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A study of mitigation strategies against excessive trackway depressurisation in stations with full-height platform screen doors

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ABSTRACT: Full-height Platform Screen Doors (PSDs) are increasingly used in underground rail systems to enhance safety, reduce energy consumption, and improve the station environment. While their benefits are widely acknowledged, their interaction with Tunnel Ventilation Systems (TVS) requires careful consideration, particularly in emergency scenarios such as fires.

The introduction of full-height PSDs in underground rail stations significantly alters tunnel ventilation dynamics. Under certain scenarios such as a train on fire in the tunnel or at the platform trackway, the tunnel ventilation response can cause excessive negative pressures at the trackway where make-up air paths are not available. This can lead to adverse life safety implications due to the inability to open PSDs and EEDs. This paper aims to draw attention to this issue and reviews various design strategies to mitigate excessive pressures.

1 INTRODUCTION

1.1 *Overview*

The introduction of full-height PSDs significantly alters tunnel ventilation dynamics. The presence of full-height PSDs can influence TVS in several ways including: restricted airflow where PSDs limit the natural exchange of air between the platform and trackway, smoke control challenges in fire scenarios due to limited make-up air paths, and excessive pressure differentials between the platform and trackway which can make it difficult for passengers to open Emergency Escape Doors (EEDs) or PSDs.

Challenges represented by excessive pressure differentials between the platform and trackway have been noted in certain TVS designs particularly during testing and commissioning where EEDs could not be opened during a fire ventilation response. This paper aims to draw attention to this issue which may potentially be overlooked during the TVS design and should be considered.

In TVS designs that consider this challenge, limited mitigation strategies are observed. This includes either the provision of full independent draught relief shafts which consumes valuable underground real estate or oversizing of fans to compensate for at least one draught relief shaft needing to remain open at one end of the station at the expense of a set of fans remaining non-operational. This paper also explores a potential mitigation strategy in the form of a pressure differential reduction mechanism concept to minimise trackway and platform pressure differentials to facilitate safe evacuation.

1.2 *Literature review*

Tunnel and trackway ventilation induced pressures across PSDs during emergency operations and the effects on door opening forces have not been widely documented. Works by the likes of Chun et al. (2004) and Zhou et al. (2021) have been undertaken to study train induced pressures across PSDs, however these are not directly comparable to the considerations in this study. Whilst Zeng et al. (2023) also analyses train induced pressures on PSDs, it also considers how train induced negative pressures may cause a failure in the proper operation of PSDs.

The use of controllable dampers in platform screen doors to mitigate excessive pressure differentials across PSDs in other works and studies have not been observed by the authors at the time of writing this study. It has been noted however that Yang et al. (2022) have proposed a similar system i.e. adjustable dampers in platform screen doors to provide energy savings to underground rail station Environmental Control Systems (ECS) by utilising the train piston effect for air exchange with the platform during normal train operations. Whilst the function of the platform screen door controllable dampers proposed in this study are different to those by Yang et al. (2022), it brings to light potential benefits outside of those that are the focus of this study.

2 FULL-HEIGHT PLATFORM SCREEN DOORS

2.1 *Overview*

PSDs are used in rail and rapid transit stations to physically separate the platform from the trackway and are a relatively new addition to rapid transit systems with some older stations being retrofitted with PSDs.

PSDs can refer to full-height and part-height barriers with the latter more commonly being referred to as Platform Edge Doors (PEDs). For the purposes of this paper, PSDs refer to full height PSDs which create a complete aerodynamic barrier from floor to ceiling between the platform and the trackway.

PSD assemblies are typically composed of Automatic Sliding Doors (ASDs) that align with train doors. Separate manually operated Emergency Escape Doors (EEDs) can also be provided as part of the PSD assembly to allow evacuation from the tunnel to the platform if the ASDs cannot open such as a train misaligned with the ASDs or a train that is stopped part in tunnel and part at the trackway.

2.2 *Passenger safety*

A key benefit of PSDs is to enhance passenger safety by creating a physical barrier between the platform and trackway which reduces the risk of accidental falls onto the trackway, being near moving trains and uncontrolled access to the trackway.

2.3 *Climate control*

PSDs also improve climate control of the platform by separating the platform from the trackway environment. This allows more efficient heating, ventilation and cooling of the platform and reduces air speeds felt by passengers due to the train induced airflows (piston effect).

2.4 *Impact on tunnel ventilation systems*

The aerodynamic separation provided by PSDs can also benefit the tunnel ventilation system when supplying air by reducing air leakage from the tunnels to the stations through open platforms when PSDs are closed. Conversely, when the tunnel ventilation system is exhausting air, closed PSDs reduce the number of available make-up air paths. In both instances excessive air pressure may become an issue where other relief and make-up air paths are not available.

3 TRANSIT SYSTEM TUNNEL VENTILATION SMOKE CONTROL

3.1 *Overview*

A key function of the tunnel ventilation system for a rail system is to provide smoke control to maintain tenable conditions in the event of a fire scenario. Tunnel ventilation design fire scenarios include fires in tunnels and at the station trackways and should support the fire life safety strategy of the specific project.

Typically, a tunnel ventilation system consists of tunnel ventilation fans that serve the tunnels at either end of an underground station. i.e. supply to or exhaust air from the tunnels. Separate trackway ventilation fans are used to provide trackway ventilation e.g. exhaust from the platform trackways via an Over Track Exhaust Duct (OTE). A typical tunnel ventilation system arrangement schematic for an underground rail station is shown in Figure 1.

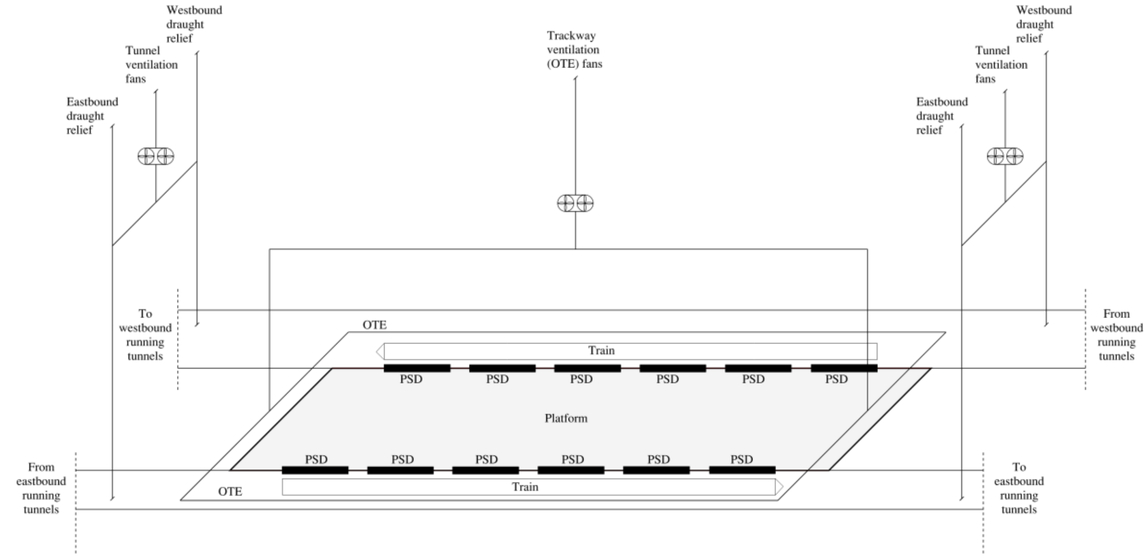

Figure 1. Simplified underground rail station typical tunnel ventilation system arrangement.

3.2 *Smoke control responses*

In the event of a train on fire in a tunnel where the train is not immobilised, the fire life strategy would dictate, where possible, that the train should continue to the next closest station to enable passengers to evacuate through the station. In this situation, typically the tunnel ventilation response would be to initiate a trackway fire response to exhaust air and smoke from the trackway in preparation to or in direct response to the incident train at the platform trackway. Like a tunnel fire response, if the response utilises all available tunnel and trackway fans for optimal use of the available equipment, a typical tunnel ventilation fan arrangement would be left with limited make-up air paths if PSDs and draught relief shafts are closed.

In either of the two situations described, an excessive net negative static pressure difference (trackway static pressure minus platform static pressure) may occur at the trackway leading to high ASD or EED opening forces required for evacuees.

3.3 *Excessive depressurisation and door opening forces*

A range of standards exist that define maximum limits for door opening forces. The Australian National Construction Code (NCC) Part D3 requires that 110N is not exceeded for a door that forms part of a required exit. This generally applies for doors within the station building, however not necessarily the PSDs which generally forms the demarcation between the NCC classified station building and the tunnels. Typically, in Australian underground rail infrastructure projects, the limit identified in NFPA 130 is applied for PSD manual opening forces. This has historically been 220N since the 2007 Edition of NFPA 130. A recent update in the 2023 Edition of NFPA 130 however has reduced this limit to 133N. 220N has been used as the limit for the purposes of this review based on available door opening force to pressure difference limits from past projects. Acceptable pressure differences across doors to maintain door opening forces less than 133N may vary depending on the project and door design.

Where the station tunnel and trackway ventilation fans are exhausting from the trackway generating a net negative static pressure difference between the trackway and the platform, a 'pulling' or 'suction' force is generated on EEDs noting that EED door swings are in the direction of evacuation i.e. open from the trackway to the platform. The pressure difference is exacerbated if make-up air paths are limited as described in Section 3.2.

A static pressure difference between the trackway and the platform can also create additional friction on the sliding door mechanism of ASDs, also making it more difficult to open manually in the event of an emergency.

A direct translation between the 220N door opening force and pressure difference generally depends on the specific door design including its area, weight and opening mechanism. Based on project experience, the pressure difference limit across EEDs have been noted to be circa 200Pa to maintain EED opening forces i.e. less than 220N. Specific pressure difference limits however are subject to the opening force limits and doors to be utilised for a given project.

Typical total tunnel and trackway ventilation fan capacities available for exhaust in an underground rail station trackway can be in the range of hundreds of m^3/s of air. Tunnel and trackway ventilation fan static pressures can range in the thousands of Pa.

The available fan capacities coupled with limited make-up air paths (which may only be made up of long and aerodynamically resistive tunnels connected to trackway) can make it challenging to maintain net negative pressures between the trackway and the platform below 200Pa.

It should be noted that in addition to tunnel ventilation induced pressures, additional transient pressures due to train movements could either positively pressurise or further negatively pressurise the trackway. For the purposes of this study however, it is assumed that train movements in the tunnels during an emergency scenario would be limited and/or stopped minimising transient train induced pressure effects.

3.4 *Mitigation strategies*

The following strategies either currently do or could exist to mitigate the risk of excessive net negative pressure differences across the trackway and the platform:

- Operating the ventilation fans at lower capacities until a confirmed number of EEDs and ASDs are open. This may adversely impact smoke control during the initial phases of evacuation and relies on ASD and/or EED operations.
- Not utilising all available tunnel or trackway ventilation fans to maintain open draught relief shafts. This does not allow for optimal use of available equipment and may lead to oversized equipment and spatial requirements at the station.
- Fully separated draught relief shafts from tunnels to atmosphere. This would typically require additional space at stations both underground and above ground, which is generally prohibitive due to the high value of increasing a station's footprint.
- A concept that includes controllable PSD dampers installed within the bulkhead above the PSD header box which can be opened to reduce the pressure differentials across the PSDs during emergency operations at stations exhausting from the trackway. The controllable PSD dampers could be closed at stations supplying air to minimise leakage air paths. This solution would introduce an opportunity to remove the OTE for smoke control purposes by using TVS fans at both stations for exhaust whilst maintaining make-up air through open controllable PSD dampers. It should be noted that this is only a concept and has not been implemented in any Australian rail infrastructure projects as far as the authors are aware at the time of writing this paper. This solution may be cost prohibitive noting the additional equipment that would be required as part of the PSD assemblies.

4 ANALYSIS DESCRIPTION

4.1 *Overview*

Noting that the proposed pressure differential reduction concept using controllable PSD dampers has not been observed by the authors for the proposed function, a proof-of-concept analysis was completed to evaluate its effectiveness. Three Dimensional (3D) Computational Fluid Dynamics (CFD) was used to compare pressure differential with and without controllable PSD dampers.

The objective was to determine whether open PSD dampers could reduce pressure differentials between the trackway and platform.

Two scenarios were modelled: one without PSD dampers and one with open PSD dampers. A typical underground station geometry was used in the simulations, with the tunnel ventilation system (TVS) and over-track exhaust (OTE) systems configured in exhaust mode. The PSD dampers were modelled as openings located above closed PSDs.

4.2 *Modelling software*

The simulations were carried out using OpenFOAM, an open-source CFD software package. The steady-state solver SimpleFoam was employed to model the airflow within the station environment. Post-processing of the CFD results was conducted using ParaView, enabling analysis of pressure contours and velocity vectors across the station domain.

4.3 *Methodology*

The key focus of this study was to observe the effect that the PSD dampers had on static pressure distribution across the platform and trackway boundary with and without the open PSD dampers. PSDs are closed in all scenarios. Figure 2 illustrates the simplified underground station geometry used and applied boundary conditions (BC).

Two 120m^3/s exhaust flowrate boundary conditions (green) were implemented to simulate a typical exhaust flow rate of a TVS system. Eight 5m^3/s exhaust flow rate boundary conditions (red) were implemented to simulate a typical exhaust flow rate of an OTE system with a total exhaust of 40m^3/s evenly distributed across the eight OTE openings.

A volumetric condition was implemented (blue) which implicitly induces a velocity-dependent pressure loss to simulate realistic aerodynamic drag and frictional losses associated with the resistance to airflow experienced in long tunnel sections either side of the trackway.

Station entrances were defined with boundary conditions set at ambient pressure to represent make-up air inlets. A simplified train was stopped at the station (purple). Seven opening to represent open PSD dampers were evenly distributed along the length of the platform above head height. Each PSD damper opening has a free-flow area of 1m^2, giving a total of 7m^2 area of pressure-relief air path between the platform and the trackway.

The analysis was performed under steady-state conditions to represent a snapshot of the ventilation response during a trackway fire scenario. The numerical CFD simulations were performed using steady-state Reynolds-Averaged Navier-Stokes (RANS) method. For the turbulence model, the k-ω SST model was applied. A structured meshing approach was used to ensure adequate resolution across key flow regions, with increased mesh refinement imposed at the PSD damper opening interfaces.

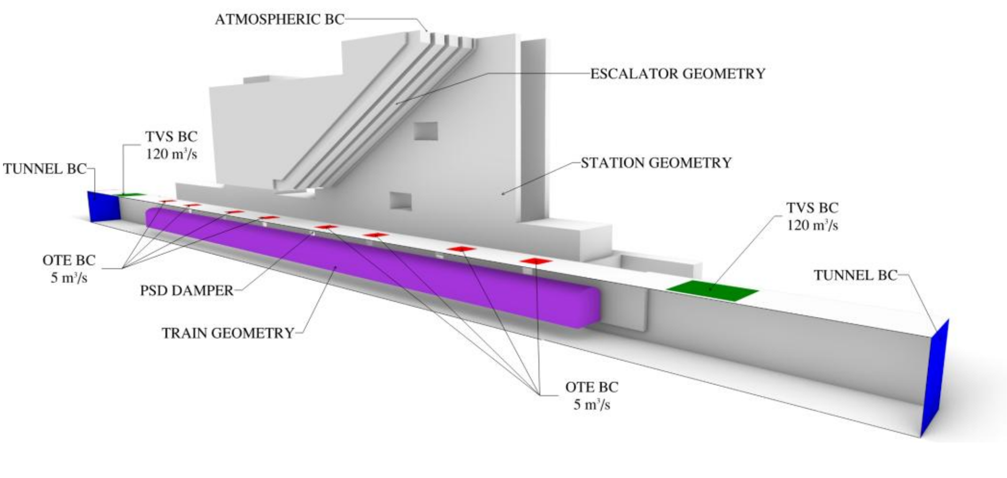

Figure 2. Simplified station geometry used for the 3D CFD study with applied boundary conditions.

5 RESULTS

5.1 *Without PSD dampers*

Results from the base case scenario without PSD dampers and closed PSDs are shown in Figure 3 (plan) and Figure 4 (section). There is minimal pressure variance across the length of the platform on the trackway. Assuming the platforms are at close to ambient pressure, the net static pressure differential between the trackway and the platform is approximately -215Pa. As discussed in Section 3.3, this pressure differential of -215Pa between the trackway and platform is an exceedance of the typical limits to maintain EED opening forces less than 220N.

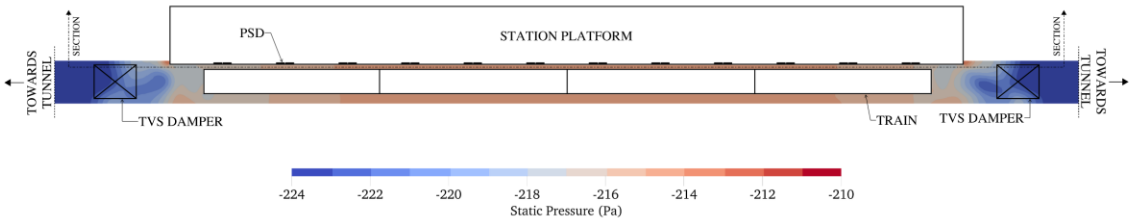

Figure 3. Static pressure profile at 1m above platform floor without PSD dampers – plan view.

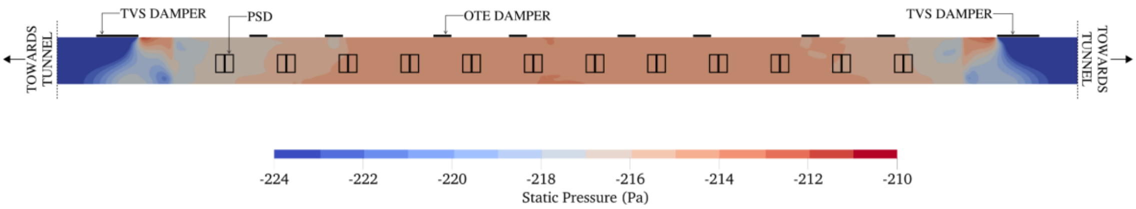

Figure 4. Static pressure profile between train and PSDs without PSD dampers – section view.

5.2 *With PSD dampers*

Results from the case with open PSD dampers are shown in Figure 5 (plan) and Figure 6 (section). There is minimal pressure variance across the length of the platform. Assuming the platforms are at close to ambient pressure, the net static pressure differential between the trackway and the platform is approximately -120Pa. This results in the pressure differential between the trackway and platform being reduced by almost half in comparison to without open PSD dampers and therefore the pressure differential is within typical limits to maintain EED opening forces less than 220N.

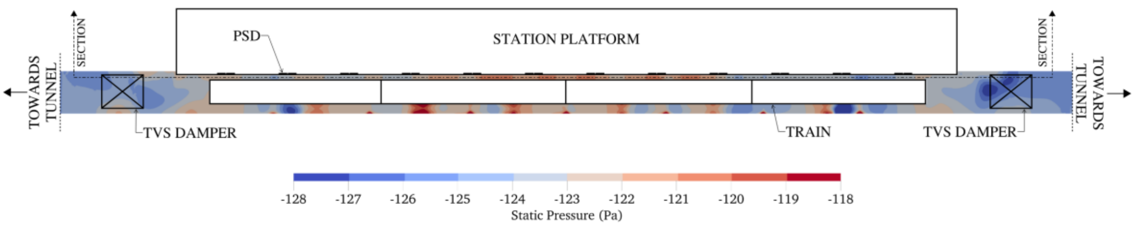

Figure 5. Static pressure profile at 1m above platform floor with open PSD dampers – plan view.

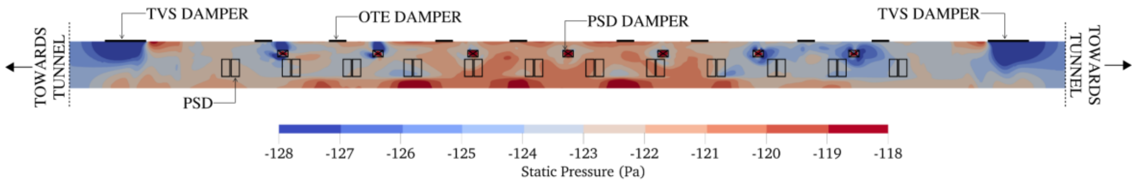

Figure 6. Static pressure profile between train and PSDs with open PSD dampers – section view.

6 CONCLUSION

Consideration should be given to mitigate excessive negative static pressure differences between the trackway and the platform due to the operation of the tunnel ventilation system such that acceptable door opening forces are not exceeded. A range of strategies exist to mitigate this issue.

The concept of using controllable dampers as part of PSD assemblies can also help mitigate excessive negative static pressure differences between the trackway and the platform due to the operation of the tunnel ventilation system. This could present an opportunity to optimise tunnel ventilation systems as it allows the full tunnel ventilation fan capacities at either station end to be utilised with a reduced risk of excessively depressurising the trackway during a tunnel or trackway emergency response when PSDs remain closed.

Example performance of this concept has been demonstrated using 3D CFD analysis. An analysis of the results of an underground rail station experiencing TVS induced air flowrates indicate that the net negative static pressure difference between the trackway and the platform when PSDs are closed can be significantly reduced using PSD dampers facilitating evacuee manual EED operation. Further reductions in the static pressure differences across EEDs could be explored using greater controllable PSD damper free areas e.g. with greater damper opening areas and/or total damper opening numbers. Pressure differences between the trackway and platform with closed PSDs and open controllable PSD dampers will ultimately depend on the specific station geometry, tunnel ventilation system arrangement and response and therefore any controllable PSD damper solution should be uniquely considered for each project.

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