Aerodynamic Characteristics and Safety of High-Speed Trains Embankment under Crosswinds

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ABSTRACT

This paper studies aerodynamic performance and safety of the high-speed train on the embankment under the action of horizontal wind. Based on the aerodynamics and multi-body system dynamics theory, the high-speed train aerodynamics and dynamics model is established to simulate field characteristics, aerodynamic performance and dynamic performance of high-speed train running on 10-meter embankment. From the simulation we get safety indexes such as derailment coefficient, wheel weight reducing load rate, lateral wheelset force and the wheel/rail vertical force. And the running security region of the train on the embankment can be determined based on high-speed train vehicle test specification. The calculation results of this paper can provide reference for the safe operation of high-speed trains in horizontal wind.

Key words: High-speed trains, Crosswind, Embankment, Safety, Aerodynamic characteristics

1. Introduction

With the continuous speeding-up of the train, the aerodynamic performance of...
the train under the crosswind embankment is an important research direction in the aerodynamics of the train. Under the influence of crosswind, not only the train air resistance, lift force and horizontal force increase rapidly, but also the transverse stability of the train is affected, which will cause the train to capsize in some situations. In order to make the train safely go through the wind area, the train aerodynamic characteristics of wind environment, wind-embankment-model coupling train aerodynamics characteristics and train operation safety guarantee system research must be carried out. In this paper, the aerodynamic characteristics and safety of the embankment under the influence of horizontal wind are studied in combination with the aerodynamics of high-speed train and the dynamics of vehicle system. Embankment road conditions established by high-speed train numerical calculation model, aerodynamic load on the body and train flow field around the structure are analyzed in detail. By establishing multibody system dynamics model of high-speed trains, the aerodynamic load as external load to the train can be calculated by the multibody system dynamics model, the crosswind on the safety of high-speed train running on embankment will be researched.

2. HIGH-SPEED TRAIN MODEL OF AERODYNAMICS CALCULATION

Train model uses eight marshalling form, i.e., it is formed by the head, the tail train of the same shape and six middle sections, retaining the main structure (frame and wheelset) of the bogie area, ignoring the pantograph, connection between two trains and other detail structure. The geometrical model of the train is shown in figure 1, and the embankment is shown in figure 2.

![Train geometry model](image1)

Figure 1. Train geometry model.

![Model of embankment](image2)

(a)Model of embankment leeward side  (b)Model of embankment windward side

Figure 2. The geometry of the train on the embankment.

Unstructured grids are applied. There are more grids in the front, the bogie
area, the body, tail flow and other areas where there is intense change of airflow. The total number of grids is 70 million.

Research and analysis on different road conditions of wind field find that, the wind speed at the monitoring point is linear to the corresponding inlet velocity and the specific value is a constant. This constant is usually called the wind speed coefficient. The wind speed coefficient of the 10m embankment is 1.277.

3. HIGH-SPEED TRAIN MODEL OF MULTI-BODY SYSTEM DYNAMICS

High-speed train is a complex multi-body system. The interaction and relative movement are not only between the various components of, but also between the wheel and the wheel. The random aerodynamic load data obtained by the crossbar of the train are loaded into the multi-body system dynamics model of the high-speed train to analyze the operational safety of the high-speed train.

![Figure 3. Eight section dynamic model](image)

4. THE DYNAMIC PERFORMANCE OF TRAINS WITH CROSSWIND ON EMBANKMENT

4.1 High-speed train surface pressure distribution

Figure 4 and Figure 5 show the train at 200km/h speed with the wind speed 15m/s in the crosswind environment, the first train and tail train on the windward side and leeward side of the pressure cloud.

![Figure 4. Head vehicle pressure cloud chart](image)

(a) First train windward side pressure cloud chart (b) First train leeward side pressure cloud chart

Figure 4. Head vehicle pressure cloud chart.
Figure 4 and Figure 5 show that the maximum positive pressure zone of the first train is biased towards the windward side of the nose of the head, and the largest negative pressure zone occurs in the leeward side of the streamlined and the body of the transition surface. Due to the impact of side wind, high-speed train windward side and leeward side flow are asymmetric, and the distribution of the vehicle surface pressure on both sides is different. In the body of the windward side for the majority it is positive pressure, transition arc on the positive pressure is decreased rapidly and turns to negative pressure from the top side of the train, and the leeward side of the train is negative pressure. In the windward side area, the positive pressure of the streamlined area is larger than that of the windward side. The negative pressure in the streamline area is smaller than that in the leeward side.

4.2 Aerodynamic performance of trains in crosswind environment

Figures 6 shows the aerodynamic load of each segment of the vehicle when the train running under crosswind at different speeds in the wind speed is 15m/s both on the windward side of the 10m embankment and on the lee side of the 10m embankment. In the form of histogram, the aerodynamic load of each section is more visually contrasted.
Figure 6. Crosswind wind speed 15m/s, 10m embankment with different speed train aerodynamic load comparison.

It can be seen from Figure 6 that the trains run at 160km/h, 200km/h, 250km/h and 300km/h respectively at the wind speed of 15m/s, the results are as follows:

(1) The resistance of the tail train is obviously larger than that of the middle train, Intermediate train resistance is slightly larger than first train, the other middle trains have little difference in resistance; With the increase of train speed, the resistance to the train also increases rapidly; the resistance of the train running on the windward side is greater than that on the lee side.

(2) Affected by the impact of the airflow, the first train produces downward component force to offset partial lift so that the head train is smaller than the other trains. As for six intermediate vehicles, the second section of the intermediate train has the largest lift force, the rest of the middle and tail trains do not have much lift. With the increase of train speed, the lift of intermediate and tail trains also
increases rapidly, but the lift of the first train is getting smaller; the lift on the windward side of the train is greater than the lift on the lee side.

(3) The side force of the head train is obviously larger than that of the middle train and the tail train; The side force of the tail train is opposite to the first train and the middle train; with the increase of train speed, the lateral force on the first and tail trains are rapidly increased the side force of the intermediate train is not obvious; the side force of the train running on the lee side is greater than that on the windward side.

(4) The side rolling moment of the middle train in the fifth, sixth section is opposite to that of the other trains; when the train is running on the windward side, the side rolling moment of the head train is opposite to that of the middle train and the side roll of the tail train; With the increase of train speed, the side roll moment of the head and tail trains is rapidly increased; the change of the side roll moment of the intermediate train is not obvious.

(5) The first train is impacted by the airflow; when the tail train is affected by the airflow, the nodding moment and the shaking moment are obviously larger than those of the middle train; with the increase of train speed, the nodding moment and the shaking moment of the first train and the tail train increase rapidly, the change of intermediate train is not obvious.

(6) The overturning moment of the first train is obviously larger than that of the middle train and the tail train; with the increase of train speed, the overturning moment of the first train and the middle train is increased rapidly, tail train is not obvious; when the train is on the lee side, the leeward side moment is greater than that on the windward side.

5 OPERATIONAL SAFETY OF HIGH - SPEED TRAINS ON EMBANKMENTS

5.1 Crosswind speed at 15m/s, Safety analysis of train operation

Five safety indexes of train operation can be calculated by applying the different vehicle speed, wind effect of 15m/s on the train aerodynamic loading to the dynamics model. Figure 7 is contrast chart of each safety index on 10m embankment with windward and leeward side. In the crosswind of 15m/s environment, the trains run at 160km/h, 200km/h, 250km/h, and 300km/h speeds respectively.
As can be seen from the above chart, the train running speed of 160km/h, 200km/h, 250km/h and 300km/h with wind speed of 15m/s crosswind environment, the results are as follows:

（1）The derailment coefficient of the head train is obviously larger than the middle and tail train. The derailment coefficient of the middle train and the tail train is not much different. Especially when the running speed is from 200km/h to 250km/h, 250km/h to 300km/h, the head train derailment coefficient becomes larger; when the train is running on the lee side, the derailment coefficient is greater than the windward side.

（2）The wheel load reduction rate of the first wheel is obviously larger than
that of the intermediate and the tail wheels, the wheel load reduction rate of the tail train is minimum. With the increase of train running speed, especially when the running speed is from 200km/h to 250km/h, 250km/h to 300km/h, the wheel load reduction rate of each vehicle increased rapidly. When the train is running on the leeward side, the wheel load reduction rate is greater than the wheel load reduction rate when running on the windward side.

(3) The overturning coefficient of the first train is larger than that of the middle and tail train. In the middle, the overturning coefficient of the second, fourth and fifth trains is larger, and the overturning coefficient of the other intermediate train is smaller. With the increase of train speed, especially when the running speed from 200km/h to 250km/h, 250km/h to 300km/h, the first train's tipping coefficient quickly becomes larger. When the train runs on the leeward side, the overturning coefficient is greater than that at the windward side.

(4) The traverse force of the first train wheel axle is obviously larger than that of the middle and tail wheel axle. With the increase of the running speed of the train, especially when the running speed is from 200km/h to 250km/h, 250km/h to 300km/h, the lateral force of the axle of the first train increases rapidly.

(5) The vertical force of the first wheel and rail is larger than the intermediate and the tail train; especially when the running speed is from 200km/h to 250km/h, 250km/h to 300km/h, the first train, the middle train and the tail train wheel of the wheel and the vertical force are rapidly becoming larger. The vertical force of the wheel and rail of the first, intermediate and tail train increases rapidly.

(6) It can be seen from various safety indexes that the safety indicators are within the limits of the relevant norms when the crosswind velocity is 15m/s, the speed of 250km/h speed range, but when the running speed of the train reaches 300km/h, the axle lateral force of the first train has exceeded the limit of the relevant specification. Overall, the train running on the leeward side is more dangerous than running on the windward side.

5.2 High-speed train safety domain calculation

According to the high-speed train test specifications, derailment coefficient of operation safety of high speed train, rate of wheel load reduction, lateral force of wheel and axle, wheel and rail vertical force to assess. The indexes should be less than the following limits: the derailment coefficient limit is 0.8, the wheel weight loss rate is limited to 0.8, and the horizontal force limit of the wheel axis is $10 + \frac{P_0}{3}$, where $P_0$ is the axial load. Track vertical force limit value is 170kN. By loading the aerodynamic load into the dynamic model, the dynamic response and
the safety index of the train operation are obtained, as shown in table I. Thus it can be seen that when the speed and wind speed are in line, the train is the most dangerous when running on the leeward.

<table>
<thead>
<tr>
<th>Operating condition</th>
<th>Derailment coefficient</th>
<th>Weight loss ratio</th>
<th>Transverse force/kN</th>
<th>Wheel rail vertical force/kN</th>
</tr>
</thead>
<tbody>
<tr>
<td>embankment windward</td>
<td>0.253</td>
<td>0.376</td>
<td>48.12</td>
<td>109.00</td>
</tr>
<tr>
<td>embankment leeward</td>
<td>0.711</td>
<td>0.722</td>
<td>53.27</td>
<td>116.48</td>
</tr>
</tbody>
</table>

Table II shows the comparison of the safe running speed domain when the emu is running on the windward side and leeward side of the 10m embankment. When the emu is running on the 10m embankment, its safe running speed domain meets the relevant specification requirements. At the same height of the embankment, the maximum permissible speed of the high speed train to safely operate on the windward side rails is greater than the maximum allowable speed for safe operation on the backside rails.

<table>
<thead>
<tr>
<th>Wind speed (m/s)</th>
<th>Maximum allowable speed (km/h)</th>
<th>Relevant specifications require speed (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windward side</td>
<td>261.51</td>
<td></td>
</tr>
<tr>
<td>Leeward side</td>
<td>255.47</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>250</td>
<td></td>
</tr>
</tbody>
</table>

6 CONCLUSION

This paper analyzes aerodynamic characteristics at different speeds when the high speed train is running on the windward side and the leeward side of the 5m and 10m embankments. According to kinetic parameters, nonlinear vehicle dynamics model is established. The calculation and analysis of the safety performance of high-speed train in cross wind environment are done by the model, we can draw the following conclusions:
(1) Under the action of horizontal wind, high-speed trains will no longer be a stagnation point. The head of the nasal tip and guide plate is the most-positive pressure zone located in the front the windward side of the tip, the flow field difference between the head and tail train is very large. The first train windward side is positive pressure area, the leeward side is negative pressure zone and the tail train windward is negative pressure. Resistance of the tail train is larger than other vehicles, the proportion is the highest, and with the increase of running speed, the resistance gradually becomes larger. The side force of the head train is the biggest, the tail train change is more complicated. Lift force of the change is the most complex. The windward side lift force is proportional to the running speed, while the back wind is inversely proportional.

(2) When the high-speed train is running in the wind at different speeds, the aerodynamic load and the dynamic performance of each train are quite different. Influences of cross wind are the greatest on aerodynamic performance and the stability of operation of the train head; the stability and safety of the first train is worst. We can run through stability of the first train analysis to evaluate the running stability of the whole vehicle. The higher the speed of the train is, the greater is the dynamic performance parameters of the head train.

(3) The safe running speed domain of the train running on the embankment is calculated. The embankment windward and leeward side of the safety index are respectively calculated. The calculation results show that leeward side is more dangerous than the windward side and shows the safe operation of the domain of the windward and leeward side. The embankment on the high-speed train running safety domain is ultimately obtained.

REFERENCES