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Numerical Analysis of the Pressure Variation in Subway Tunnel When an On-Fire Train Runs at Different Speed

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ABSTRACT

When a subway train runs in the tunnel from one platform to next platform, there will be a pressure pulse both acting on the surface of train and tunnel. These pressure variation brings a significant noise and structure safety problems if the train speed is too large. What's worse is that the train is on-fire, it becomes more complex to study the pressure in tunnel. Hence, considering the piston effect, using the dynamic mesh method to simulate train's movement, this paper established a model including subway train, tunnel and platform to study the pressure variation in subway tunnel when the train runs at different speed. The results show that pressure in tunnel are both affected by the moving of train and burning of fire. With the increasing of train speed, pressure in train surface and tunnel surface changes greater, they are presenting a similar variation characteristics like sine curve.

1. INTRODUCTION

With the development of economy and growing of urban traffic pressure, underground railway transportation become a very important method to remit these problems[1-2]. When a subway train runs at a relative high speed in the narrow tunnel, there will be strong piston effect as the blockage of vehicle, the highly positive pressure formed with the moving of vehicle will influence the safety of facilities in the tunnel and structure itself. It is mainly decided by the moving speed of train. At the same time, once a fire suddenly occurs in these running process, which will make it more complex to study the pressure variation. It not only contains the aerodynamic pressure, but also the fire-wind pressure generated by the combustion of vehicle.

In recent years, a lot of work have been done on the aerodynamic problems in subway tunnel, but there's little to study the pressure variation when a on-fire subway runs in the tunnel. Sun ZhenXu[3] studied the critical diameters of the subway tunnel

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and different airtight of train when trains runs at 120 and 140 km/h based on passengers' aural discomfort caused by rail tunnel pressure variation. Joong-Keun Choi[4] analyzed the aerodynamic drag when speed increases from 100 km/h to 200 km/h, and the influence of train nose length and the tunnel cross-sectional area on the aerodynamic drag. Otherwise, Marta López González[5] analyzed the influence of the piston effect in the longitudinal ventilation system of subway. He is mainly aiming at to study the temperature in tunnel without considering pressure variation.

This paper established a model including subway train, tunnel and platform, using the dynamic mesh method to simulate train's movement, considering the piston effect and the action of fire-wind pressure, numerically studied the pressure variation in subway tunnel when the train ran at different speed.

2. GEOMETRY MODEL

Vehicle model used in this paper is a 1:1 three-dimensional 6-cars subway train, each car has a height of 3.8m, width of 2.8m, length of 19.5m, and the cross sectional area of subway train is 9.2m^2 (Fig.1.). Model ignores some parts like wipers etc. which has little effects on the aerodynamic performance, retains the important parts such as bogie and equipment cabin. Fire source located in the bottom of the first car.

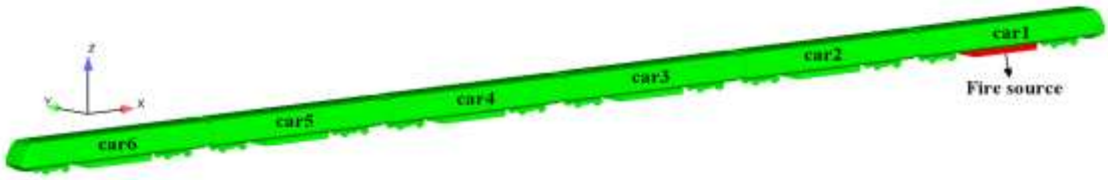


Fig.1 Vehicle model

The interval length between two connected platforms is 1500m, and tunnel height is 4.565m, blockage ratio is up to 0.453.

The whole process contains three sections: 1. Subway train starts running at a uniform speed (50km/h, 60km/h, 70km/h and 80km/h respectively) from X=350m for 10s; 2. A fire occurs in the first car, train starts to decelerate at -1m/s^2 then stop in the center of tunnel at 30s; 3. Train stops in the center of tunnel (X=750m) for 4mins.

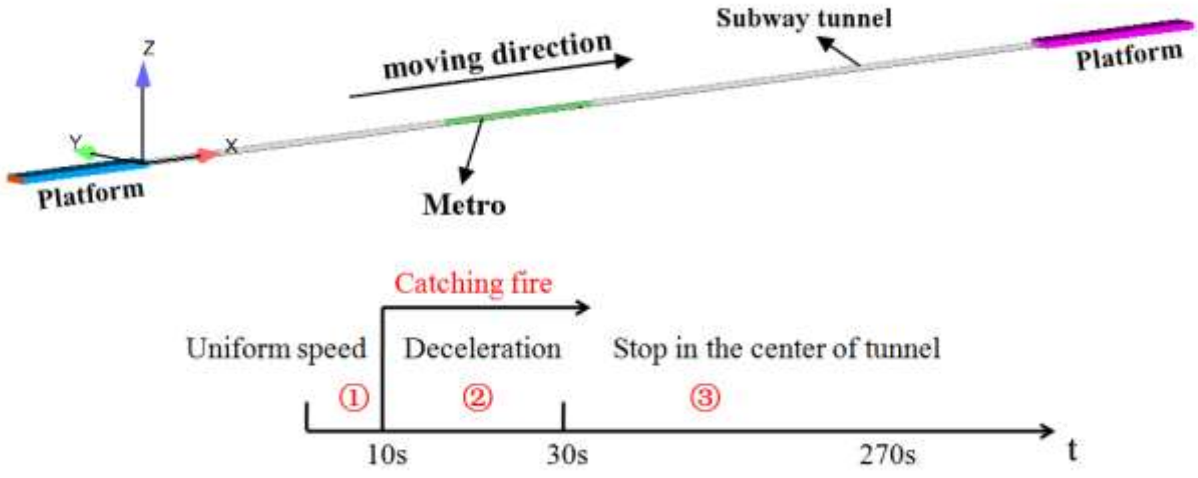


Fig.2 Scene setting

3. RESULTS AND DISCUSSION

3.1 Pressure distribution

Fig.3.shows that the pressure around subway train varies with time when it passes through the subway tunnel at the initial speed of 70km/h and HRR is set as 10.5MW. At 10s, it can be seen that pressure in front of head car is much higher than the pressure behind tail car when the train runs at a uniform speed. In this period, air in front of head car are continuously compressed by the moving of train, which makes the positive pressure grow fast. At the same time, air behind tail car will be absorbed to move forward with train running, and the pressure become negative with the volume expanding. After 10s, train catches a fire and then starts to slow down, the piston effect gradually weakened with the decreasing of speed and fire-wind pressure increase by degrees. Difference of pressure between upstream and downstream is becoming less and less. At 30s, pressure in upstream becomes higher than downstream instead when the subway stops in the center of tunnel under the action of the residual piston wind. After 60s of stopping(t=90s), pressure around train decrease nearly 700Pa comparing with t=30s, and the difference of pressure decline to less than 50Pa. At 150s, upstream pressure is still higher than downstream and pressure in the whole tunnel become very small, it can be concluded that there is still a tiny piston wind.3mins later, piston wind have almost disappeared and the air upstream of fire source starts to flow back under the action of fire-wind pressure. Pressure in the tunnel are mainly decided by the fire-wind pressure after 210s.

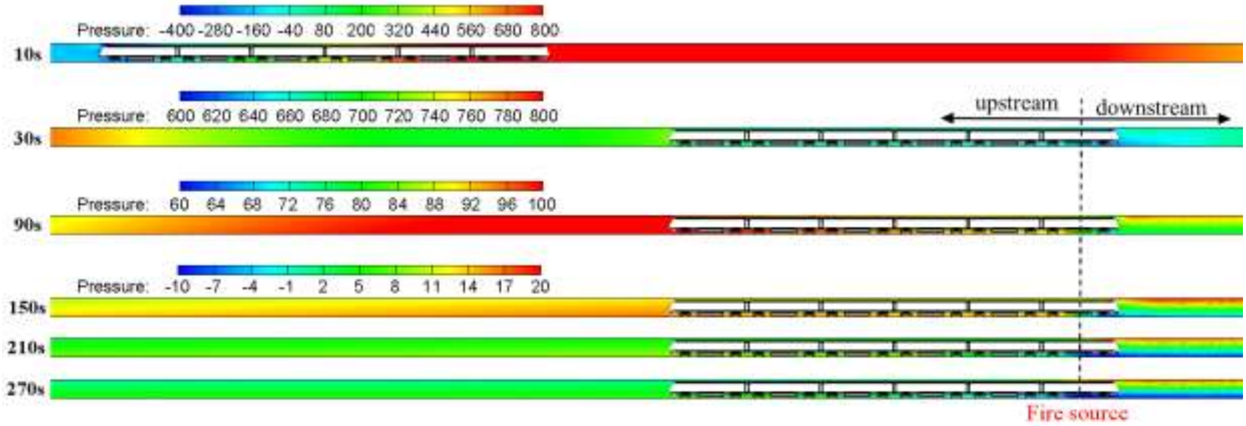


Fig.3 Pressure around train varying with time

To study the pressure variation in the whole process, three typical locations were selected when subway train runs at the speed of 70km/h: X=300m, it located at the roof of tunnel behind tail car before train starting to move; X=500m, a position located in the way train ran to the center of tunnel; X=800m, it located downstream of train after it stopped. It can be seen that pressure fluctuation is obvious in section1 and section 2, and pressure in these three positions are both close to 0Pa after 90s. At the position of X=300m, pressure stays negative in section1, then increases after train starting to decelerate; In X=500m, positive pressure gradually decreases when the train runs to this position, while it becomes negative after train pass through it; X=800m,pressure is invariably influenced by the piston wind and fire-wind pressure at the same time as it always in the front of train, and it constantly changes between positive pressure and negative pressure.

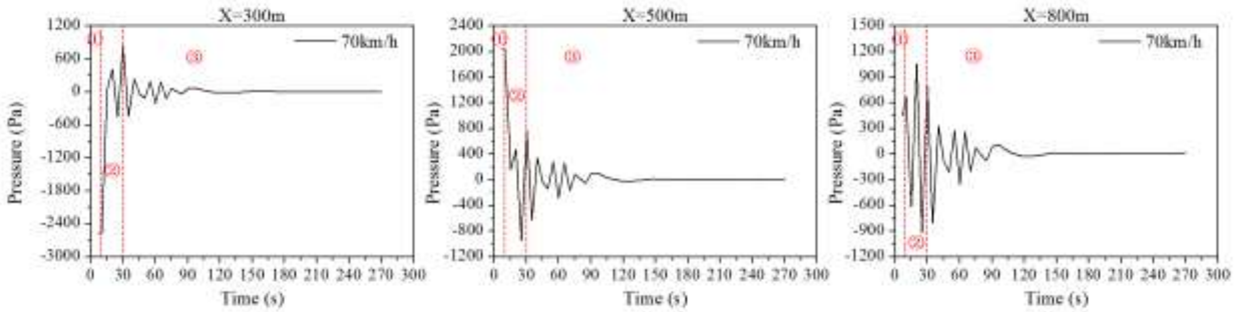
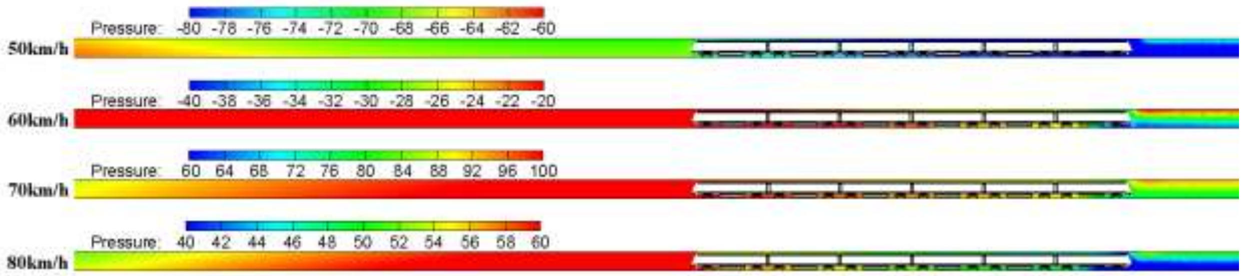


Fig.4 Pressure variation with time of three typical locations

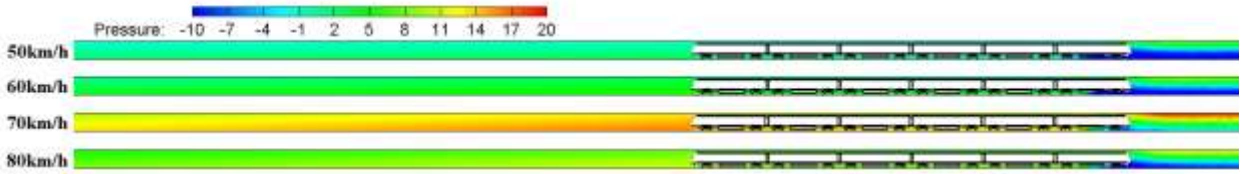
3.2 Influence of train speed

Figure 6 shows the pressure distribution at three typical moments when train runs at the speed of 50km/h, 60km/h, 70km/h and 80km/h respectively. At 30s, pressure in the tunnel are positive in these four situations, the faster train runs, the larger positive pressure is. When train speed is less than 60km/h, pressure around vehicle is less than 500Pa; while train runs faster than 70km/h, pressure is bigger than 500Pa. At 90s, pressure turns negative if train speed is less than 60km/h and it is still positive in other two conditions, that is because the pressure in the tunnel is mainly influenced by the piston wind in the initial stage of stopping. Lower speed can only provide smaller piston wind. The larger train speed is, the smaller difference of pressure is. At 150s, pressure become very small, train speed has little influence on the pressure variation in the subway tunnel.

(a) t=30s



(b) t=90s



(c) t=150s

Fig.6 Pressure distribution in different train speed: (a) t=30s; (b) t=90s; (c) t=150s

Figure 7 shows the pressure of three typical locations variation with train speed at three typical moments. At 20s, pressure in X=500m has a intense fluctuations as it locates in the middle of deceleration process. It decreases nearly 90% when train speed increases from 50km/h to 60km/h. They are both increasing first and then decrease if speed is faster than 60km/h. At 30s, three positions present a similar variation characteristics like sine curve. It peaks highest when train speed is 70km/h. After train stopping 60s(t=90s), pressure decreases sharply as the weakened piston effect, train speed has little influence of pressure variation in tunnel at that time.

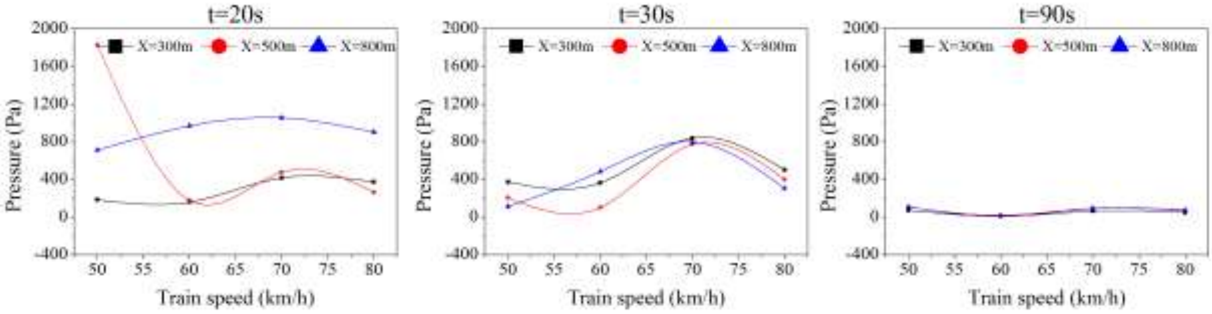


Fig.7 Pressure variation with train speed: (a) t=20s; (b) t=30s; (c) t=90s

4. CONCLUSIONS

Under the combined action of train's movement and fire of vehicle, pressure in subway tunnel mainly influenced by two parts: piston wind and fire-wind pressure. The influence of train speed to pressure variation in subway tunnel can be summarized as below:

1. Three positions present a similar variation characteristics like sine curve.
2. 1min after stopping, pressure turns negative if train speed is less than 60km/h and it is still positive in other two conditions.
3. 2mins later, train speed has little influence on the pressure variation in the subway tunnel.

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