Experimental and numerical research on the safety of an EMU running on a normal-speed railway line under strong wind

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Abstract. In order to establish the rapid traffic economic circle in Xinjiang province, there is a plan to operate the EMU (Electric Multiple Units) in Nanjiang normal-speed railway line. But there is few standard and experience that the EMU running on the normal-speed railway under strong wind. Therefore, the present work conducts a full-scale test to research the safety of the EMU running on the normal-speed railway to obtain the train aerodynamic and system dynamic performance. Furthermore, the part of deteriorate reasons of train aerodynamic performance is studied by the CFD (Computational Fluid Dynamics) method. In the next step, based on the experimental and CFD results, the disadvantage of current windproof facility will be found and improved to satisfy the requirement of the operation safety of the EMU.

1. Introduction

With the train speed increases, serious challenges the train safety facing with also become more and more, especially under the strong crosswind. Under the crosswind, the aerodynamic performance of the train become worse due to the impact of the wind. Some researchers have paid attention on this problem[1-4]. Chen et al[5] studied the nose length on the aerodynamic performance under crosswind, and concluded the law of the aerodynamic forces and moments change with the nose length increases. In order to reduce the crosswind on the train safety, the windproof facilities are necessary[6, 7], He et al[8] considered different types of wind barriers and studied the effect of wind barriers on the flow field and aerodynamic forces of a train–bridge system.

In China, the Xinjiang railway runs through the strong wind area, and there are some accidents occurred before[9-11]. In order to reduce the effect of strong wind on the train and improve the transportation efficiency, different windbreaks are researched and built along this railway[12, 13]. Meantime, the optimization of the train shape, and the wind warning system are also researched by many scholars[14, 15].

In the present work, in order to operate the EMU in Nanjiang railway, which is a normal-speed railway line, the full-scale test is conducted. Furthermore, the feasibility and the weakness of the current windproof facilities in Nanjiang railway line are found. The present work will as a base to modify and improve the current windproof facilities.
2. The test train and current windproof facilities
The test train is CRH5G, and the train marshalling is shown in figure 1, there are eight cars, the height and width of the train are 4.27 m and 3.2 m, respectively. The length of head car and tail car is 27.6 m, the length of middle car is 25 m. The test region of railway line is between Turpan-Yuergou (K0–K114). The railway is a double line, and define the line-1 is that near the windbreak, and the line-2 is that far away from the windbreak.

![Figure 1. The marshalling of the EMU train.](image)

The type of windproof facilities includes: straight plate, soil dike, cutting, slope soil dike, bridge-windbreak and so on. The detailed size and shape of part of windproof facilities are shown in figure 2. The height of windproof facilities is all 3.5 m, and the distance from the top of the windproof facility to the top of the rail is 2.5 m, the distance from the windproof facility to the centre of the railway line-1 is 3.95 m. The distance between the centre of line-1 and line-2 is 4.4 m.

![Figure 2. The different windproof facilities. Unit: mm](image)

3. The full-scale test methodology and the layout of test point
The dynamic pressure test system is used to test the surface pressure of the train, and after the pressure integral calculation, the aerodynamic forces and moments of the train are obtained. The frequency of the dynamic pressure sensor is 512 Hz.

There are three cars are tested, including the head car (car-1), tail car (car-8) and middle car (car-4). The number of total test points on these three cars are 222. There are 100 test points on the head car and tail car, respectively. The layout of test point on the head car and tail car is same, and the layout of test points in the left and right, top and bottom are all symmetrical. The layout of test points on the head car and tail car is shown in figure 3. For the middle car, there is only one middle cross-section’s pressure is tested and the layout of the test points is shown in figure 4.
4. Experimental results analysis

4.1. The definition of different parameters

The pressure coefficient on the train surface is defined as follow:

\[ C_p = \frac{P - P_0}{0.5 \rho v^2} \]  

(1)

Here \( C_p \) is pressure coefficient, \( P \) is the absolute pressure, and \( P_0 \) is the reference pressure-atmospheric pressure value. \( \rho \) is the air density, here is 1.225 kg/m\(^3\), \( v \) is the resultant velocity of ambient wind speed and train speed. In addition, as shown in figure 5, the overturning motion of the train under crosswind is defined as follow: when the wind-proof effect of the windbreak is insufficient, the train will overturn around the point \( O_1 \), in this case, the overturning moment is positive. Otherwise, the train will overturn around the point \( O_2 \), the overturning moment is negative. Similarly, the definition about the positive/negative values of side force and dynamic overturning coefficient is same with that of overturning moment; in addition, the positive lift force is upward.

4.2. The surface pressure of the train under different windproof facilities

In order to analyse the effect of different windproof facilities on the train surface pressure, the surface pressure distribution when the train runs in the railway line-2 under the bridge-windbreak (K15+270), slope soil dike (K25+650), soil dike (K46+420) and straight plate (K46+700) are chosen and analysed. The train speed is 56~60 km/h, and wind speed is 19.7~28.2 m/s when the train runs through these regions. Note that the pressure coefficients in these four regions are shown on the middle car.

Figure 6 shows the pressure coefficient distribution of the cross-section in the middle car, it can be seen that under the straight plate windbreak, the windward side (WWS) and leeward side (LWS) are all negative pressure, and the negative pressure in the WWS is larger, so the side force is opposite to the wind direction, but the side force is not big. Under the soil dike and slope soil dike windbreaks, the
pressures are all positive in the WWS, and there is small negative in the LWS, it indicates that the ability of these two windproof facilities is insufficient, namely, the direction of side force is same with the wind direction in these cases, and these two windproof facilities need be improved. Under the bridge-windbreak, the both side of the train is all smaller negative pressure, the shelter effect of bridge-windbreak is relative good for the middle car.

![Figure 6](image)

(a) Straight plate           (b) Soil dike                 (c) Slope soil dike          (d) Bridge-windbreak

**Figure 6.** The train surface pressure distribution under different windproof facilities.

### 4.3. Analysis of the maximum aerodynamic parameter value

In fact, except the surface pressure distribution, the aerodynamic forces and moments for the head car and tail car are the most important parameters to evaluate the safety of the train. Therefore, for the head car, the maximum values for different aerodynamic parameter are shown in table 1, it can be seen that the maximum positive overturning coefficient is 0.55 (Note that it is the dynamics parameter, and the limitation value is 0.8), and it occurs in the transition region between the straight plate and soil dike windbreak. The maximum negative value is -0.43, it occurs in the deep cutting region, meantime, the maximum negative side force also occurs in this region. In addition, the maximum positive overturning moment, side force and lift force all occur in the slope soil dike region, it indicates that regions of slope soil dike are dangerous. The maximum negative overturning moment and lift force occur near the straight plate windbreak region.

**Table 1.** The maximum aerodynamic parameters for the head car.

| The maximum value | Mileage       | The type of windproof facility                              | Train speed (km/h) | Wind speed (m/s) |
|-------------------|---------------|-------------------------------------------------------------|-------------------|-----------------|
| Positive overturning coefficient | 0.55          | K52+770 The transition region between the straight plate and the soil dike | 58.1              | 14.9            |
| Negative overturning coefficient | -0.43         | K23+880 Deep cutting                                        | 59.9              | 26.1            |
| Positive overturning Moment (KN\(\cdot\)m) | 160.28       | K52+860 Slope soil dike                                    | 58.1              | 31.6            |
| Negative overturning Moment (KN\(\cdot\)m) | -93.12        | K23+200 Straight plate                                      | 59.5              | 28.7            |
| Positive side force (KN) | 64.72         | K52+840 Slope soil dike                                    | 58.4              | 31.8            |
| Negative side force (KN) | -41.84        | K23+880 Deep cutting                                        | 59.9              | 26.1            |
| Positive lift force (KN) | 32.88         | K52+860 Slope soil dike                                    | 58.1              | 31.6            |
| Negative lift force (KN) | -8.30         | K67+810 Straight plate                                      | 36.5              | 21.6            |
4.4. The position where the maximum aerodynamic parameter value occurs

According to the experiment results, the number of times for the maximum aerodynamic parameter value for head car and tail car are listed in table 2. It shows that the most times of positive overturning efficient and overturning moment occur in the bridge-windbreak, and next is windbreak transition region and soil dike region; the positive value indicates that the ability of the windbreak is worse. The most times of negative overturning efficient and overturning moment occur in the straight plate region, and the next one is transition region, station, and cutting; the negative value indicates that the ability of the windproof facility is excessive. But according to the table 1, it can be seen the negative absolute value is smaller than that of positive value, so the maximum negative value has a smaller effect compared to that of positive value.

In addition, due to the terrain’s effect in the WWS of the straight plate region, so some maximum values occur in the straight plate region. But generally, for the 3.5 m height straight plate windbreak, the ability to against the wind is sufficient.

Table 2. The number of times for the maximum aerodynamic parameter values occur in different positions.

| Parameters                   | Soil dike | Straight plate | Bridge-windbreak | Cutting | Transition between different windbreaks | Train station |
|------------------------------|-----------|----------------|------------------|---------|----------------------------------------|---------------|
| Positive overturning Moment  | 3         | 1              | 7                | /       | 4                                      | /             |
| Positive overturning coefficient | 2        | 1              | 7                | /       | 4                                      | /             |
| Negative overturning Moment  | /         | 11             | /                | 1       | 1                                      | 2             |
| Negative overturning coefficient | 1        | 10             | /                | 1       | 2                                      | 1             |

5. CFD analysis of the train aerodynamics under the slope soil dike

Due to the wind-proof effect of slop soil dike is relative worse among different windbreaks, so here it is chosen to analyse by the CFD method. The 3D-incompressible, steady N-S equation and $k - \varepsilon$ turbulence model are used in the present work, the governing equations and other details about the numerical method can see the reference [16].

Figure 7 shows the pressure distribution of train surface under the windbreak type of slope soil dike. In the WWS of the train, there is all positive pressure, and except the nose part of the head car and tail car, the top of the train is all negative pressure. In addition, compared the pressure distribution between the railway line-1 and line-2, it can be seen the pressure distribution positions and values are similar for line-1 and line-2. Therefore, it indicates that under the windbreak of slope soil dike, no matter the train runs in the railway line-1 or line-2, it will face the similar risk.
In order to understand the pressure action mechanism induced by the slope soil dike, the streamlines around the head car are shown in figure 8. It seems that the soil dike has no any protective effects when there is a slope occurs. Namely, the airflow goes to the railway lines along the slope, it results in the strong positive pressure in the WWS as shown in figure 7. Furthermore, when the train runs in the railway line-1, there is a small vortex occurs between the car body and the windbreak; in the LWS, there is a small vortex occurs near the side of the train. When the train runs in the railway line-2, the large amount of airflow impacts on the car body directly, so the vortex of WWS is invisible; in the LWS, the vortex is larger than that in the railway line-1, and the core of the vortex is farther from the train side, so it results in a more unstable state for the train running on the railway line-2.

6. Conclusions
The full-scale test of EMU running on the normal-speed railway line is conducted in the present work, and the simple CFD analysis is also done, the conclusions can be drawn as follows:

(1) The full-scale test method and the layout of the test points on the train surface are introduced briefly.

(2) The windproof ability of the soil dike, slope soil dike, the transition region between different windproof facilities, and bridge-windbreak are worse, these types are the key weakness currently.

(3) Under the case of slope soil dike, the airflow goes to the railway lines along the slope, it results in the strong positive pressure in the WWS and it is easy to make the train face the overturning risk.

(4) The results obtained from the full-scale test provide the base reference for the deeply CFD analysis, and provide the base values to modify and improve the current windproof facilities.

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