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A highway tunnel portal: A case study for ground-level wind mapping

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SUMMARY:
The present study investigates the observational surface wind speed in the immediate area of a highway tunnel portal. Since winds in such public open spaces have a great impact on human activities and safety, especially wind snow drifting and accumulation, rain driving, polluted air recirculating, and siting of micro-turbines, investigating wind speed levels are necessary for assessment purposes. The quantitative analyses of the ground level (at 1 m) wind speeds are based principally on wind tunnel modeling. The experimental methodology for such simulation is discussed and typical characteristics of the subject site winds are provided. The study provides some practical generalizations and confirms such constructions are best modeled in an appropriate wind tunnel to anticipate at the early planning stage the benefits and detriments of winds.

Keywords: wind tunnel, wind outdoor conditions, wind speed.

1. INTRODUCTION

The design of the highway tunnel would require several parameters to be taken into account, mainly travel lane and shoulder, sidewalks and emergency egress walkway, drainage, ventilation, lighting, and traffic control (Hung et al., 2009). In addition, tunnel portals may require additional careful design considerations. Wind may interfere in different scenarios, including wind lifting dust and ice particles to the cars, driving rain, and recirculating polluted air. Other fields of application, on the other hand, include the potential use of the land surrounding the tunnel portal for the siting of micro wind turbines. Therefore, designers concerned with the wind outdoor environments will have to address these issues.

The focus of the previous studies on wind outdoor environments was limited to built-up areas, including pedestrian comfort studies (Blocken et al., 2016), driven rain and snow (Ge et al., 2018; Tominaga & Stathopoulos, 2020), and pollutant dispersion (Cui et al., 2021). Furthermore, some studies have dealt with the terrain and land topographical features effects (Stathopoulos and Alrawashdeh, 2020). The present experimental study is practically inspired by maximizing the benefits and minimizing the detriments of winds for regions surrounding tunnel portals. As these regions are commonly typified by sufficient open areas.

The north portal of the Louis-Hippolyte Lafontaine (LHL) Tunnel in Montreal has been used as a case study for a ground-level wind map using an atmospheric wind tunnel. The surface roughness in the vicinity of the portal is relatively low, and the terrain is fairly open. The assembly of a meteorological mast at the portal of the LHL tunnel consists of a Lufft WS800 compact smart weather sensor and an SPN1 sunshine pyranometer of Delta-T Device, a CR1000 data logger by Campbell Scientific, and a Sierra cellular modem RV50. The measurement instruments (WS800 and SPN1) are installed at 10 m height above the ground. The data concerned in this study include the wind speed and direction averaged over a period of 1 hour.

2. WIND TUNNEL SIMULATION

The north portal of the LHL Tunnel surroundings is scaled down to be tested in the Boundary Layer Wind Tunnel at the Building Aerodynamics Laboratory of Concordia University. For the simulated terrain exposure, Fig. 1 shows longitudinal mean wind velocity (V/V_g) and turbulence intensity (I_u) of the wind tunnel approaching flow. The profiles were measured at the test section in place of the model using a 4-hole Cobra probe.

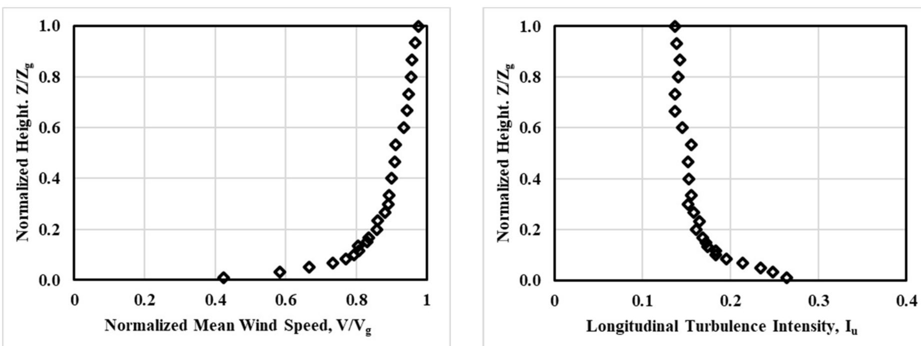
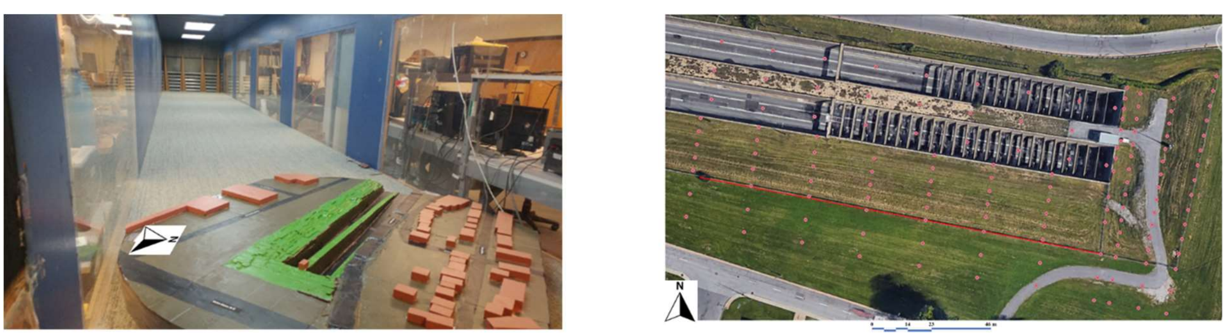


Figure 1. Velocity and turbulence intensity profiles of the wind tunnel flow (Z_g is the gradient height and V_g is the velocity at gradient height)

Based on the selected geometric scale (1:200), it is considered for the wind tunnel simulation the surrounding within a circle of diameter 320 m (to fit with the tunnel width at the test section, 1.6 m). An upstream view of the working section with the model of the north portal of the LHL Tunnel and its surroundings is shown in Fig. 2 (a).



(a) (b)

Figure 2. (a) Upstream view of the wind tunnel with the model, and (b) Illustration of the measurement points on the subject site

3. WIND TUNNEL RESULTS

Histograms of the derived on-site wind speed frequency in hours were calculated for the entire grid points illustrated in Fig. 2 (b). The detailed analysis of the percentage of hourly mean wind speed for several locations, which are not provided for the sake of brevity, pointed to the fact that the vicinity of the tunnel entrance is exposed to mean wind speed in the range of 2 m/s to 8 m/s at different frequencies (i.e., 20% - 30%).

Considering that the orientation of the portal is direct to the northwest, which may cause a blinding sun glare for drivers by sunsetting, roofing over the tunnel portal would be a safety-ameliorating measure. Certainly, such a roofing system would not only shelter the tunnel from weather conditions such as sun, hail, snow, and rain, but also it would minimize the blinding sunlight if a semi-transparent or transparent photovoltaic canopy were used.

The proposed design structure (i.e., simple arched canopy) for the roof of the LHL Tunnel's portal has been investigated from wind aerodynamic perspectives. That is to assess how the proposed canopy affects the surface winds, particularly along its passages' centers and around the portal. The model of the proposed canopy is placed to the wind-tunnel model of the LHL Tunnel. The canopy model length, width, and height are 70 cm, 3.4 cm, and 6.8 cm, which are equivalent to 140 m, 6.75 m, and 13.5 m in the field, respectively – as shown in Fig. 3.

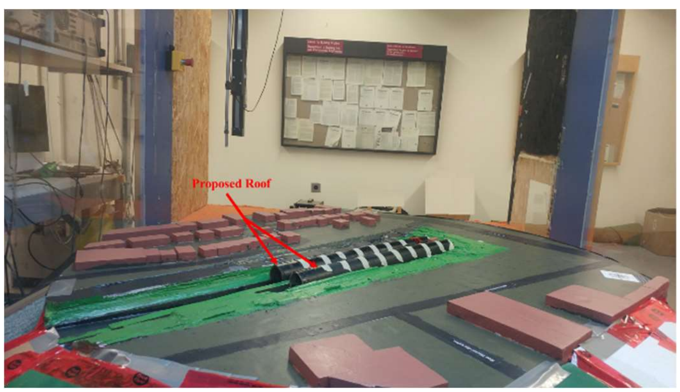
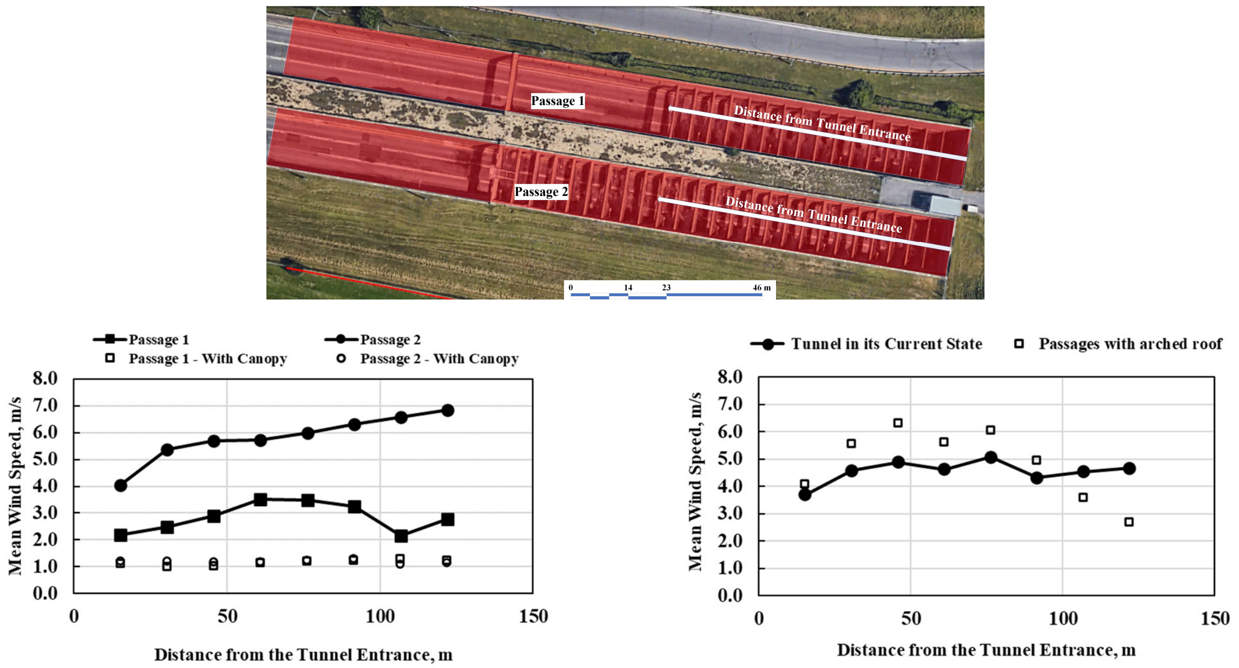


Figure 3. Photograph of the wind tunnel model with the proposed arched canopy

Fig. 4 shows the variation of the wind tunnel mean wind speed for the situations with and without the canopy, along its passages center and the middle zone between the passages. The results demonstrate that the wind speed along the passages of the tunnel is dramatically reduced in the presence of the canopy – see Fig. 4 (a). As observed in Fig. 4 (b) for middle zone between the passages, the mean wind speed values within a distance of 90 m from the tunnel entrance are increased and decreased as drawing closer to the proposed canopy entrance (i.e., at distance 100 m and farther away).

The results provide supporting evidence that the roofing configurations over a highway tunnel portal would greatly improve the outdoor wind environment. It serves to avert the downwash on the tunnel entrance and positively influences wind over considerable areas for the siting of micro wind turbines.



(a) (b)

Figure 4. Comparison of the mean wind speed at 1.0 m from the ground surface: (a) along the center of the tunnel passages, and (b) between the passages

CONCLUSION

The use of boundary-layer-wind-tunnel model studies to map ground-level wind in the vicinity of the highway tunnel portals appears very beneficial, particularly for the assurance of safety. For a specific site, considering the weather condition, the tunnel orientation, land-topographical features, and surroundings, it is proved that the roofing over the tunnel portal would alleviate wind-related issues (hail, snow, rain, and pollution).

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