EXAMINING TUNNEL VENTILATION IN A POINT EXTRACT-SUPPLY TUNNEL

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ABSTRACT

The rehabilitation of a highway tunnel in the United States resulted in an underground ventilation building with an eccentric ventilation layout, see **Figure 1**. The point extract-supply was retrofitted with a damper door at the interface.

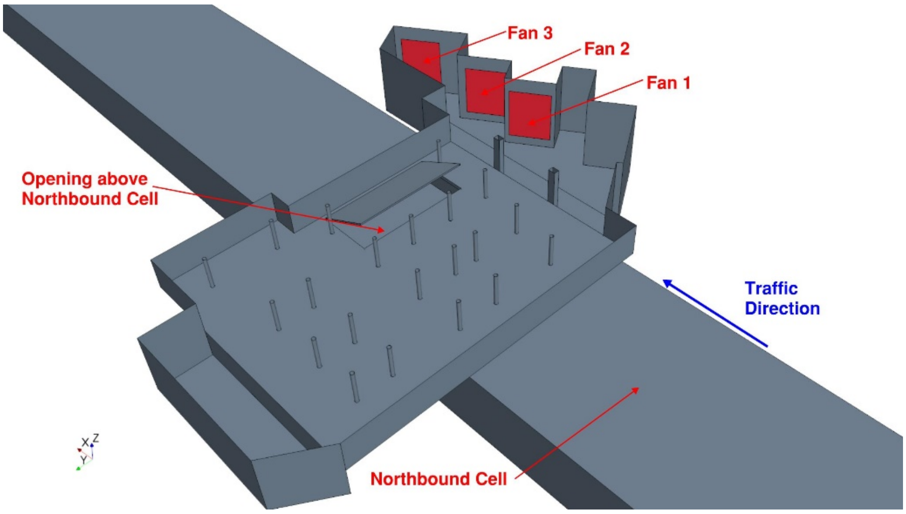

Figure 1: Eccentric Ventilation Layout

Very high velocities, in excess of 80 km hr^{-1}, resulted in a small area, approximately 3m by 5m, on the roadway. The damper door arrangement also resulted in a Saccardo nozzle effect and generated a strong longitudinal flow on the tunnel roadway.

This paper presents the ventilation arrangement as designed, the high velocities determined on the roadway, and the solutions established. Computational Fluid Dynamics was used to establish the solution and the model results were field verified.

Keywords: Tunnel Ventilation, Airflow, Saccardo nozzle, Computational Fluid Dynamics, CFD, physical tests

1. INTRODUCTION

A road tunnel rehabilitation was recently completed in the United States. The rehabilitation resulted in the installation of a new underground ventilation building under a park in an urban area. The ventilation building was not located directly over the tunnel roadway, instead it was located to one side. Further, due to limitations on the surface for excavation, the tunnel ventilation building was oriented about 60° from the direction of travel. This resulted in a non-normal alignment of the tunnel ventilation fans relative to the roadway, see **Figure 1**.

To bring air from the fans to the roadway, a large air plenum was available due to the original construction of the tunnel. The air plenum is a common airflow path connecting three separate roadway tunnels. The penetrations to the roadway were limited due to structural concerns which resulted in air velocities of approximately 15 m s^{-1} without obstructions in the penetration. These openings were covered by a flat damper door arrangement to prevent higher air velocities through the penetration, see **Figure 2**.

Figure 2: View of damper installation

Each of the three tunnel ventilation fans have a high speed capacity of 375 m^3 s^{-1}. Each is designed with a full speed and a half speed and are bi-directional.

The eccentric floor plan, alignment of the fans, and high velocities through the penetrations, coupled with the damper doors, resulted in two physical phenomena:

1. The damper doors with the high air velocities resulted in a Saccardo nozzle effect on the roadway. Airflow was induced from the portal by the impulse of the airflow downstream of the penetration.
2. A vortex was generated that resulted in high velocities, in excess of 80 km hr^{-1}, in a approximately 3m by 5m area, on two roadways.

Two roadways were affected by this phenomenon. On the Northbound roadway the Saccardo nozzle effect was beneficial and resulted in an improvement in performance. On the adjacent roadway the Saccardo nozzle acted opposite to the direction of traffic which resulted in reduced fire protection performance.

The solution to this dilemma was established using computational fluid dynamics (CFD). CFD modelling guided the development of simple airflow improvement solutions which drastically enhanced the airflow induced at roadway level; demonstrated herein by the predicted airflows and the verified field measured data. Simple solutions were modelled such as redirecting airflows to disrupt the vortex effect and louvers to redirect the airflow to the roadway. These solutions are presented in the following sections.

The use of CFD resulted in low cost solutions that fit within the existing air plenum geometries and minimized roadway closures.

It is notable that the solution to reverse the airflow in one roadway resulted in a reverse Saccardo nozzle effect with simple straight blade louvers.

Figure 3: Photos of dampers and installation

2. NORTHBOUND TUNNEL – HIGH AIR VELOCITY

Solutions modeled and subsequently established using CFD, were then implemented in the field and field verified. This section summarizes the results of the field testing before and after the modifications were implemented.

Table 1: Northbound Roadway Results

Case No.	Configuration	Ventilation Response	Reading location	Field Measurements
3.	Initial Installation	Supply (3 Fans at Full Speed)	Downstream	3.3 m s^{-1} with local velocities reaching 28.4 m s^{-1}
4.	Post Modification	Supply (3 Fans at Half Speed)	Downstream	3.56~4.07 m s^{-1}

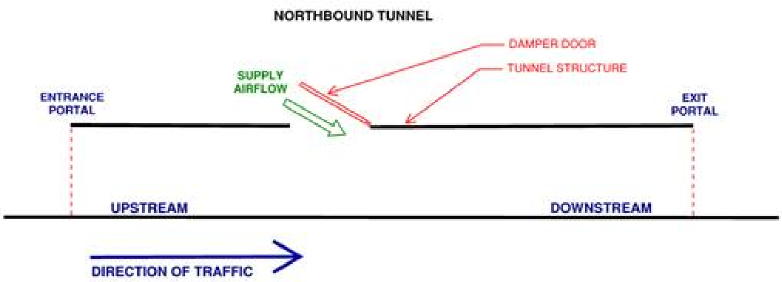

Figure 4: Schematic showing measurement locations

Modelling accurately replicated the high air velocities occurring on the Northbound Roadway as shown in **Figure 5**. Modelling results show a small, intense region on the roadway level with air velocities of 25 m s^{-1} or 90 km hr^{-1} winds. This predicted velocity and location compared well with field measurements which were approximately 88 km hr^{-1}. The field measurements were performed with an axial flow vane anemometer and the high velocity was out of range for the instrument.

To determine why the high velocities were occurring, the velocity vectors in the air plenum were reviewed, see **Figure 6**. These vectors revealed strong airflows crossing the ventilation opening and swirling behind the damper door. The airflow vectors in region 1 of **Figure 6** show an arch away from the damper door as it descends through the opening in a focused manner. Further airflow is entering the opening with a strong cross velocity originating in front of the opening, see region 2 in **Figure 6**. Last, there was strong flow circulating around the back of the damper and feeding additional air velocity at the side of the damper, see region 3 in **Figure 6**.

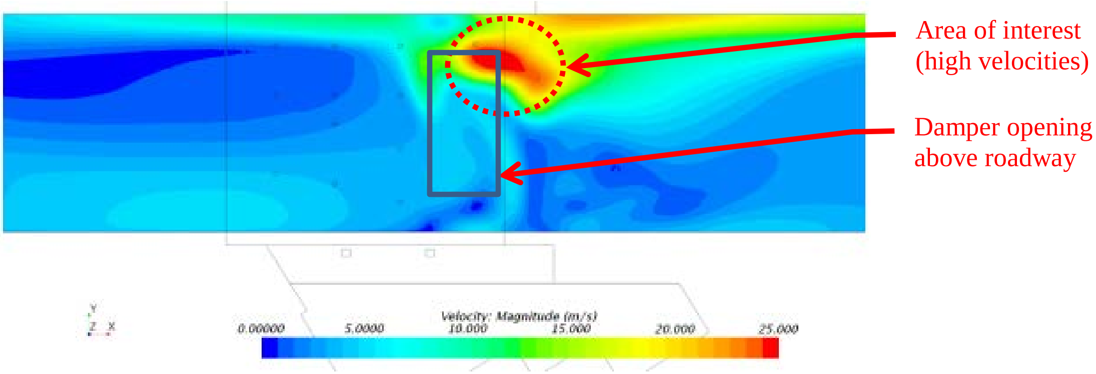

Figure 5: CFD Airflow Predictions "Before" – Roadway Level

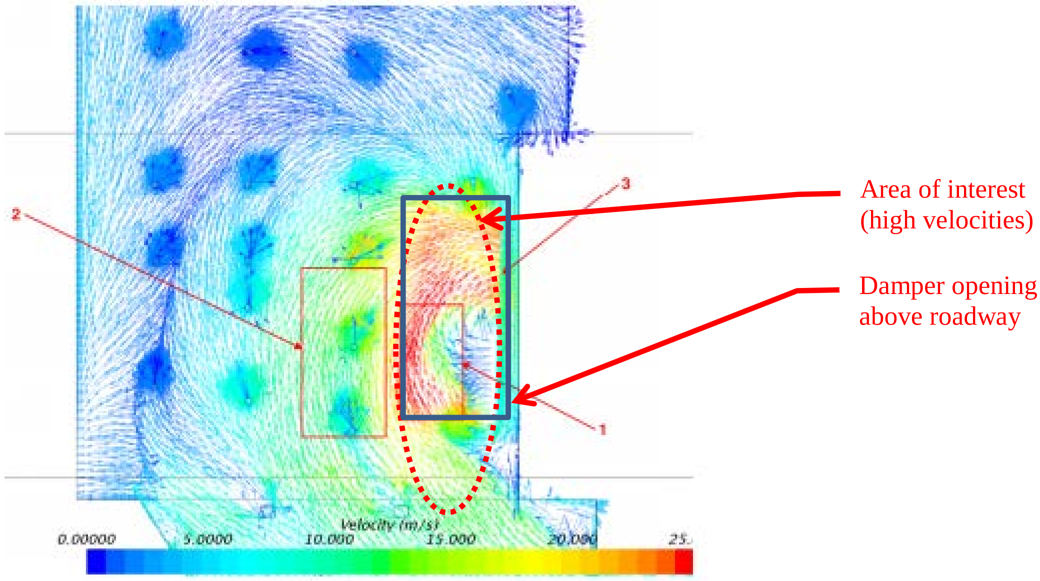

Figure 6: Results of "Before" simulations – air plenum

Based on the location of the swirling flow, air baffles were added at specific locations within the air plenum with the intent to improve the flow distribution through the opening. Further, the fan operation was changed from three fans operating at full speed to three fans operating at low speed. See **Figure 7** for a view locating the air baffles.

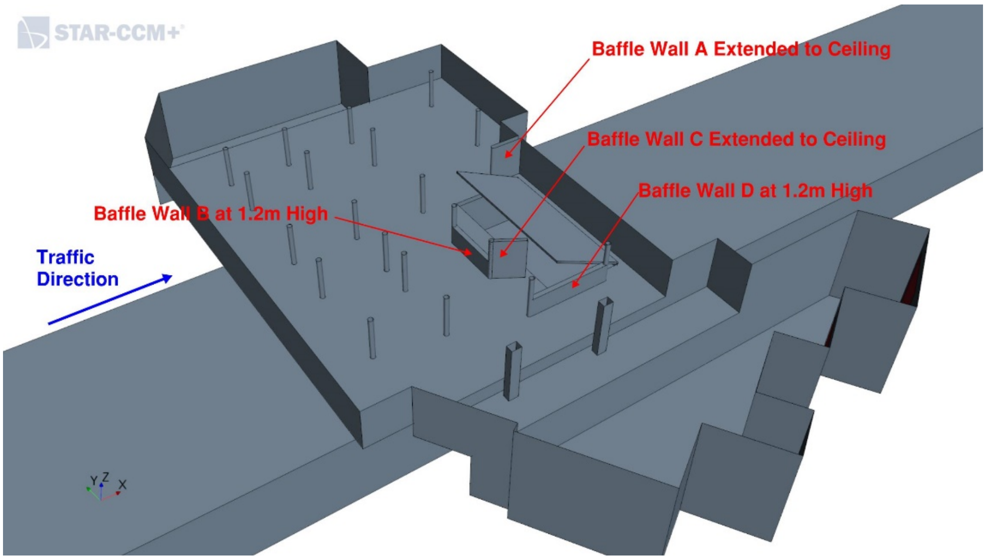

Figure 7: CFD rendering of air baffle arrangement

Reducing the fan airflow resulted in lower air velocities and placing the baffles in the prescribed locations resulted in a more evenly distributed airflow, see **Figure 8**. As shown previously, field measurements confirmed the improved performance. The actual installation is shown in **Figure 9**.

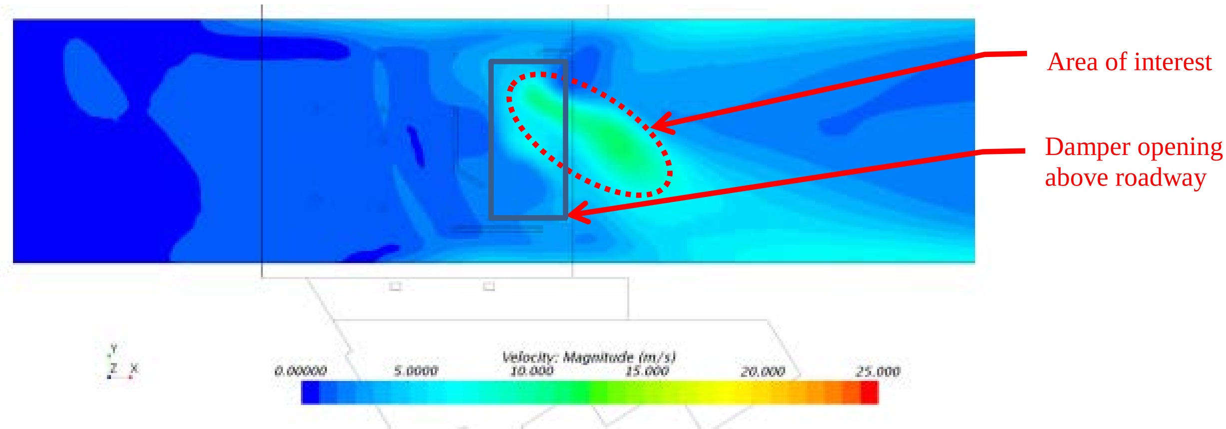

Figure 8: CFD Airflow Predictions "After" – Roadway Level

Figure 9: Photos of air baffles

3. ADJACENT TUNNEL – AIR VELOCITY REVERSAL

Solutions modeled and subsequently established using CFD, were then implemented in the field and field verified. This section summarizes the results of the field testing before and after the modifications were implemented.

Table 2: Adjacent Tunnel Results

Case No.	Configuration	Ventilation Response	Reading location	Field Measurements	Notes
3.	Initial Installation	Supply (2 Fans at Full Speed)	Toward the entrance portal Toward the exit portal	6-7 m s^{-1} toward the entrance portal 0.7 m s^{-1} toward the exit portal	Local high velocities, along with low velocities recorded downstream of the damper. Ventilation response was revised.
4.	Post Modification	Supply (1 Fan at Full Speed)	Toward the exit portal	4.06~4.19 m s^{-1}	

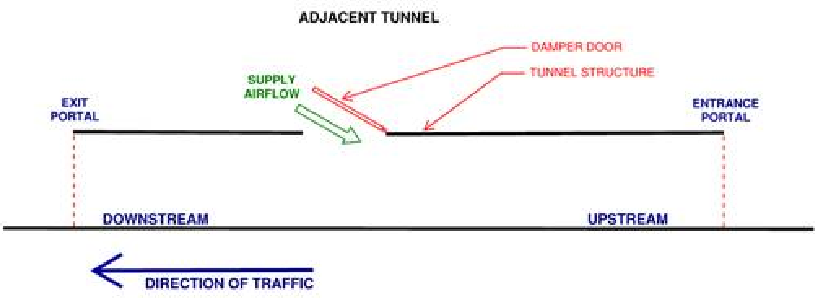

Figure 10: Schematic showing measurement locations

The adjacent tunnel contains a single traffic lane. The orientation of the damper forces air longitudinally toward the entrance portal via the Saccardo nozzle effect instead of the desired direction, see **Figure 11**. In addition to flow moving in the wrong direction, localized high air velocities were experienced on the roadway, see **Figure 12**.

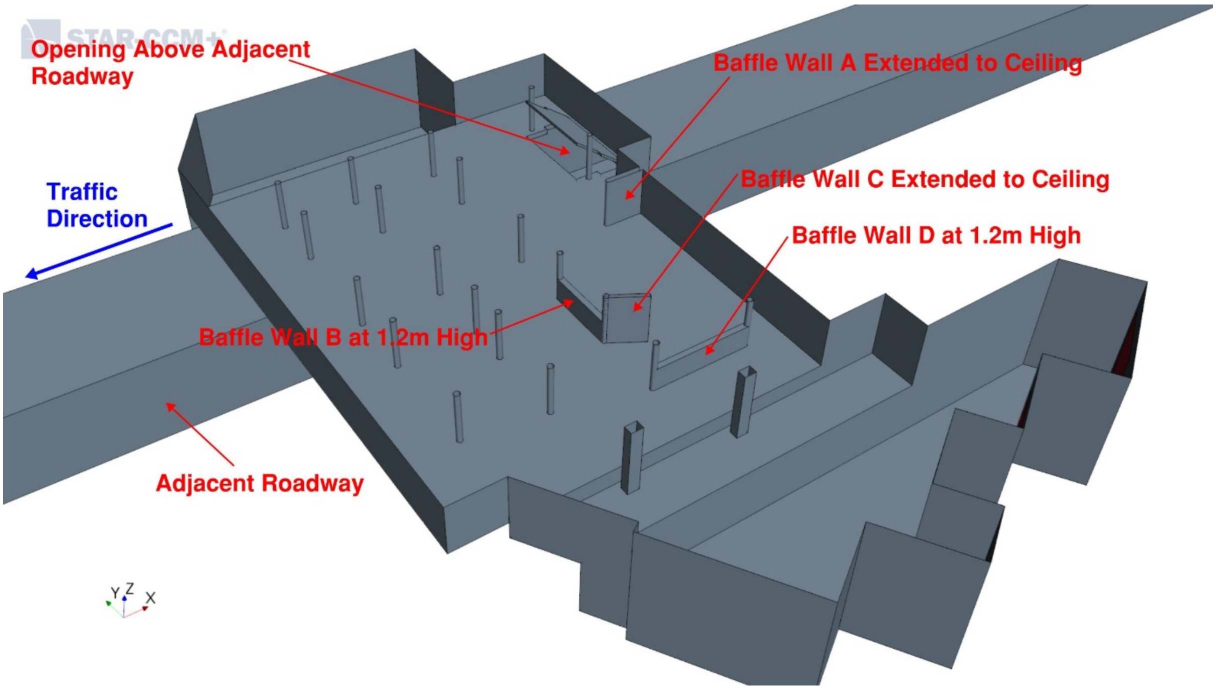

Figure 11: CFD Rendering of adjacent tunnel with damper

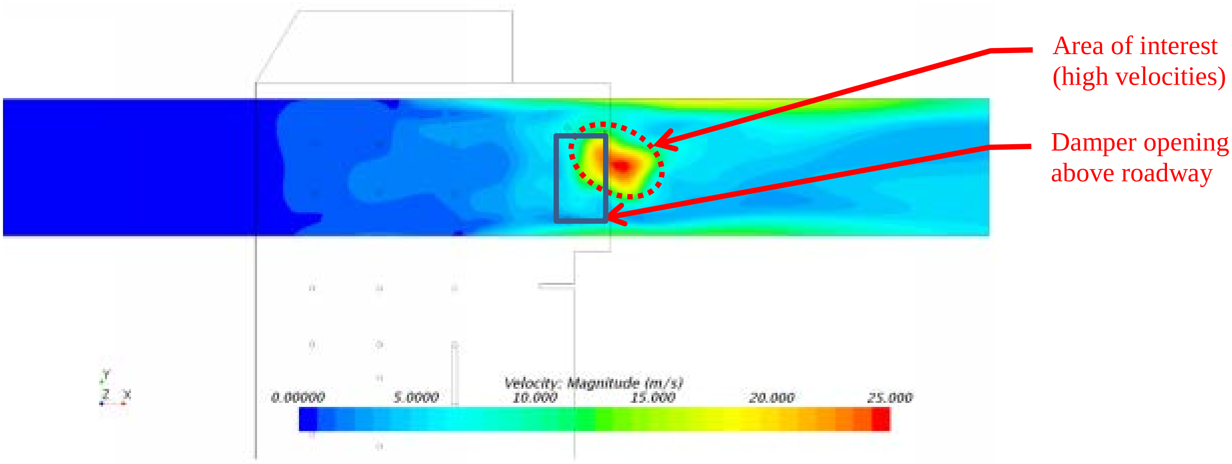

Figure 12: CFD Results showing induced longitudinal airflow toward the entrance portal

Since the airflow had to be reversed on the roadway level, a solution of adding deflector vanes, see **Figure 13**, in the ventilation opening was immediately modelled with one fan on high speed instead of two fans on high. The stiffeners in the vanes are expected to disrupt the vortex flows that produce the high velocities on the roadway. Halving the airflow is also expected to alleviate these issues.

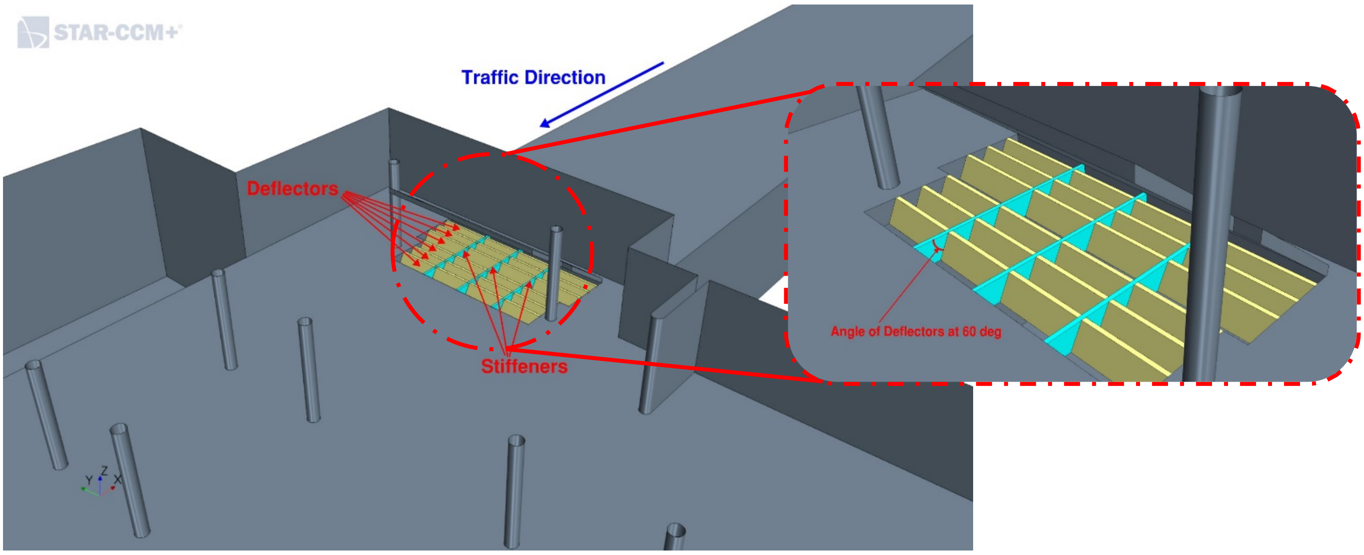

Figure 13: CFD Rendering showing louvers used to redirect flow

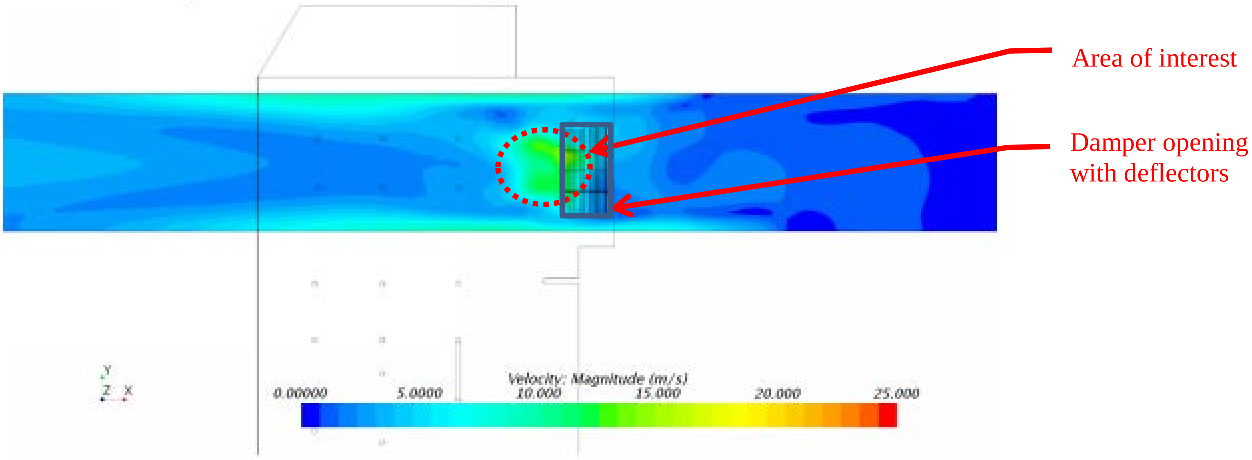

Figure 14: CFD results showing redirected flow and airflow distributions.

The velocity contour in **Figure 14** shows that the deflectors successfully distribute the airflow and fully reverse the airflow in the tunnel. All flow generated by the fans moves from the supply point to the exit portal. There are minor flows entering the entrance portal.

Figure 15: View of installed air vanes from the roadway.

4. CONCLUSIONS

The changes implemented were cost effective and limited required active roadway closures to implement. The removal of the vortex effect was effective without impairing the Saccardo nozzle effect. Most notable was a full flow reversal on the roadway with a simple straight bladed louver installation.