequency of the tunnel when design the secondary lining. It is worth noting that the stress of the lining structure caused by the passing of the train is a cycle of tension, compression and tension, therefore, the calculated traffic frequency of the train should be 2 times that of actuality.

Tab. 3 - The load spectrum of the tunnel lining structure due to the suspension under different speed

Train running speed (km/h)	*Maximum positive stress (Pa)*	*Maximum negative stress (Pa)*
200	85596	-131679.016
250	133150	-134773.641
300	192234	-171765.75
350	263598	-235658.328
380	313027	-279730.906
400	348901	-311536.75

5. CONCLUSION

Due to the compressibility of air and limited internal space in tunnels, the high-speed trains will induce a series of tunnel aerodynamic effect when going through, the trains and the tunnel structures and various ancillary facilities will be influenced by aerodynamic load. The paper takes a tunnel on Qinhuangdao-Shenyang Railway as an example, and the force of lining structure is studied by numerical simulation. The conclusions are as follows:

(1) The compression wave will be generalized when high-speed trains going through the tunnels, the bolt anchored catenary will be affected by aerodynamic loads because they will become an obstacle when the compression wave moves forward. Being fixed by the affiliated facilities, the load will finally deliver to the tunnel lining structures.
(2) The numerical simulation shows that the force imposed on the lining structures by affiliated facilities under the aerodynamic loads stress is mainly on Y direction, and the stress of the lining structure caused by the passing of the train is a cycle of tension, compression and tension.
(3) When the train speed is 400 km/h, the stress of X direction is 88215 Pa, while Y- direction stress is 348901 Pa. with no consideration of aerodynamic load when designing the lining structures is obviously unreasonable.
(4) The maximum normal stress of tunnel lining with train speed according to the power law, and maximum normal stress with train speed according to quadratic function relation;
(5) Considering about the safety of the actual operation of the train and the complexity of the treatment of the tunnel structure disease, this paper has some reference values for the design of the lining structures of the high railway tunnels.

REFERENCES

[1] Miyachi T, Ozawa S, Iida M, et al. Propagation characteristics of tunnel compression waves with multiple peaks in the waveform of the pressure gradient: Part 2: Theoretical and numerical analyses. Proceedings of the Institution of Mechanical Engineers Part F Journal of Rail & Rapid Transit, 2015, 35(2):220–235.
[2] WOODS W A, POPE C W. Secondary Aerodynamic Effects in Rail Tunnels During Vehicle Entry// Proceedings of the Second International Symposium on the Aerodynamics and Ventilation of Vehicle

Tunnels. Cranfield: BHRA, Fluid Engineering, 1976:71-86.
[3] Cross D, Hughes B, Ingham D, et al. A validated numerical investigation of the effects of high blockage ratio and train and tunnel length upon underground railway aerodynamics. Journal of Wind Engineering & Industrial Aerodynamics, 2015, 146(17):195-206.
[4] LUO Jianjun. Aerodynamic Effect Induced by High-Speed Train Entering into Tunnel in High Altitude Area. Journal of Southwest Jiaotong University, 2016, (04):607-614.
[5] LUO Jianjun. The Influences of Enlarged Sections and Ventilation Shafts on Pressure Waves in High-Speed Metro Tunnels. Modern Tunnelling Technology, 2016, (04):22-28.
[6] LI Hongmei. Research on Distance between Tracks for Intercity Railway Based on Aerodynamics. Railway Engineering, 2016,(10):101-104.
[7] CHENG Aijun, MA Weibin. Analysis of aerodynamics effect in changeable cross-section tunnel. Railway Engineering, 2016,(01):29-32.
[8] ZHANG Fengyu, CHENG Shu. Development of wireless data acquisition system in real vehicle passing through tunnels during Aerodynamic tests. Journal of Railway Science and Engineering, 2016, (07):1401-1406.
[9] POPE C W, GAWTHORPE R G, RICHARDS. An experimental investigation into the effect of train shape on the unsteady flows generated in tunnels// The 4th International Symposium on the Aerodynamics and Ventilation of Vehicle Tunnels. Cranfield Bedford England：BHRA，1982. C2, 107-128.
[10] SHI Cheng-hua, YANG Wei-chao, et al. Analysis of catenary's safety under train wind action in high-speed railway tunnel. Journal of Central South University (NATURAL SCIENCE EDITION), 2012, (09):3652-3658.
[11] SHI Cheng-hua, YANG Wei-chao, et al. Study on Aerodynamic Influence on Stability of Ditch Covers in High-speed Railway Tunnels. Railway Transaction, 2012,(01):103-108.
[12] Briffaut M, Benboudjema F, D'Aloia L. Effect of fibres on early age cracking of concrete tunnel lining. Part I: Laboratory ring test. Tunnelling & Underground Space Technology, 2016, 59:215-220.
[13] Briffaut M, Benboudjema F, D'Aloia L. Effect of fibres on early age cracking of concrete tunnel lining. Part II: Numerical simulations. Tunnelling & Underground Space Technology, 2016, 59:221-229.