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Dynamic Numerical Simulation of a High Speed Train Passing Through Tunnel

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Abstract: Internal pressure waves will be caused when high speed train travels through tunnels, which induce big pneumatic loads for car body. Tunnel pressure wave problem is the key factor which must be considered during the design of high speed train and the air ventilation system. Based on three - dimensional unsteady incompressible flow Navier - Stokes equations, the large eddy simulation (LES) turbulence model and dynamic mesh algorithm that ground is stationary but the train is moving is utilized to make dynamic numerical simulation computations for CRH2 high - speed train which is passing through a 100 m tunnel at a speed of 100 m/s. The results show that when the headstock of the train passes through a tunnel, a positive pressure wave is generated in front of the headstock of the train which propagates along the tunnel towards the exit and reflects when reaching the exit, and it becomes a negative pressure wave which propagates towards the entrance. The propagation and reflection of the pressure wave dramatically change the pressure of the air in the tunnel, which seriously affects safe and smooth running of the trains.

Key words: aerodynamics; large eddy simulation; dynamic mesh

中图分类号:TB533+.2　　**文献标志码:**A

Introduction

Development in train industry in the last century led to a new generation of high - speed trains. Aerodynamic loads in train - passing problems are becoming increasingly important due to the booming development of high - speed railways and their effects on the surrounding buildings[1-4]. Among them the most serious and typical case is that trains pass through tunnel. Recent investigations mainly focus on real vehicle tests, scaled model experiments and numerical simulations[5-6].

Many researchers studied experimentally the flow around two high - speed train passing by each other at the same speed while others used numerical techniques[7-11]. At the present time, wind tunnel experimental methods of static trains in relative flowing air have been widely carried out[12-14], but the dynamic numerical simulation method has rarely been used.

In this paper, we aim to use the dynamic numerical simulation method to simulate a high - speed train passing through tunnel and analyze the propagation and reflection of the pressure wave induced during this process.

1　Numerical model and method

1.1　Large Eddy Simulation (LES)

In LES, large eddies are solved directly, and the influ-

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作者简介:徐 伟(1987-),男,江西宜春人,博士生,主要从事流致振动方面的研究,(E-mail)xw4996@163.com ences of the small – scale eddies on the large – scale eddies are modeled[6]. Thus, the incompressible Navier – Stokes equations and continuity equation are filtered using an implicit spatial filter. The resulting filtered equations are:

$$\frac{\partial \bar{u}_i}{\partial x_i} = 0$$

$$\frac{\partial}{\partial t}(\bar{u}_i) + \frac{\partial}{\partial x_j}(\bar{u}_i \bar{u}_j) = -\frac{\partial \bar{p}}{\rho \partial x_i} + \frac{\partial}{\partial x_j}\left(\nu \frac{\partial \bar{u}_i}{\partial x_j}\right) - \frac{\partial \tau_{ij}}{\rho \partial x_j} \quad (1)$$

where $\bar{u}_i$ and $\bar{p}$ are the resolved filtered velocity and pressure, respectively, while $\tau_{ij} = \rho \overline{u_i u_j} - \rho \bar{u}_i \bar{u}_j$ are the subgrid scale (SGS) stresses. The subgrid scale stresses are the contribution of the small scales, and the unresolved stresses are unknown and must be modeled. The Smagorinsky – Lilly model is used to model the SGS stresses.

1.2 Dynamic mesh method

Dynamic layering method has been used to dynamically simulate motion of a high – speed train. In prismatic or hexahedral mesh zones, it can be used to add or remove layers of cells adjacent to a moving boundary, based on the height of the layer adjacent to the moving surface. The layer of cells adjacent to the moving boundary is split or merged with the layer of cells next to it based on the ideal layer height.

1.3 Physical model of the train

The real and whole train comprised a series of connected railroad and one or more locomotives, but in this work, the simplified China Railways High – speed 2 (CRH2) high – speed train model consists of three parts, a head car (HC), a middle car (MC) and a tail car (TC), and length are 25.5 m, 25 m and 25.5 m respectively (see Fig. 1). The train body is of a similar cylindrical shape with a height 3.7m, a width 3.38m, and a total length 76m. The flow field structure around train is similar between a curtate train model and a real train model[1].

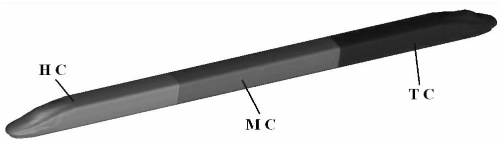


Fig. 1 Sketch of the train model

1.4 Mesh topology

Computational region is completely made up of hexahedral mesh cells. Fig. 2 shows mesh of the model when the distance between head car and tunnel entrance is 50 m. There are two type of computational region in the present paper. One is a cube used in the Section 2.1 with a length of 360 m, a width of 80 m, and a height of 40 m. The other is two cubes connected by a cylinder (Section 2.2), and the two cubes are of the same size with the cube using in Section 2.1. The cylinder has the length of 100 m.

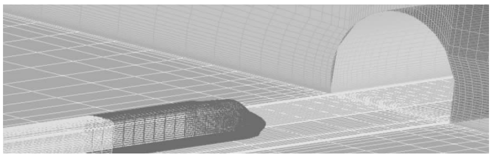


Fig. 2 Sketch of the mesh grid

2 Numerical results and discussion

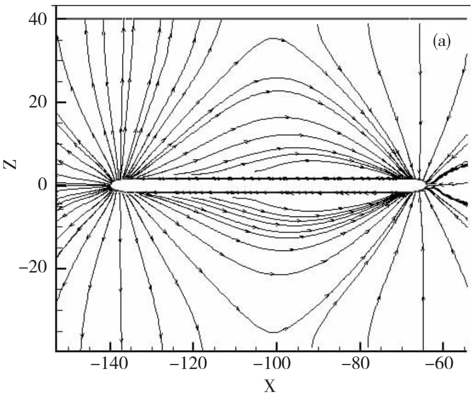
2.1 Differences between dynamic numerical simulation and wind tunnel experimental method

Side force coefficient of the train with 70m/s are respectively -6.33×10^{-4} and 9.77×10^{-5} by the dynamic mesh method and wind tunnel experimental method (motionless mesh) on the ground plane with no crosswind. The flow field structures around train are almost mirror symmetry, but they are completely different[1]. Fig. 3 shows streamlined diagram on the central nose of head car section with the two methods. As shown in Fig. 3(a), the flow field is similar to segistration of point source and point sink with moving train: the nose resembles the point source, and tail resembles the point sink. Fig. 3(b) is the usual flow field around train. Streamlined diagram on the ground section with two methods are shown in Fig. 4, and it shows same result.

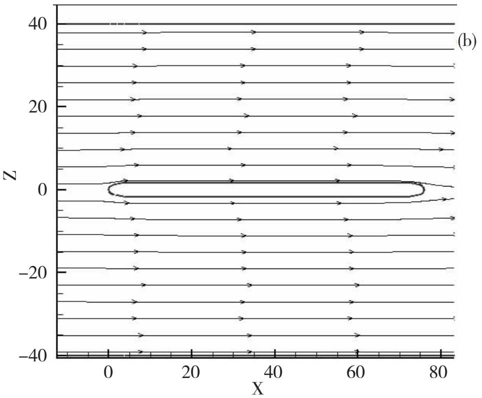
In the wind tunnel experimental method, the grid system is fixed during the whole computation process and the effect of train motion is represented by relative flowing air. In the dynamic mesh method, however, the grids adjoining to the train are updated at each time step based on the actual motion of the train. Thus, the moving boundaries of the train can be accurately tracked during the simulation. And it is found that the flow field structure around train predicted by using the dynamic mesh method are in good agreement with the model tunnel experiment carried out by Bell[3].

2.2 Pressure wave induced by a train passing through tunnel

When the train runs at a high speed in open air, the compressed air on the front end of the train is free to spread

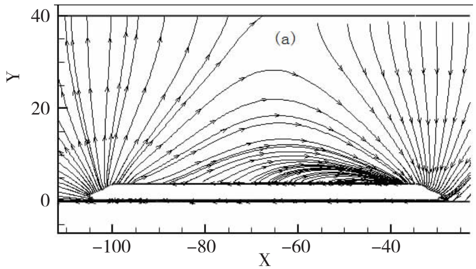


(a) dynamic numerical simulation

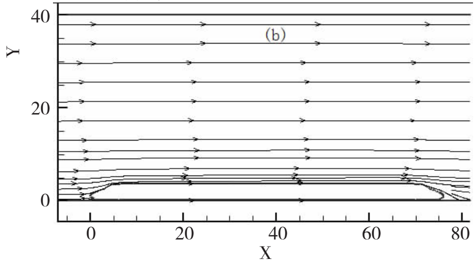


(b) static numerical simulation

Fig. 3 Streamlined diagram on the central nose of head car section with 70 m/s



(a) dynamic numerical simulation



(b) static numerical simulation

Fig. 4 Streamlined diagram on the ground section with 70 m/s

out and the air pressure slightly changes on the surface of car body. However, when the train enters into the tunnel at a high speed, air flow is blocked due to constraints by the tunnel so that the front end air of the train is compressed, causing the air pressure to increase suddenly and the formation of compression waves that propagate at sonic velocity.

Take the trains passing a tunnel with the length of 100 m at the speed of 100 m/s as an illustration. The original distance of between head car and tunnel entrance is -50 m, time of the trains passing through (when distance between tail car and tunnel exit is 50 m) is about 3 s. The pressure contours on the central nose of head car section at the time of 1s is shown in Fig. 5. It shows some air around the train flows forward with the train and the remaining air pushed aside by the train flows to the rear of the train through the limited space formed by the train and the tunnel.

Fig. 6 shows the pressure time history curve of each monitoring point. The distance between the pressure monitoring points A, B, C, D, E and the tunnel entrance is -10 m,5 m,50 m,95 m,110 m respectively.

The pressure monitoring points A and E which locate outside the tunnel basically have the same variation tendency. When the train passes through the monitoring point, the pressure at the monitoring point will undergo pressure change along the train. The pressure monitoring point C, which is just at the middle of the tunnel, has a complex pressure change. When the train head enters into the tunnel, since the absolute pressure at the head is higher than the atmospheric pressure, air flows to the outside of the tunnel entrance. A high pressure area named compression wave forms in front of the train and propagates along the tunnel towards the exit. So the pressure at the monitoring point C is higher than the atmospheric pressure because of the compression wave. When the train passes through, the pressure will change just as the pressure monitoring points A and E. When the train tail exits the tunnel, a low pressure area named expansion wave forms behind the train, and it propagates along the tunnel towards the entrance. The expansion wave makes the pressure at the monitoring point C lower than the atmospheric pressure. The influence of tunnel pressure wave for the pressure monitoring points B and D, which is near the tunnel opening, is smaller than that of pressure monitoring point C, so they have a smaller amplitude of pressure variation.

The maximum pressure of first compression wave when train is entering the tunnel is 1500 Pa, And The force generated by the pressure wave affects safe running of the trains.

Fig. 5　The pressure contour at the middle plane of the tunnel

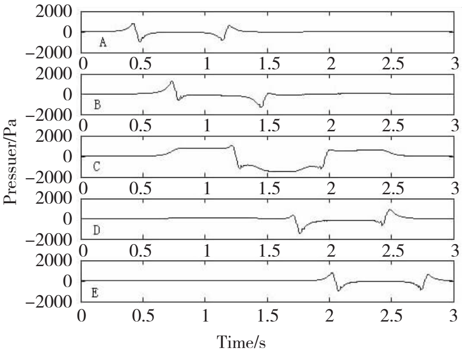


Fig. 6　The pressure time curves of the monitor points

3　Conclusion

In the investigative methods of high – speed train aerodynamics, wind tunnel experimental methods of static train with relative flowing air and dynamic mesh methods of moving train are completely different, and the method of moving model is correct.

When the train is passing through tunnel, a positive pressure wave is generated in the front end of the train. It propagates along the tunnel towards the exit and gets reflected when reaching the exit, becoming a negative pressure wave that propagates towards the entrance. The propagation and reflection of the pressure wave greatly change the pressure of the air in the tunnel, which affects safe running of the trains.

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高速列车通过隧道时动态数值模拟

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摘 要:高速列车通过隧道时会引起较大的隧道内压力波动,对车体造成较大的气动载荷,是高速列车车体设计和通风系统设计中所必须要考虑的问题。基于三维非定常不可压缩流动的纳维-斯托克斯方程,采用大涡模拟的湍流模型和地面静止而列车移动的动网格算法,对 CRH2 动车组以 100 m/s 的速度通过长 100 m 的隧道进行了动态数值模拟计算。结果表明:当列车车头进入隧道时,车头前端会形成一个向隧道出口传播的正压波,到达隧道出口后反射,并形成一个向隧道入口传播的负压波,压力波的传播与反射使隧道内空气压力发生剧烈变化,严重影响列车的安全平稳运行。

关键词:气动力;大涡模拟;动网格