THE NUMERICAL INVESTIGATION OF HIGH SPEED TRAIN-TUNNEL INTERACTION AT ENTRANCE AND EXIT

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Abstract: *In the study, the flow pattern due to the interaction between a high-speed train and the tunnel at the model scale was analyzed. Six different tunnel entry geometries were used variably for a single train speed. The most important issues as a condition of comfort in high speed trains are noise and vibration. In particular, flow-induced noise is triggered by pressure changes in the flow. For each geometry, the pressure changes at the tunnel entrance and at the tunnel exit are plotted with depending on time. As a result, the least amount of pressure change was found in the tunnel entrance model with openings in the side walls.*

Keywords: COMPUTATIONAL FLUID DYNAMICS, HIGH SPEED TRAINS, OVERSET MESH, PRESSURE CHANGES

1. Introduction

In recent decades, with the increase of international economic activities, transportation have become an important issue all over the world. The amount of passengers and goods that can be carried in a single time and duration of transportation are critical parameters in economic transportation systems. For this reason, railway transportation is an important alternative by being faster than sea transport and having more load carrying capacity than airlines. Although the cargo capacities of the vehicles used in railway are high, as well as marine transport, the transportation time is not short enough. Thus, there is an increasing afford to speed up the vehicles on the sea and railway transport. However, the increase of the speed of vehicles causes some problems, which are mainly drag, noise and vibration. Especially in high speed rail systems, most of the energy wasted to overcome the drag of the air with the speed up of the vehicle. Besides, when the rail systems are considered, the vibration and the noise are important issues due to the interaction of vehicles with non-vehicle elements such as tunnels. This problems creates an undesirable environment considering the passenger comfort.

In the literature, it is possible to reach some studies examining this problem. Ogawa and Fujii [1] numerically studied the flow induced by a high-speed train moving in a tunnel using three-dimensional compressible Navier-Stokes equations. In time-dependent solutions, the focus is on the compression wave that causes the noise burst at the entrance and exit of the tunnel. The calculated pressure increments in the tunnel are compared with the measured data. It is stated that the compression wave in the tunnel depends on the tunnel position. Kwon et al. [2] studied the effect of the high-speed train nose geometry on explosion in their work and optimized the nose geometry using axial symmetric Euler equations and response surface methodology. By using the results of the study, they have examined the mechanism of train-tunnel interaction. Shin and Park [3] investigated the compression wave, which is similar to the piston effect, created at the tunnel entrance of the high speed train. They have modeled the problem with three-dimensional, time-dependent Navier-Stokes equations and the movement of the train with the multi-block slider approach. At the entrance of the tunnel, the pressure that induced by the piston effect was increased on region around train nose, and the drag force acting on the train was 2.7 times higher than the value outside the tunnel. Xiang et al. [4] have numerically investigated the compression waves that high-speed trains creates at tunnel entrances. They have seen that the compression wave is caused by the development of a large number of waves. Three equations have been proposed to understand the train Mach number, the ventilation rate and the effect of the ventilation zone on the compression wave.

When these studies are examined, it is seen that most of these studies considering the high speeds with compressible fluid. In this study, the effect of different tunnel entrance geometries on pressure gradient in train-tunnel interaction at low speed voyage was investigated. In this context, six different entrance concepts were determined and flow analyzes were made for each geometries. The results were analyzed in terms of pressure changes.

2. Mathematical Model

The equations that model the three-dimensional, incompressible, time-dependent turbulent flow around the high-speed train, which are Navier-Stokes equations, are given below. The k-epsilon turbulence model is used to model the turbulent behavior [5].

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (1)$$

$$\frac{\partial \rho u}{\partial t}+\frac{\partial}{\partial x}\left(\rho u^2+p-\tau_{xx}\right)+\frac{\partial}{\partial y}\left(\rho uv-\tau_{xy}\right)+\frac{\partial}{\partial z}\left(\rho uw-\tau_{xz}\right)=\rho f_x \quad (2)$$

$$\frac{\partial \rho v}{\partial t}+\frac{\partial}{\partial x}\left(\rho uv-\tau_{xy}\right)+\frac{\partial}{\partial y}\left(\rho v^2+p-\tau_{yy}\right)+\frac{\partial}{\partial z}\left(\rho vw-\tau_{yz}\right)=\rho f_y \quad (3)$$

$$\frac{\partial \rho w}{\partial t}+\frac{\partial}{\partial x}\left(\rho uw-\tau_{xz}\right)+\frac{\partial}{\partial y}\left(\rho vw-\tau_{yz}\right)+\frac{\partial}{\partial z}\left(\rho w^2+p-\tau_{zz}\right)=\rho f_z \quad (4)$$

$$\frac{\partial k}{\partial t}+U_j\frac{\partial k}{\partial x_j}=\tau_{ij}\frac{\partial U_i}{\partial x_j}-\varepsilon+\frac{\partial}{\partial x_j}\left[\left(\nu+\nu_T/\sigma_k\right)\frac{\partial k}{\partial x_j}\right] \quad (5)$$

$$\frac{\partial \varepsilon}{\partial t}+U_j\frac{\partial \varepsilon}{\partial x_j}=C_{\varepsilon 1}\frac{\varepsilon}{k}\tau_{ij}\frac{\partial U_i}{\partial x_j}-C_{\varepsilon 2}\frac{\varepsilon^2}{k}+\frac{\partial}{\partial x_j}\left[\left(\nu+\nu_T/\sigma_\varepsilon\right)\frac{\partial \varepsilon}{\partial x_j}\right] \quad (6)$$

$$\nu_T=C_\mu k^2/\varepsilon \quad (7)$$

$$C_{\varepsilon 1}=1.44 \,\|\, C_{\varepsilon 2}=1.92 \,\|\, C_\mu=0.09 \,\|\, \sigma_k=1.0 \,\|\, \sigma_\varepsilon=1.3 \quad (8)$$

3. Numerical Method

The model train and model tunnel cross-sections used in the numerical study are shown in Fig. 1 Model height H_{train} = 980 mm, width B_{train} = 900 mm and is length L_{train} = 16000 mm, model tunnel main dimensions are tunnel diameter D_{tunnel} = 1250 mm and tunnel length L_{tunnel} = 47900 mm. Scale factor is chosen 1/10.

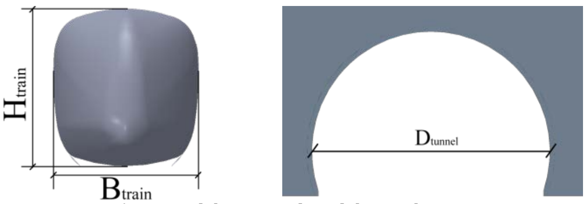

Fig. 1 *Model train and model tunnel cross-section views*

The speed of the model train is taken as 3 m / s which is equal to the 108 km/h for full scale. Fig. 2 shows tunnel entrance geometry variations.

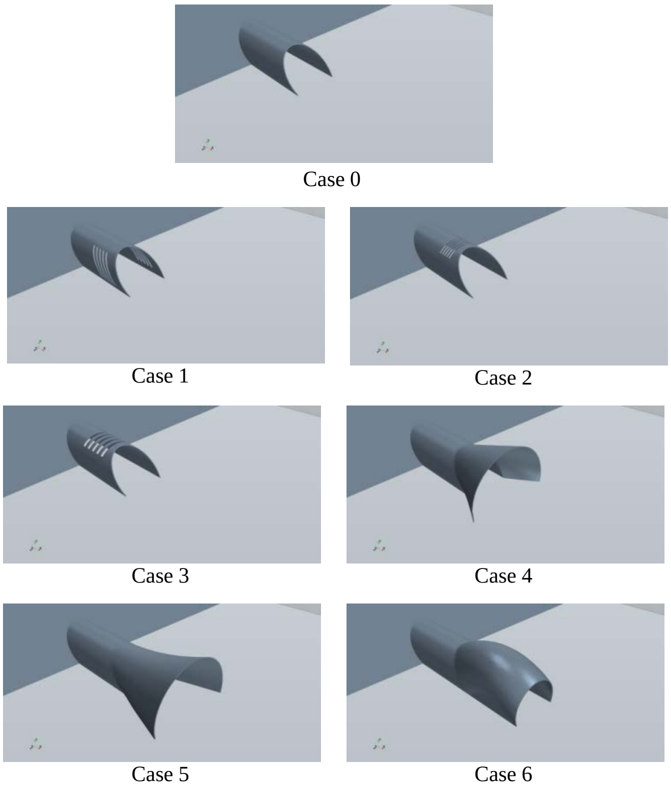

Fig. 2 *Tunnel entrance geometry variations*

Fig. 3 shows the solution grid for the domain used in the study. Solution domain is created by using unstructured hexahedral elements. As a result of solution grid dependency study, 1378300 grid elements were used in domain solution grid. Movement of the train is modeled with overset meshing technique. All computations are carried out via commercial code, CD ADAPCO Star-CCM+.

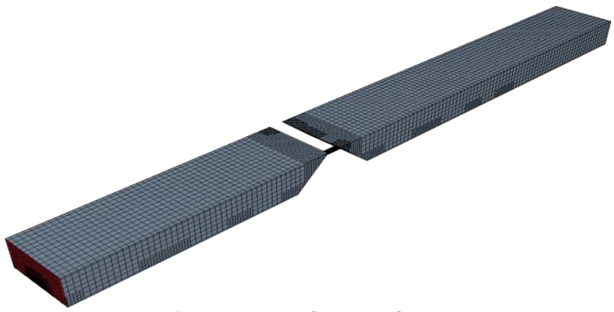

Fig. 3 *Domain solution grid scene*

4. Results

Fig. 4 shows the time-dependent pressure measurement locations at the inlet and outlet of the tunnel.

Fig. 4 *Measured inlet and outlet cross-sections*

The solution is completed with the voyage of the train, which is started from the outside of the tunnel, passing through it and going out of the tunnel again. The train's nose was entered the tunnel at the sixth second of the solution, while the tail was entered at the eleventh second. Besides, the nose and tail of the train was come out of the tunnel at the twentieth and twenty-fifth second of the solution, respectively. Fig. 5 shows the time-dependent pressure values for all geometries in the tunnel entrance section.

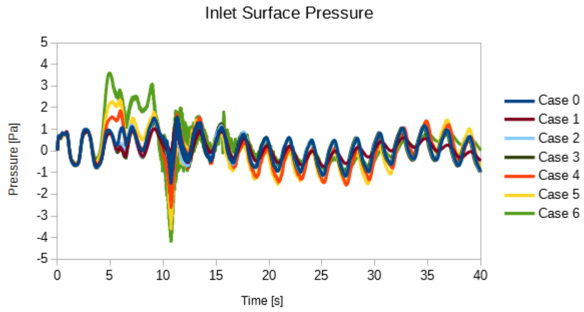

Fig. 5 *Time-dependent pressure values for all geometries at tunnel entrance section*

As can be shown in Fig.5, the same pressure values are obtained for all geometries at the beginning of the movement at the outside the tunnel. When the train gets closer to the tunnel entrance, it is seen that the pressure values are varying for different entrance geometries. The lowest pressure change was obtained in the “Case 1”, by considering the entrance of both the nose and the tail of the train. Besides that, when the entrance effects of the nose and tail regions of the train are compared, it is seen that the pressure variation is much higher in the tail zone. The maximum pressure variations were obtained in the "Case 6" geometry. Fig. 6 shows the time-dependent pressure values for all geometries in the tunnel exit section.

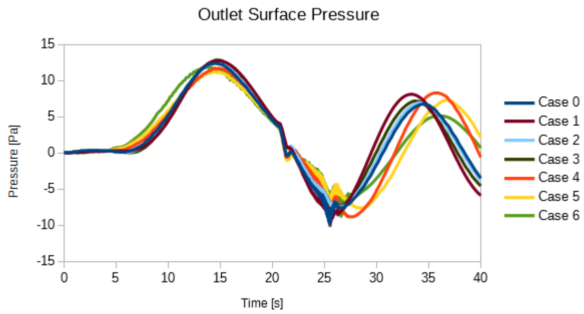

Fig. 6 *Time-dependent pressure values for all geometries in the tunnel exit section*

The tunnel exit pressure values are quite different from the tunnel entrance pressure values. A two-peaks curve is obtained at the outlet while an oscillatory pressure distribution is obtained at the inlet region. As mentioned before, at twentieth second, the train's nose region, and at twenty-fifth second, the tail region of the train came out from the tunnel. In contrast to the inlet zone, the minimum pressure variation is found in the "Case 5" geometry. However, it was observed that the maximum pressure change was obtained in the "Case 1" geometry.

5. Conclusion

Six different tunnel entrance geometries have been investigated in the study in order to investigate the high-speed train-tunnel interaction and to show the effect of different tunnel entrance geometries. The pressure values against time at entrance and exit of the tunnel are presented. When the results are examined, the lowest pressure variation for the tunnel entrance is obtained by the "Case 1" geometry, which has large openings on the top surface. On the other hand, the lowest pressure change for the tunnel exit is observed in the "Case 5" geometry, which is a parabolic nozzle. These sudden pressure variations may be explained by the aerodynamic structure formed by the movement of the train into a narrower area. When the optimal cases are considered, at the entrance of the tunnel, the high-pressured air in the nose region of the train is balanced by atmospheric air and the pressure change is reduced by the openings at the tunnel entrance. At tunnel exit, pressure variations are reduced, by the gradual movement of the high pressured air at the inside of the tunnel through the atmospheric pressure level, using the nozzle geometry.

6. References

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