MEANS TO IMPROVE METRO STATION ENVIRONMENT WHEN VENTILATION SHAFTS ARE IN CLOSE PROXIMITY TO PLATFORMS

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ABSTRACT

Conventionally tunnel ventilation shafts are constructed at a certain justified distance from stations. They serve as pressure relief shafts during normal operation in order to divert as much air as possible from the tunnel, thereby minimizing the blast in the station. Insufficient draught relief may result in excessive train induced flows in the public areas of the station. This paper discusses the impact of very close proximity of tunnel ventilation shafts to station platforms on the environment, and the means that help to mitigate the problems. The effectiveness of the proposed technical devices is verified by CFD analysis.

Keywords: tunnel ventilation, draught relief shafts, station air velocity and rapid pressure change

1. INTRODUCTION

Train piston action induces air motion and air pressure changes. High air velocities and rapid pressure changes in metro systems can be a source of passenger discomfort and also be harmful to mechanical equipment and structure. This paper addresses the issues of how relocating the ventilation shaft closer to the ends of the platform will affect the station environment, and pressure changes in the tunnel, and on board the train.

Distance between the station portal and the draught relief shaft is an important value that affects station aerodynamics. When the required (computed) distance between the station portal and the draught relief shaft is greater than the actual distance, the maximum velocity in the station will occur before the train approaches the draught relief shaft (SES Handbook 1976). In other words, when the draught relief shaft is too close to the station, people standing on the platform waiting for the train may experience high pressures and high air velocities before the train reaches the draught relief shaft. The shaft, in this case, is not effective. A practical shaft location varies from 60 feet (20 m) to 300 feet (90 m). For example, 60 feet (20 m) could be found in the Toronto subway design and etc. This distance allows for piston pressure relief from the trains and a decrease of air velocities at the station. It will also decrease the station impact on tunnel airflow for smoke control in case of a tunnel fire emergency.

Relocation of the ventilation shafts closer to the station to within approximately 15 feet (4.5 m) of the end of the platform, may be considered as the unique nature of the design as it effects the station environment. Such relocation may be required for geotechnical and economical considerations due to the soil conditions and metro station overall length limitations.
2. IMPACTS OF VENTILATION SHAFTS LOCATION ON STATION ENVIRONMENT

2.1. Pressure Transient Impact

The purpose of the draught relief shaft (one of the functions of ventilation shafts) is to divert as much air and pressure as possible from the tunnel, thereby minimizing the blast in the station. Insufficient draught relief may result in excessive train induced flows in the public areas of the station. Taking into consideration relatively low metro train speeds, problems with pressure transients are not expected at stations and in the running tunnels (see fig. 1).

![SB Pressure Rise at Train Traveling Speed 55 mph](image)

**Fig. 1:** Pressure rise inside the tunnel as a function of train travel time

The major impact of relocating the ventilation shafts closer to the ends of the platform is expected to be on air velocities at the platforms as discussed below.

2.2. Air Velocities at the Platform

The effect of air velocity increase at the platform of metro stations can result in the following:

- Discomfort to passengers;
- Hats, bags, etc. to be blown away / over;
- Raising dust and lose paper;
- In a worst-case scenario, people could stumble or fall over.

Factors that affect airflow at the station are:

- Train speed;
- Distance from the station where train starts deceleration and where the train starts acceleration when leaving the station;
- Single or multiple train scenario;
- Draught relief shaft cross section area;
- Location of the draught relief shaft relative to station;
- Cross passage area and features;
- Draught relief shaft length and resistance;
- Resistance (friction loss) in the tunnel section between the draught relief shaft and the station portal;
- Station impedance; and
- Expansion loss as tunnel air expands into the station platform area.
This paper focuses on the location of the draught relief shaft relative to the station. Air velocities at the platform should not exceed 5 m s\(^{-1}\) (1000 fpm). The maximum airflow depends on the ratio of air speed to train speed as well as the resistances to flow in the tunnels, up the vent shafts, and through the station. Air jet velocity entering the station will depend upon the velocity of the air in the tunnel just beyond the draught relief shaft, but before the station:

\[ V_{\text{jet}} = V_{\text{tunnel}}(1 - \text{mass flow ratio for the draught relief shaft}) \]

Areas along the first 50 ft (15 m) to 150 feet (45 m) of the platform adjacent to the approach tunnel may be exposed to peak jet velocities. As the air jet expands, its velocity is reduced.

Preliminary estimates, based on braking distances and up to 55 mph (88.5 km h\(^{-1}\)) train speeds for the vehicle approaching the station from either side, indicate predicted maximum station air velocities to be 20% higher than the maximum allowed of 5 m s\(^{-1}\) (1000 fpm) if no means for velocity reduction is implemented. Such air velocities will create moderate breeze, raising dust and loose paper. The resultant manually estimated air velocities require verification.

It should be noted that Mr. Pope (Pope and others 1976) stated “the largest mean flow velocities on the platforms and in the cross passages are little affected by increasing the distance between the shafts and the station head walls. There is a small increase in the peak flow velocities in the platform tunnels. The peak flow velocity in the cross passages increase quite significantly (by about 16%), however, as the separation of the draft relief shafts from the headwall of the station is increased from 0 to 20 m [60 ft]. Increasing the separation further only results in relatively small further increase in the peak flow velocity through the cross passage.”

### 3. MEANS TO IMPROVE STATION PLATFORM ENVIRONMENT

The goal is to improve the efficiency of the draft relieve shaft. A short length of tunnel between the blast shaft and the station portal can be used to increase overall impedance. The intent of the design is to create additional resistance and turbulence in the short tunnel, between the station portal and the ventilation shafts, and to direct as much air flow as possible to the ventilation shafts that serve as draft relief shafts under normal train operation. This short tunnel length should accommodate track tunnel dampers.

Several potential solutions were reviewed that address the means to reduce the station air velocities:

- An orifice plate was proposed by engineers from the AEA Technology Rail, UK for railway tunnel from Sweden to Denmark (T. Prevezer, J. Johnson, 2003). The orifice plate was constructed in concrete as part of the tunnel wall and designed to constrict the flow locally and provide a high pressure loss at its location. In theory, if the orifice plate is located between a draught relief shaft and station entrance, then the pressure loss would discourage the airflow from travelling down the tunnel towards the station. Instead, it would encourage airflow to travel up the airshaft, where there would be an easier path to the open air. Simulations showed that the orifice plate could provide a significant influence on the flow velocity in the station. The optimum design, they say, could reduce the air velocity by the same amount as reducing the speed of the train by 40 km/hr. Air velocities at the station would reduce by 15% to 20%. The effectiveness of the orifice plate is fairly insensitive to its location within the tunnel between the station and the air shaft.
Baffle plates were proposed to reduce station air velocity by engineers from the Technical University of Vienna, Austria (P. Paseva, H. Sockel, 2000). Analyses were performed with 15% reduction of cross section as well as with 20% reduction of cross section. The idea and theory is very similar to the one presented above.

Isolation of the station from the tunnel by air jets and air curtains are discussed in the SES Handbook (1976). The air jet concept has been proposed to isolate the station from the tunnel. This is an air jet located between the draught relief shaft and the station, which is used to deflect the incoming tunnel air up into the draught relief shaft. Potential problems with noise, control, cost, and train operations are evaluated. This solution seems expensive, difficult to implement, and is not considered.

Space orifices at a distance of 8 feet (2.5 m) to 11 feet (3 m) apart, along the tunnel between the draught relief shaft and the station portal, are recommended by Russian engineers (V.I. Tcodikov 1975). This introduces a significant increase of pressure drop in the tunnel between the draught relief shaft and the station portal.

Orifice (baffle) plates along with airshafts, as a means to reduce underground station air velocity, are considered for installation as part of the City-tunnel-project in the tunnel that connects Sweden and Denmark (T. Prevezer, T. Johnson, 2003). In theory, if the orifice plate is sited between a specifically located airshaft and the station entrance, the pressure loss would discourage the airflow from travelling down the tunnel, towards the station, and instead it would encourage it to travel up the airshaft, where there would be an easier path either to the open air or to the opposite track as noted above. The additional blockage did not adversely affect the tunnel pressures.

3.1. Proposed Design Improvements

The need to relocate ventilation shafts as close to the platforms as practical came due to the geotechnical reasons as the result of the soil conditions. Our proposed design changes (see fig. 2) include extension of the platform tunnel to the track damper area, relocation of the ventilation shafts closer to the station to within approximately 15 feet (4.5 m) of the end of the platform, and construction of a platform headwall (an orifice plate). This platform headwall leaves the minimum acceptable clearance for the vehicle and serves to divert pressure waves travelling in front of the vehicle into the draught relief chamber and shaft, and hence, decreases the airflow to the platform area itself. This isolated end section of the platform tunnel forms a draught relief chamber at the entrance to the ventilation (draught relief) shaft.

![Fig. 2: Proposed changes due to ventilation shafts relocation.](image-url)
We also propose to use baffle plates (orifice plates) spaced at a distance of 8 feet (2.5 m) along the draught relief chamber. Plates should be constructed out of concrete as part of the tunnel wall and designed to constrict the flow locally and provide high pressure loss at their location.

Baffle plates (orifices) are good for both – reduction of station air velocity and reduction of pressure waves. When a train enters a tunnel, a compression wave is induced which passes through the tunnel at the speed of sound relative to the velocity of air. During the propagation of a compression wave along the tunnel, the gradient of the wave increases due to non-linear effects ("steepening"). Baffle plates reduce steepening of the pressure waves. (P. Paseva, H. Sockel, 2000)

![Fig. 3: Damper chamber sections with baffle plates, track dampers and platform headwall](image)

Clearly, the ability to use an orifice plate is constrained by the size of an existing tunnel since the orifice plate will reduce the available tunnel cross-section area locally. The free area (defined as the tunnel cross section area minus the orifice plate area) must still allow enough space for the train vehicle dynamic envelope, catenaries equipment, fire standpipe and walkway. Thus our design includes an extension of the platform tunnel to accommodate track damper and orifice (baffle) plates. Airflow from the tunnel will have to go through a set of sudden expansions and contractions that would lead to increased pressure losses and would direct part of the airflow into the ventilation shaft. Increased tunnel area will locally decrease air velocity, while plates will increase turbulence, creating secondary airflows behind them, leading to increased pressure drops. The platform headwall will serve a dual purpose – firstly as the last barrier (resistance) before airflow gets into the platform tunnel and will protect the platform adjacent to the headwall from high air velocities. Secondary, it will serve as an architectural and security feature that will hide the track dampers, plates, and fire equipment from public at the station. We should note that this is true that the platform headwall will create local increase of air velocity, however the resistance it creates to the airflow will eventually decrease average airflow through the station and hence platform air velocities.

Using train speed restrictions to control air velocities is very effective, but may be very expensive and should be considered only as the last means. Platform screen doors are not considered.

4. AIR VELOCITY AND RAPID PRESSURE CHANGE ANALYSIS

Analyses were performed using the SES methodology (SES Handbook, 1976) for the scenarios when trains by-pass the station at 88.5 km h⁻¹ (55 mph) and when trains operate according to the train operation schedule. (Fig. 4) Results were verified and analysed in details using sliding mesh features of the Computational Fluid Dynamics (CFD) Fluent program.
Using Computational Fluid Dynamics the following cases were analysed:

- Two trains running from opposite directions at constant speed 64 km h\(^{-1}\) (40 mph) passing the station with ventilation shafts located at 60 feet (20 m) from platform ends (typical ventilation shaft location).
- Two trains running from opposite directions at constant speed 64 km h\(^{-1}\) (40 mph) passing the station with ventilation shafts located at 15 feet (4.5 m) from platform ends as required. No orifices in the damper area modelled.
- Two trains running from opposite directions at constant speed 64 km h\(^{-1}\) (40 mph) passing the station with ventilation shafts located at 15 feet (4.5 m) from platform ends. Orifices in the damper area modelled to compare results with the previous case.
- Two trains running from opposite directions at variable speed passing the station according to the train operation schedule with ventilation shafts located at 15 feet (4.5 m) from platform ends. Modelling was performed with and without orifices in the damper area.
- Detailed 3D Aerodynamic analysis of the damper area with and without orifices / baffle plates. The sensitivity analyses were used for setting time dependant pressure boundary conditions.

As a result of the analysis we confirmed the proposed design changes:

- Extend the platform tunnel length to the end of the vent shafts to accommodate track dampers, to accommodate orifices and baffle plates.
- Install a station platform headwall at each end of the public platform area to separate the public area from a damper chamber area and to create an effect of the orifice, increasing resistance to the airflow and creating an aerodynamic shade area at the platform for public use.
- Install a set of baffle plates / orifices on the inbound side at the track damper chamber, as shown in fig. 2, 3, to direct tunnel airflow to the ventilation shaft.

The baffles installed in the outbound damper chamber, however, create additional pressure to the airflow to further escape. Thus the effectiveness of the baffle plates in the outbound chamber was questionable and the final decision was to eliminate them.
5. **HOW RELOCATING THE VENTILATION SHAFTS CLOSER TO THE END OF THE PLATFORM WILL EFFECT THE PERFORMANCE OF THE TUNNEL VENTILATION SYSTEM**

The following design changes may effect the air distribution:

- Relocation of the ventilation shafts closer to the east and west ends of the station to within approximately 15 feet (4.5 m) of the end of the platform may result in greater airflow getting into the station and less flow getting into the tunnels;
- Baffles, orifices and platform end walls may provide an opposite effect increasing the resistance of the airflow to get to the station and improving airflow into the tunnel;
- Tunnel size increase in the track damper area allows for less resistance and thus greater station airflow.

If balancing between the tunnel and station airflow is required, the motorized deflecting vanes should be installed to control air distribution. However, motorized deflecting vanes will:

- increase the airshaft pressure drop that will effect the fan pressure and horsepower;
- make the control system more complicated;
- increase the capital and maintenance costs.

Thus the question that needs to be answered by this study is the necessity of the motorized deflecting vanes installation for fire / smoke management. The focus of this study is to find out if the vent shafts relocation would cause the misbalance so much, that motorized deflecting vanes or other means would be needed to balance the system properly.

A comparison CFD study performed to find out the system balancing in order to make a decision on motorized deflecting vanes:

- Supply and exhaust tunnel ventilation fans operation with ventilation shafts located at 60 feet (20 m) from platform ends (typical ventilation shaft location). Full tunnel and station length was modelled.
- Supply and exhaust tunnel ventilation fans operation with ventilation shafts located closer to the station at approximately 15 feet (4.5 m) from platform ends with and without orifices and baffles.
- A detailed 3D CFD analysis of the track damper area with orifices and baffles. Tunnel ventilation fans running in supply and exhaust modes. The results of detail analysis help to understand aerodynamics around baffles, orifices, platform end wall and in the damper chamber.

If the difference of airflow between the original geometry and the new geometry exceeds the allowable misbalance, the motorized deflecting vanes are needed. Otherwise no deflecting vanes are required.

When modelling the full tunnel length, it would take a huge amount of computer memory and time to do 3D CFD analysis. Thus 2D CFD analyses were performed for the entire tunnels that were used for boundary conditions of a detailed 3D CFD analysis of a damper chamber (see fig. 5). Nevertheless a 2D model can not represent all the features as a 3D model can, we believe that based on the Reynolds Re number modelling, we can get a close result that can be further verified.
The main conclusions that come from the results of the analyses are:

- Relocation of the ventilation shaft close to the platform impacts on airflow distribution from the tunnel ventilation system by increasing airflow from/to the station tunnels and decreasing airflow from/to the running tunnels;
- When the ventilation shaft is closer to the station, we get more airflow to the platform tunnel and less airflow to the running tunnel, as proved by the CFD results with NO baffle plates. In this case, the motorized deflecting vanes may be effective to direct the airflow into the running tunnel.
- Baffle plates and orifices significantly affect the airflow distribution. This was proved by results of CFD analysis with baffle plates, and by a 3D CFD analysis that show complicated aerodynamics around baffle plates, and the resistance the baffle plates create to the airflow.
- Complicated aerodynamics and impact of baffle plates and other design features cannot be evaluated using a 1D computer program, or manual calculations, and requires CFD analyses.
- Orifices and baffle plates proposed for platform air velocity control create a significant resistance for the ventilation air, and create an opposite effect by increasing airflow from/to the running tunnels and decreasing airflow from/to the platform tunnels;
- When baffle plates are installed, the resistance they create to the airflow decreases the flow rate the station tunnel gets and increases the airflow through the running tunnel. No motorized deflecting vanes are needed to direct airflow into the running tunnel, but airflow to the platform tunnel is to be considered.
- No motorized deflecting vanes are recommended for air distribution tunnel ventilation system control;
- No baffle plates are needed in the outbound damper chamber, but baffle plates in the inbound damper chamber should remain for platform air velocity control and for ventilation system balancing;

The changes to the ventilation shafts relocation impact the pressure drops and eventually the pressures required by the fans. This happens due to changes to track dampers locations, the addition of baffles and orifices, and also due to changes in air distribution between the tunnel and station. However, overall impact on the fans horsepower was found insignificant.
6. CONCLUSIONS AND DESIGN RECOMMENDATIONS

Calculations and CFD analyses demonstrate that relocation of the ventilation shafts closer to the ends of the platform does not impact significantly on the pressure transient results and that the pressure transients at the train and in the station are acceptable.

Movement of the ventilation shafts close to the platform effects on platform air velocities. However, by implementing design recommendations, station platform air velocities will be within the comfort limits under normal operating conditions. When a train travels at 55 mph (88.5 km h⁻¹) (higher than the design speed) and bypasses the station at that speed, some precautions should be taken for people standing at the platform, or the train should slow down to a speed of 41 mph (66 km h⁻¹). The platform air velocities locally may slightly (within 10%) exceed the 1000 fpm (5 m s⁻¹) design criteria limit, which should not create any major problems.

Also, maintenance people should take some precautions when working in the ventilation shaft in wintertime, when two trains simultaneously pass the ventilation shaft at speed 55 mph (88.5 km h⁻¹), and fan dampers are closed.

Results of air flow CFD analysis confirmed that relocating the ventilation shafts closer to the platform ends with the proposed design changes allows to control platform air velocities within the design criteria limits, or close to them when trains bypass the station at 40 mph (64 km h⁻¹), or operate according to the design schedule. Results also confirmed the effectiveness of the orifices / baffle plates at the inbound side that can decrease the airflow to the platform for up to 16% by directing airflows to the ventilation shafts. When orifices / baffle plates are not installed, platform air velocities may slightly exceed 1000 fpm (5 m s⁻¹).

Based on the results of the analysis, the following design changes are recommended to be included in the relocation ventilation shaft:

1. Increase the platform tunnel length to the end of the vent shafts to accommodate track dampers, to accommodate orifices and baffle plates.
2. Install a station platform headwall at each end of the public platform area to separate the public area from a damper chamber area and to create an effect of the orifice, increasing resistance to the airflow and creating an aerodynamic shade area at the platform for public use.
3. Install a set of baffle plates / orifices to direct tunnel airflow to the ventilation shaft under normal operation and to balance air flow created by the tunnel ventilation system in fire emergency.
4. No motorized deflecting vanes are needed for air distribution tunnel ventilation system control;
5. No baffle plates are needed in the outbound damper chamber, but baffle plates in the inbound damper chamber should remain for platform air velocity control and for ventilation system balancing;
6. Impacts on the fans horsepower requirements are insignificant.
REFERENCES


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