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INVESTIGATION OF TEMPERATURE RISING MECHANISM IN LONG TUNNEL BY NUMERICAL SIMULATION

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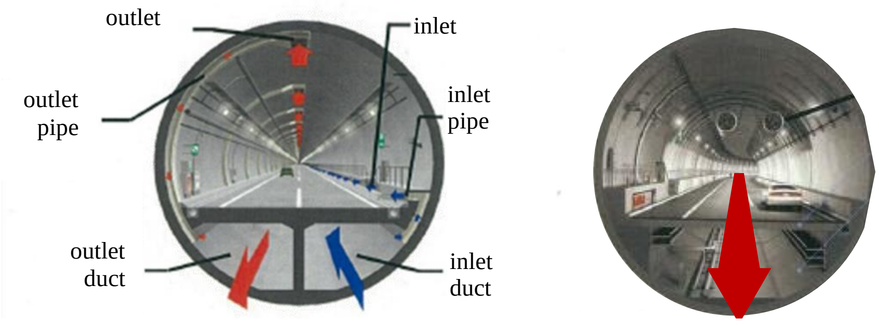
Abnormally high temperature inside the long, undergrounded tunnel is a problem in the urban area. As one of the countermeasures, a ventilation fan has been operated. However, the insufficient temperature reduction effect and high cost are an issue and improvement is required. In this study, in order to improve the operating plan of ventilation, the flow field and temperature distribution characteristics are clarified by computational thermal fluid analysis, and the operation of the optimum ventilation was decided. The dominant factors for the temperature rising were identified as traffic volume, lane axis wind speed, cross flow ventilation, and heat flux between tunnel body and air in tunnel. In the analysis, we focused on these four factors, and applied these factors obtained from long-term on-site measurement to the boundary condition and the initial condition. In addition, the amount of heat from vehicle traffic was calculated based on the measurement and the past report results. The analytical model is 1000 *m* partial tunnel section where the temperature rising was intense. The validation of numerical model was verified from the comparison between the analysis results and the measured values. It was confirmed that the effect of increasing lane axis wind speed as a countermeasure was not significant, and the ventilation amount of crosswind is recommended as 60 m^3/s.

Keywords: Heat flux, Ventilation, Computational thermal fluid analysis.

1 INTRODUCTION

The Yamate Tunnel is the longest road tunnel in Japan, which has 18,200 meters in length. There are inner tunnel and outer tunnel which have two lanes each. Two kinds of ventilation method as shown in Figure 1 are adopted according to the location. One is the cross flow method. This is a method of providing air supply and exhaust ducts in parallel with the roadway and simultaneously ventilating at various places in the tunnel. The other method is a longitudinal flow method, using the car flow and exhausting it at a stroke in a certain place. This long underground tunnel in the urban area has become a problem of high temperature inside the tunnel. In August, the average monthly temperature rises above 40 degrees regardless of day and night, and the maximum temperature becomes 48. 3 degrees as shown in Figure 2. The motorcycle driver and the inspection worker due to the high temperature inside the tunnel are in trouble in terms of the comfort and safety and this should be solved. As one of the countermeasures, ventilation fans have been operated. However, the insufficient temperature reduction effect and high cost are an issue and improvement is required. Therefore, in this study, in order to quantify temperature reduction effect of ventilation operation and to reduce cost, field measurement and 3 dimensional computational thermal fluid analysis were conducted.



(a) Cross flow method (b) Longitudinal flow method

Figure 1. Ventilation method (red arrow: exhaust, blue arrow: air supply).

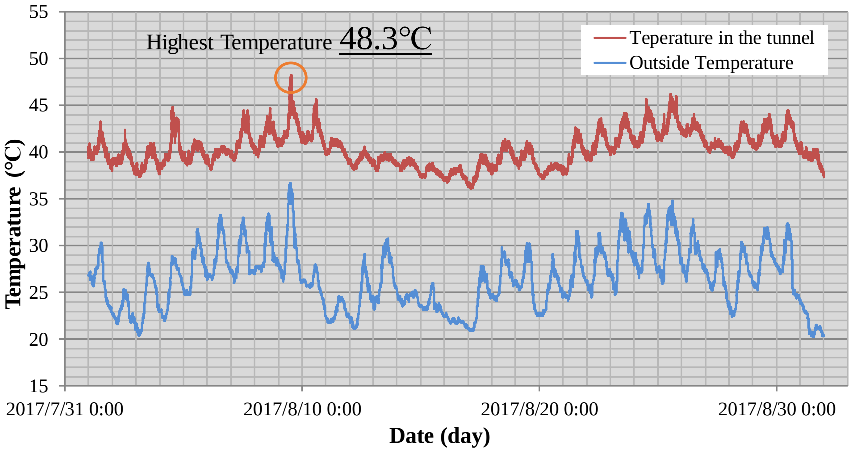
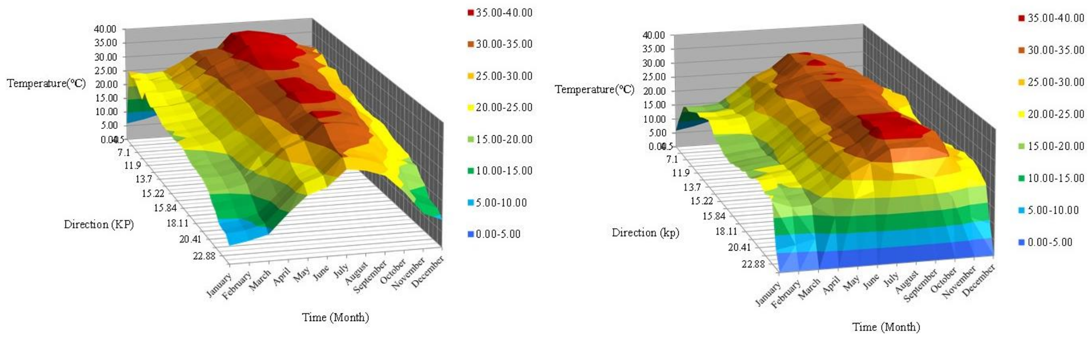


Figure 2. Temperature inside tunnel on August 2017.

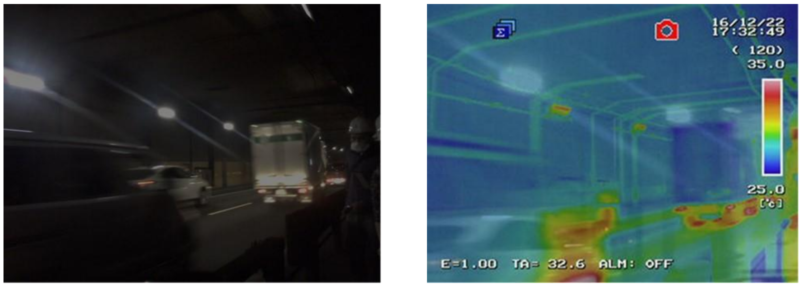
2 FIELD MEASUREMENT

Many kinds of observation data such as temperatures, number of cars, wind speed and heat flux between tunnel body and air in tunnel were obtained by Metropolitan Expressway Co. Ltd. and this research team. These data were sorted out and analyzed for figuring out the current situation and setting boundary condition of thermal fluid analysis. From the observation data, it was confirmed that the temperature rise on the downstream side of the tunnel is remarkable throughout the year for both sides of the Yamate tunnel as shown in Figure 3. In addition, temperature distribution inside tunnel taken by the thermal camera is shown in Figure 4. From this temperature distribution, the planar heat source was applied to the asphalt in thermal fluid analysis model.



(a) Inner tunnel (b) Outer tunnel

Figure 3. Annual temperature distribution in Tunnel.



(a) Photo taken by Camera (b) Photo taken by thermal Camera

Figure 4. Photos of inside of tunnel.

3 COMPUTATIONAL METHOD

3. 1 Numerical Set-up

A three-dimensional steady state analysis was conducted and a modified k-ε model was used for the turbulence model. The dominant factors for the temperature rising were identified as traffic volume, lane axis wind speed, cross flow ventilation, and heat flux between tunnel body and air in tunnel. In addition, planar heat source of the pavement part obtained from the long-term on-site measurement were applied to the boundary conditions. The details of numerical set-up and model are shown in Table 1 and Figure 5 respectively.

Table 1. Details of numerical model set-up.

Simulation software	StarCCM+
Turbulence Model	Revised k-ε model
Model length	1000 *m*
Boundary condition	
Tunnel body-air heat transfer	Convection
Pavement part	Planar heat source: Temperature: 28 ℃
Inlet duct	Velocity inlet: 4. 0 *m/s*, 26℃
Outlet duct	Velocity inlet: 3. 75 *m/s*, 29℃
Inlet	Velocity inlet: 2. 75 *m/s*, 25. 6℃
Outlet	Zero-pressure condition
Total exhaust heat quantity of vehicles	Input in air part


(a) Section plane view (b) Span-wise direction view

Figure 5. Numerical model.

The amount of exhaust heat generated by vehicle traffic are calculated based on the past report by Japanese Ministry of the Environment (2004) and numbers of vehicles. The analysis range was 1000 meters from the tunnel where the temperature rise was intense. The validation of numerical model was verified from the comparison between the analysis result and the actual measurement value as shown in Figure 6.

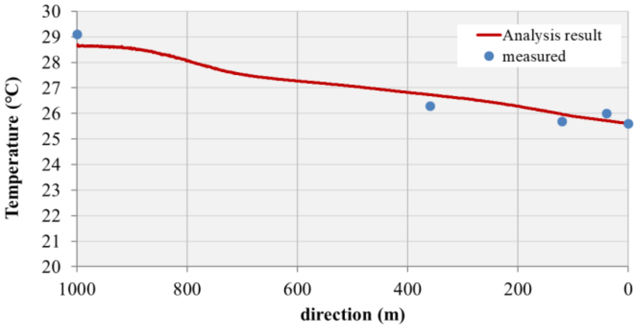


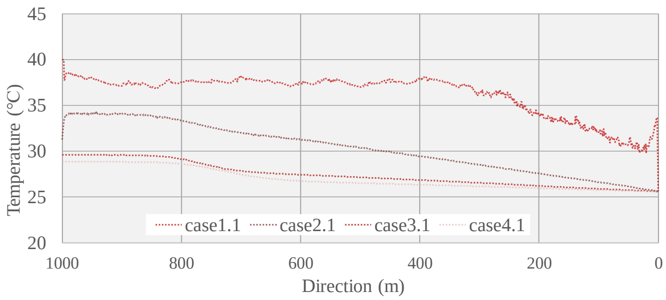
Figure 6. Temperature comparison between numerical result and measurement data.

4 NUMERICAL RESULTS

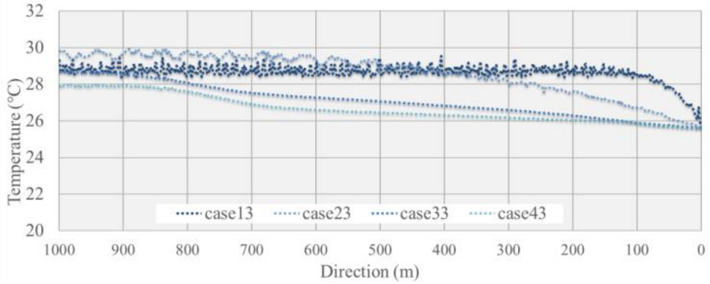
Table 2. Numerical cases.

No.	Lane direction wind speed [m/s]	Air volume of cross flow ventilation [m^3/s]	No.	Lane direction wind speed [m/s]	Air volume of cross flow ventilation [m^3/s]
Case11	0	0	Case12	0	30
Case21	0. 75	0	Case22	0. 75	30
Case31	2. 75	0	Case32	2. 75	30
Case41	4. 75	0	Case42	4. 75	30
Case13	0	60	Case14	0	120
Case23	0. 75	60	Case24	0. 75	120
Case33	2. 75	60	Case34	2. 75	120
Case43	4. 75	60	Case44	4. 75	120

We conducted a parametric study in which the cross flow ventilation air flow rate and longitudinal ventilation air flow rate (lane axial wind speed) were varied as shown in Table 2. The effectiveness of the longitudinal ventilation was confirmed from the analysis result in Figure 7(a) that temperature of cross-section increases by 9.13 degrees in case11 of w/o wind. However, Figure 7(b) shows that the effect of increasing lane axis wind speed as a countermeasure with cross flow ventilation was not significant. In addition, Figure 8 shows the temperature distribution at the height where people sense the temperature and Figure 9 shows the temperature distribution of cross section according to the air volume of cross flow ventilation. Table 3 summaries the average cross-sectional temperature according to air flow rate of cross-flow ventilation and the air temperature at the height where people sense the temperature. In case of air flow rates of the cross flow ventilation changes 60 m^3/s to 120 m^3/s, there is no change in the temperature at the height of people sensing position.



(a) W/O cross flow ventilation



W/ cross flow ventilation

Figure 7. Average temperature of cross section.

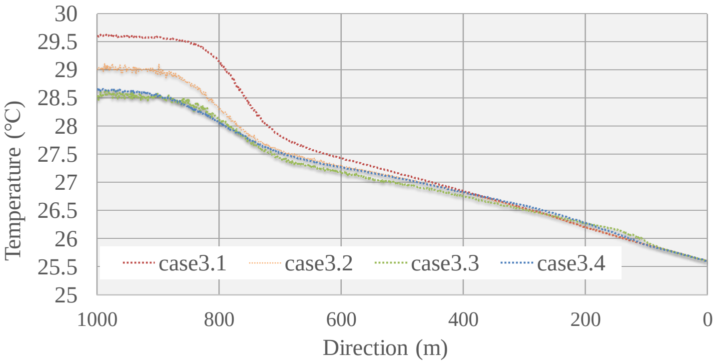
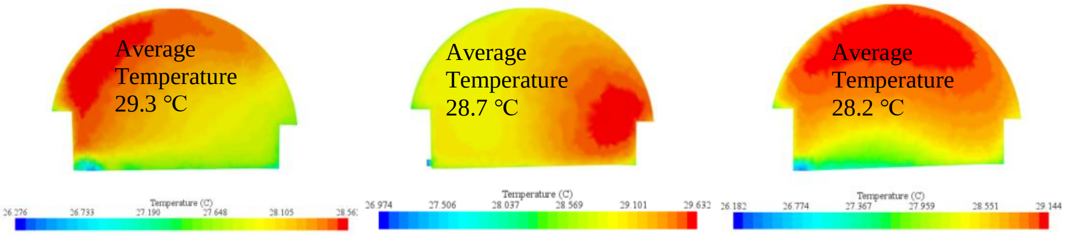


Figure 8. Temperature at the height where the user senses the temperature.



(a) 0 m^3/s (b) 60 m^3/s (c) 120 m^3/s

Figure 9. Temperature distribution of cross-section according to the air volume of cross flow ventilation.

5 CONCLUSIONS

Computational thermal fluid analysis and field measurement was conducted to investigate the mechanism of temperature rising in long urban tunnel. The dominant factors for the temperature rising were identified as traffic volume, lane axis wind speed, cross flow ventilation, and heat flux between tunnel body and air in tunnel. The effectiveness of the longitudinal ventilation without cross flow ventilation was confirmed from the analysis result while the effect of increasing lane axis wind speed (longitudinal ventilation) with cross flow ventilation was not significant and the optimum ventilation amount of crosswind is recommended as 60 m^3/s.

References

Japanese Ministry of the Environment, *Reports on Measurement Against Heat Islands by Urban Population Exhaust*, 74, 2004.