E3S Web of Conferences **356**, 02013 (2022) https://doi.org/10.1051/e3sconf/202235602013
ROOMVENT 2022

Field Measurement and Evaluation of Effective Ventilation of Air Shafts in Subway Tunnel

Haibo Qu[1], *Jianbin* Zang[1*] *and Yan* Wu[1]

[1]School of Mechanical Engineering, Tongji University, Shanghai 201804, China.

Abstract. The ventilation performance of air shaft is important to the air quality of subway tunnel, but there lacks of unified evaluation index of ventilation performance. In this paper, the air shafts at different locations in subway tunnel were taken as research objects, and the wind speed of each air shaft was tested. The effective ventilation volume of air shafts was defined to evaluate the ventilation performance. It was found that on average, during the subway train serve once, the station air shaft in train-arriving side can discharge 2050 m^3 dirty air in the tunnel and inhale 218 m^3 fresh air from the outside environment, while the station air shaft in train-leaving side can absorb 2430 m^3 fresh air, but can hardly effectively discharge dirty air; meanwhile, the middle air shaft can not only effectively exhaust 1519 m^3 dirty air, but also absorb 7572 m^3 fresh air. And the middle air shaft has better ventilation performance if its inner opening set on the top rather than on the side of the tunnel. This research can provide guidance for ventilation performance evaluation of subway air shafts and reference for the subway tunnel air shaft location design.

1 Introduction

With the rapid growth of urban subway operation mileage, the air quality of the subway environment has also received increasing attention. Since the fresh air of the subway train cabins is introduced from the tunnel through air-conditioning system, the air quality in the cabins is related to the tunnel environment. When the subway trains run in the tunnel, the temperature in the tunnel will rise[1] and the particulate matter will be produced[2]. Thus, effective ventilation for the subway tunnel is necessary to discharge the heat and pollutants. While the natural ventilation driven by piston wind plays such a role which works through the air shafts during the subway operation time. Station air shafts are generally set at the both ends of subway stations. Middle air shafts are set in the middle of some long tunnels. If the ventilation performance of air shafts is poor, the air quality in the tunnel will gradually deteriorate during the operation time.

The effect of different parameters to the ventilation rate of air shafts have been studied. Kim KY and Kim JY[3] investigated the effect of distance between the air shaft and station on ventilation performance when air shaft was installed only at the train-arriving side. Liu et al.[4] found that the train density is a significant factor affecting the air exchange rate of the air shaft. Wu et al.[5] found that the ventilation system with two air shafts in the station has better performance than that with only one shaft. For the one-shaft system, the location of the shaft in the train-leaving side of the station performs better than in the train-coming side. Shi et al.[6] found that different design schemes of both single and double piston vent shafts supplemented by station exhaust ventilation system can meet the needs of tunnel fresh air volume. However, the results of above studies are all based on numerical simulation method. There is little field measurement research on air shaft. Although Wang[7] and Zhang[8] tested the wind speed on the air dampers of air shafts, they didn't pay attention to the ventilation rate. Furthermore, most research use the ventilation volume of air shaft section to evaluate the ventilation performance, which cannot effectively reflect the air change between the tunnel and outdoor atmosphere since the volume of air shaft is not taken into consideration.

This study focused on the ventilation performance of different air shafts in subway tunnel with platform screen doors, aiming to provide a reasonable evaluation index for ventilation performance of air shaft and provide reference for the subway tunnel air shaft location design. Field measurements were carried out to obtain the wind speed of air shafts. The effective suction/exhaust air volume of different air shafts were defined and calculated to evaluate the ventilation performance of different air shafts.

2 Field measurements

2.1 Research object

The research objects are different air shafts of subway tunnel with platform screen doors. The test objects are

* Corresponding author: 98798@tongji.edu.cn

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).

the station air shaft ① in train-arriving side and the station air shaft ② in train-leaving side on the upline of Line 1 (Fig. 1), as well as the middle air shaft ③ on the downline and the middle air shaft ④ on the upline in Line 2 (Fig. 2). The train running interval of Line 1 and Line 2 is different. The subway train running on Line 1 and Line 2 is B-type, which is composed of 6 cars, with a total length of 120 m. The distance between Staion1 and Station 2 of Line 2 is 2.6 km.

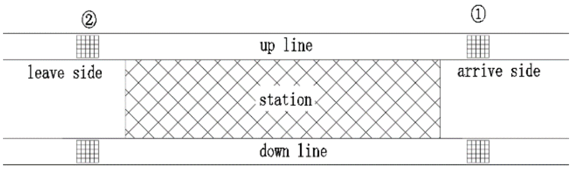

Fig. 1. The location of station air shafts in Line 1

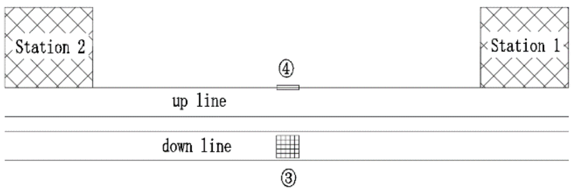

Fig. 2. The location of middle air shafts in Line 2

The test sites were on the air damper at the inner opening where is the connection of subway tunnel and air shafts (Fig. 3). The inner opening of air shaft ①②③ were set on the top of the tunnel, while the inner opening of air shaft ④ was set on the side of the tunnel. The information of each air shaft is shown in Table 1.

Table 1. Information of each air shaft

Air shaft	Location	Damper area, m^2	Total duct volume, m^3	Inner opening location
①	Train-arriving side of station	20.14	1634	Top of tunnel
②	Train-leaving side of station	20.14	1634	Top of tunnel
③	Middle of interval tunnel	20.14	1500	Top of tunnel
④	Middle of interval tunnel	20.14	1500	Side of tunnel

2.2 Equipment and method

The Testo480 anemometer from Detu Corporation of Germany was used to measure the wind speed. The test range is 0~20m/s and the test accuracy is ±0.01m/s. The recording interval was set to 1s.

To reduce the test error, each air damper was divided into four parts uniformly, and each centre of the part was arranged with one wind speed measuring point (Fig. 4.). The wind speed was obtained by taking the average value of the four measuring points. The test was carried out during the subway operation period. Each test ensured that at least 5 trains pass through the air shaft.

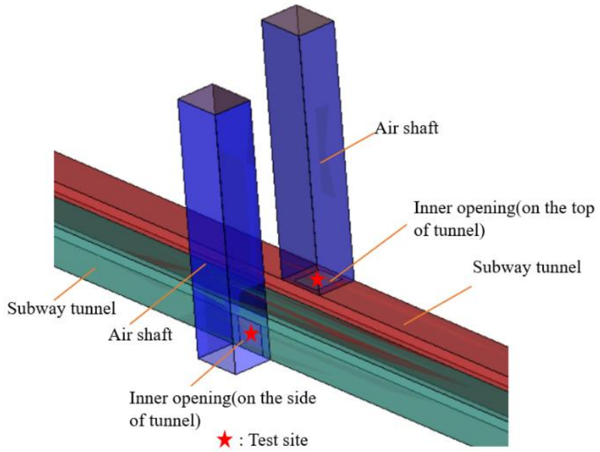

Fig. 3. The schematic diagram of test site

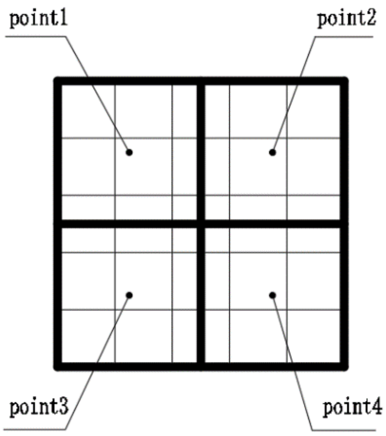

Fig. 4. Wind speed measuring points on air damper

2.3 Ventilation Performance Evaluation Method

Define the effective exhaust air volume Q_e and the effective suction air volume Q_s of the air shaft as follows when each train passes:

$$Q_e = G_{out} - V_{shaft} \quad (1)$$

$$Q_s = G_{in} - V_{shaft} \quad (2)$$

Where: Q_e / Q_s for effective exhaust/suction air volume (m^3/run); G_{out} / G_{in} for air volume passing through the air damper (m^3/run); V_{shaft} for total air shaft volume (m^3).

Q_e reflects the capacity for the air shaft to discharge the dirty air in the tunnel to the outside environment when the train is approaching. Q_s reflects the capacity for the air shaft to suck fresh air from outside environment to the tunnel when the train is moving away.

When $G_{out} < V_{shaft}$, $Q_e = 0$, which represent that the air shaft can't effectively exhaust air; when $G_{in} < V_{shaft}$, $Q_s = 0$, which represent that the air shaft can't effectively suck air.

G_{out} and G_{in} can be calculated according to equation (3):

$$G = \int_0^T v_i A dt_i \quad (3)$$

Where: v_i for wind speed (m/s); A for ventilation area of the air damper (m^2); t_i for sampling interval time (s); T for time that the piston wind acts on the damper (s).

The indices Q_e and Q_s take air shaft volume into consideration and can reflect the actual ventilation performance of air shafts.

3 Result and discussion

3.1 Wind speed

The inflow-air direction was defined as negative, which means that the air shaft is sucking fresh air from outside. Whereas the outflow-air direction was defined as positive, which means that the air shaft is exhaust dirty air from tunnel. The wind speed variation at the inner opening of each air shaft during the five trains passing by are shown in Fig. 5 and Fig. 6.

It can be seen from the figures that the wind direction at the air damper will change when the train passes by the air shaft. Before the train passes, the air shaft exhausts air, and after the train passes, the air shaft sucks air. This is because when the train is running in the tunnel, the front of the train is a positive pressure zone, and the rear of the train is a negative pressure zone.

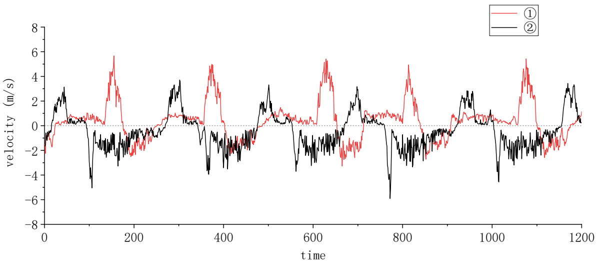

Fig. 5. Wind speed variation at the inner opening in station air shaft ① and ②

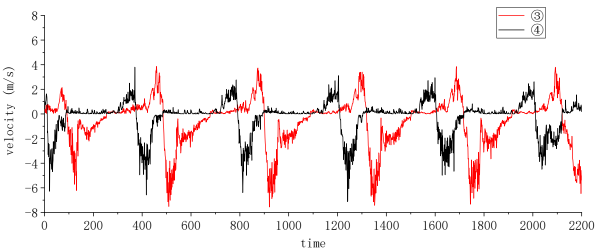

Fig. 6. Wind speed variation at the inner opening in middle air shaft ③ and ④

The maximum wind speed in air shaft ① appears in the air exhaust process, while in air shaft ②③④ appears in the air suction process. For station air shaft ① and ②, it is because the train decelerates to enter the platform and accelerates to leave the platform. For middle air shaft ③ and ④, it can be explained that the pressure at the rear of the train is greater than the pressure at the front of the train in the subway tunnel when the train is in constant speed.

The maximum wind speed of middle air shafts ③ and ④ is larger than station air shafts ① and ②. According to previous studies, piston wind speed is related to train speed. During the test, it is found that it takes 20 s for the train in Line 1 to pass through the station. Therefore, it can be calculated that the speed of the train accelerates from 0 to 43.2 km/h when it leaves the station in Line 1. As for Line 2, it takes 175 s for the train run from Station 1 to Station 2. According to the acceleration of 0.6 m/s^2, it can be calculated that the maximum running speed is 64.8 km/h for the train between Station 1 and Station 2, which equals to the speed of the train passing by the middle air shaft, and is obvious larger than station air shafts.

3.2 Effective ventilation volume

The effective exhaust/suction air volume of each air shaft during five subway trains passed by is calculated and shown in Figure 7. The horizontal axis of the graph refers to train round and the vertical axis, effective exhaust/suction air volume. The effective ventilation volume of the air shaft changes relatively smoothly during the test period.

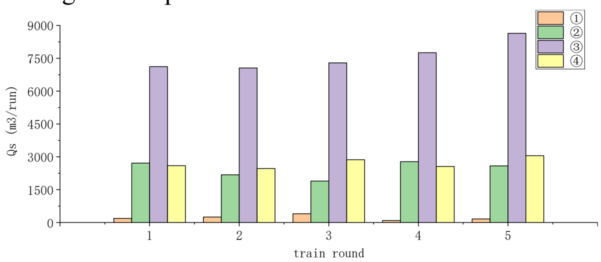

Fig. 7a. Effective exhaust air volume (Q_e) of each air shaft per train

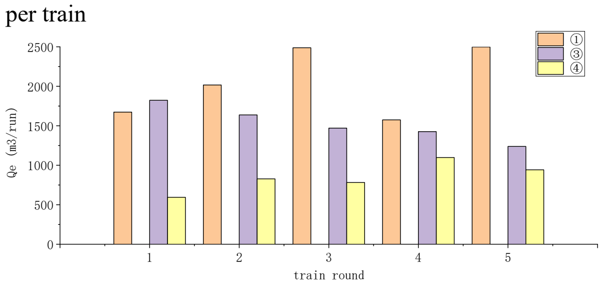

Fig. 7b. Effective suction air volume (Q_s) of each air shaft per train

Take the average value of the effective ventilation volume of five trains, as shown in Fig. 8. The order of magnitude of ventilation volume is consistent with the study of Lee et al. [9]. They tested six air shafts between two subway stations and the ventilation flow rate of each shaft during the train serve once ranges from 197.67 to 1292.24 m^3/run.

As can be seen from Fig.8, the station air shaft in train-arriving side mainly discharges the dirty air in the tunnel and can inhale a small amount of fresh air from the outside, while the station air shaft in train-leaving side can inhale a large amount of fresh air, but can hardly effectively exhaust the air. This is because when the train is approaching the station, most air flow to the outside through the air shaft in train-arriving side, and the pressure in front of the air shaft dropped, so little air

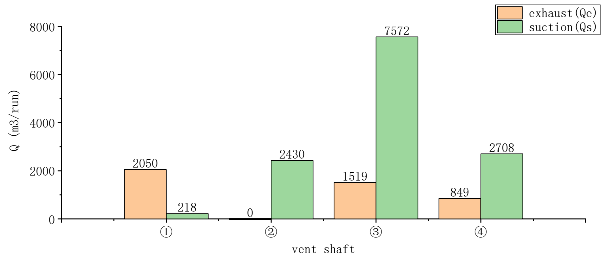

Fig. 8. Average effective exhaust/suction air volume of different air shafts

flow to the air shaft in train-leaving side. After the train passes by the air shaft in train-arriving side, it stops at the station and the piston wind quickly decays. There is no driven force for the air shaft in train-arriving side to inhale fresh air before the train starts to run. When the train starts to run, the train speed is not high, so the air shaft in train-arriving side can only inhale a little fresh air from outside. However, when the train passes through the air shaft in train-leaving side, the train speed reaches to 43.2km/h, thus the driven force is enough for the air shaft to suck a large amount of fresh air.

The middle air shaft can not only effectively discharge the dirty air in the tunnel, but also inhale a large amount of fresh air from the outside, and the suction capacity is obviously stronger than the exhaust capacity. This is due to the longer duration of outside wind flowing into the tunnel. In addition, the effective ventilation volume of the middle air shaft is significantly larger than that of the station air shaft, which is due to the greater speed of the trains passing through the middle air shaft generating greater piston wind.

Comparing the middle air shaft ③ and ④, it can be seen that the effective ventilation volume of the air shaft with the inner opening set at the top of the tunnel is significantly greater than set at the side of the tunnel. The air shaft volume and train passing speed of ③ and ④ are the same. One possibility is that the airflow resistance of the two air shafts is different. Air shaft has less airflow resistance with inner opening set at the top of tunnel. It indicates that when design a new tunnel, it is better to set the inner opening of the air shaft at the top of the tunnel to obtain better ventilation performance.

From the measurement data, it is obvious that the air shaft volume and effective ventilation volume are an order of magnitude. So, the air shaft volume will greatly affect the actual ventilation performance. According to previous study [10], if the buried depth of subway tunnel is constant, appropriate increase in the cross-sectional area of air shaft will improve the air volume passing through the air damper. But the air shaft volume will also increase, and more air will be trapped in the air shaft. The effective ventilation volume may not increase. Therefore, it is necessary to use effective ventilation volume to evaluate the ventilation performance.

4 Conclusion

In this paper, the wind speed at the inner opening of the subway tunnel air shaft during the subway operation period is obtained through field tests, and the effective ventilation volume is defined to evaluate the ventilation performance of the air shaft. The main findings are summarized as follows:

(1) The station air shaft in train-arriving side can effectively exhaust a large amount of dirty air (average 2050 m^3/run) in the tunnel and inhale a small amount of fresh air (average 218 m^3/run). While the station air shaft in train-leaving side can effectively inhale a large amount of fresh air (average 2430 m^3/run) from outside atmosphere, but can hardly discharge the dirty air in the tunnel. The middle air shaft can not only effectively exhaust dirty air (average 1519 m^3/run), but also inhale a large amount of fresh air (average 7572 m^3/run), and the effective air suction/exhaust volume is significantly larger than station air shafts.

(2) The air shaft has better ventilation performance if its inner opening set on the top of the tunnel rather than on the side of the tunnel. When design a new tunnel, it is better to set the inner opening of the air shaft at the top of the tunnel to obtain better ventilation performance

(3) It is necessary to adopt effective ventilation volume to evaluate the ventilation performance of subway tunnel air shafts.

Acknowledgements

This work is supported by the National Natural Science Foundation of China under the project number of 52108087.

References

1. J.B. Yang, M.Z. Liu, H. Zhang, W.D. Zheng, S.J. You. Tunn. Undergr. Sp. Tech. **120**,104291(2022).
2. O. Font, T. Moreno, X. Querol, V. Martins, D.S. Rodas, E.D. Miguel, M. Capdevila, Transport Res. D-Tr. E. **72**,17(2019).
3. J. Y. KIM, K. Y. KIM, J Wind Eng Ind Aerod, **97**, 174(2009).
4. Y. Liu, K. F. Shi, Y. Zhang, X.F. Li, Y.B. Yu, HAVC, **49** ,7(2019).
5. Y. Wu, N. P. Gao, L. H. Wang, X.P. Wu, Indoor Built Environ, **23**, 1420326X13479623(2013).
6. K. F. Shi, Y. Liu, Y. Zhang, X.F. Li, Railway Standard Design, **63**, 111(2019).
7. L. H. Wang, W. Gong, J. Song, Z.Q. Shen, Z.C. Yan, J. Refrig. **33**, 54(2012).
8. Y. Zhang, Q. Zhang, H. Q. Bi, J.Y. Wang, Refrig. & Air Cond. **34**, 463(2020).
9. K. B. Lee, J. S. Park, M. D. Oh, S.J. Bae, S.D. Kim, J. Mech. Sci. Technol. **28**,2677(2014).
10. C. Chen, X. N. Li, Q. Li, H.T Yuan, L.Y. Wang, Y.R. Li, China Rail. Sci. **38**, 87(2017).