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# Computational evaluation of peak wind induced pressures on buildings

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**SUMMARY:**
Computational wind engineering for structural applications has progressed in the last decade and the focus of the community has turned into generating uniform procedures to calculate peak values of wind-induced loads. The present research targets to contribute to this direction by using a novel approach for modelling the high turbulent wind in the lower ABL that interacts with buildings. The Dynamic Terrain method is based on introducing at the computational inlet plane experimental velocity time-series, for different terrain roughnesses. LES has been applied in this study, in which vortices smaller than the filter size (sub-grid) are modelled and related with high frequency fluctuations, playing a key role in the peak pressures on the building envelope. Due to the nature of LES, these small scales are depicted with a loss of energy compared to experimental findings by the traditional methods in the current state-of-the-art. The Dynamic Terrain method reduces this drop of energy; thus, the high frequency velocity fluctuations are expressed more accurately. The numerical peak pressure coefficients on the building envelope are in good agreement with those established experimentally, while the computational burden and complexity of the included procedures is reduced for practical use.

*Keywords: computational wind engineering, LES, dynamic terrain method*

## 1. INTRODUCTION

The chaotic nature of the wind flow can be translated in physical terms by the large range of length and time scales, in which the various vortices fluctuate and interact with each other and solid surfaces. The computational and analytical understanding of this interaction with building surfaces, has been the subject of research of structural computational wind engineering in the last decades (Potsis et al., 2023). After many significant contributions, the field has reached a stable state and focus is given in LES applications that can capture the peak loads on building envelopes.

The present endeavour works on these lines by using a novel approach to model the turbulent flow in the lower atmospheric boundary layer (ABL). The so-called Dynamic Terrain method utilizes wind tunnel velocity time series as inlet conditions in the computational domain (Potsis and Stathopoulos, 2022). The experimental procedure to extract the velocity time series is discussed in Section 2 and the details of the novel numerical approach are in Section 3. Results in terms of peak pressure coefficient values are presented in Section 4 with comparisons among experimental procedures. Future challenges for the improvement of the numerical method are also stated in Section 4. Finally, the last Section refers to conclusions and future targets.

## 2. EXPERIMENTS

The experimental procedure to extract wind tunnel velocity time series was conducted in Concordia Wind Tunnel and the schematic of the wind tunnel is presented in Fig. 1. The velocity field is measured 0.40 m after the last roughness element, at 22 vertical locations. In Fig. 1 the schematic of the computational domain is also presented, that starts at the aforementioned location and ends at the end of the wind tunnel. The building is located after 1.25 m, at the centre of the turntable. The length scale was selected to be 1:400, thus the first 200 m of the ABL where modelled.

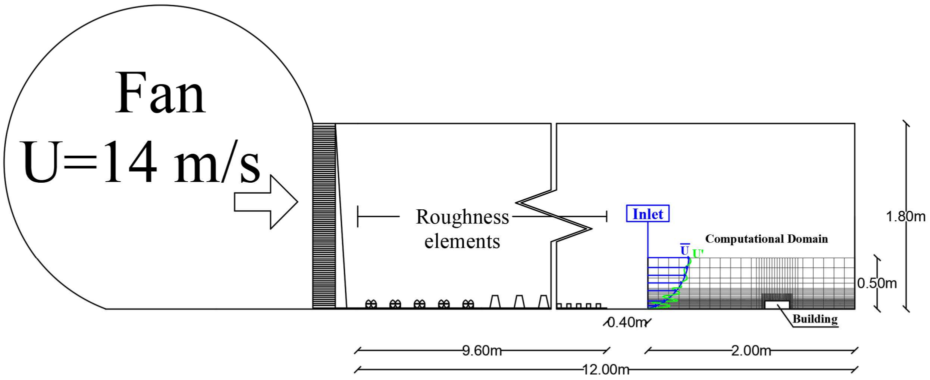

**Figure 1.** Concordia wind tunnel schematic.

## 3. DYNAMIC TERRAIN COMPUTATIONAL APPROACH

The time series measured from the wind tunnel are inserted uniformly in the horizontal direction and at the same vertical positions on the inlet plane of the computational domain, where the Navier-Stokes are solved by using the LES approach. The inlet frequency of the imposed velocities proved to play a key parameter in order to express accurately the spectral content of the longitudinal velocity, at the location where the building will interact with the fluctuating wind flow (Potsis and Stathopoulos, 2022). In Fig. 2(a) the turbulence intensity of the streamwise velocity from the experiments of TPU (Aerodynamic Database, 2013) and the Dynamic terrain method are presented.

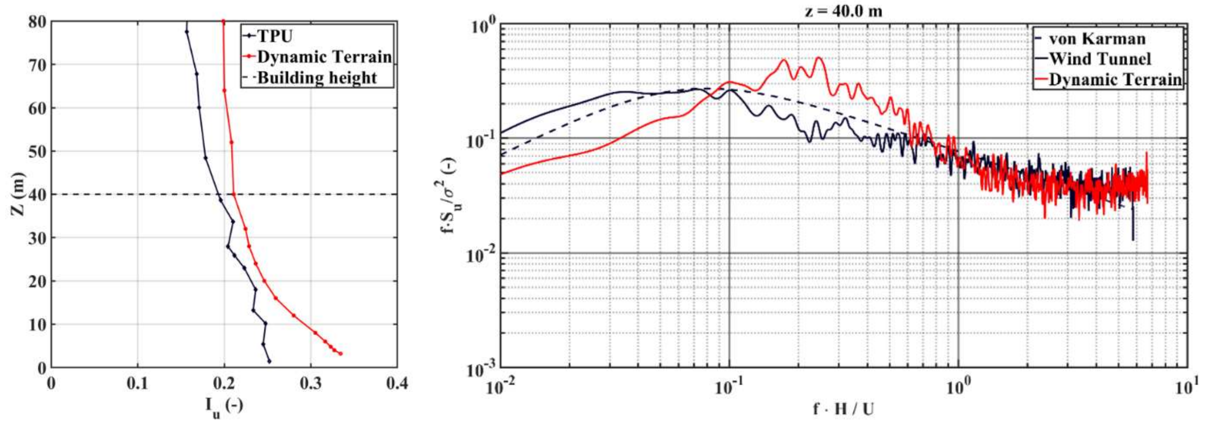

**Figure 2.** (a) Mean and turbulence intensity distribution from experiments and computational results, (b) Normalized spectral content for z=40 m in full-scale at the building location.

The spectral content for the height of interest is presented in Fig. 2(b) in the building location, in terms of normalized components, where f is the frequency, S is the power spectral density, σ is the standard deviation of the velocity time series, H is the building height and U is the mean velocity. The results more accurately depict the high-frequency energy of the fluctuations, when compared with current state-of-the-art works, e.g. Lamberti et. al (2018), Melaku and Bitsuamlak (2021).

## 4. PEAK PRESSURES ON BUILDINGS

The building selected for the study has full-scale dimensions B x D x H = 20 m x 20 m x 40m, for which experimental results are available in TPU database (Aerodynamic Database, 2013). Virtual pressure taps are inserted in the computational model of the building, at the same locations as the 200 pressure taps on the model of TPU. The computational domain was constructed by considering a y+ mean value less than 5, and consists of 4 million computational cells. More details regarding numerical set-up (e.g., turbulence model, numerical schemes etc.) will be discussed thoroughly in the presentation. Pressure coefficients are calculated by normalizing the instantiations pressures with the dynamic pressure at roof height. Extreme value analysis is conducted to calculate the peak values of the pressure coefficient by using the Gumbel distribution (Type 1). The Best Linear Unbiased Estimator (BLUE) was used to calculate the necessary fitting parameters and the percentage of non-exceedance was chosen as 78% (TPU Aerodynamic Database, 2013). In Fig. 3 (a) the correlation of the mean values between the experiment and the Dynamic Terrain approach is presented and in Fig. 3 (b) the corresponding correlation of peak pressure coefficients for wind direction of 0°, perpendicular to the building envelope.

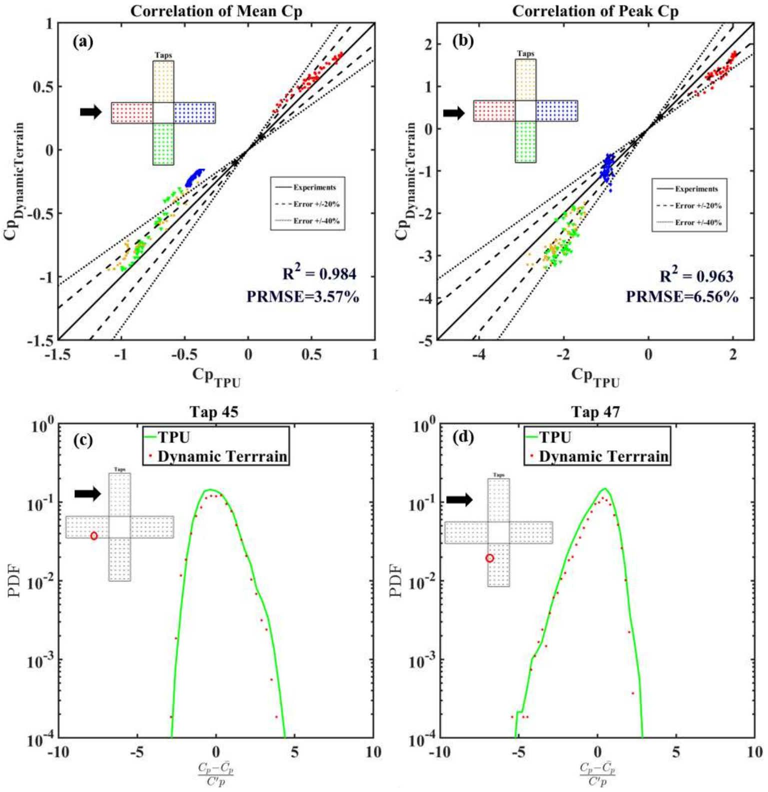

**Figure 3.** Correlation of (a) mean and (b) peak pressure coefficients between experiments of TPU and the Dynamic Terrain Method for 0° wind direction, (c) PDF of wind ward pressure tap, (d) PDF of side pressure tap.

Linear fit of the data produced the regression coefficient $R^2$ and the root mean square error (RMSE), that was normalized with the range of the experimental data. These values are also presented in Fig. 3. Peak values are found to be in promising agreement with experiments for all 200 pressure taps. Local loads were also investigated for design of cladding elements. In Fig. 4 the probability density function (PDF) of the pressure coefficient was calculated for two pressure taps, locate at the windward and side face. Similar accuracy was established for more taps, but it is not presented for clarity. The accuracy of the PDF distribution of the pressure coefficient between experiments and the Dynamic Terrain give a confident outcome for the applicability of the method for cladding elements design.

The basic idea of the Dynamic Terrain Method is to utilize specific velocity time series from wind tunnels to generate different upstream roughnesses in CFD environment, that respect the physical features of the turbulent wind. This necessitates to form a database where these velocities are included and can be used for practical use; a challenge which is currently being addressed by the authors. The range of exposure conditions that the given set of velocities can express is also currently addressed, as to define properly the various velocity time series that will be included in the database with experimental results.

## 5. CONCLUSIONS

A novel computational approach is presented that utilizes wind tunnel velocity time series as inlet conditions in computational domain that uses the LES modelling approach. The target of the procedure is to capture peak pressures on the envelope of buildings sensitive to wind loads for design. An initial tuning process is presented as to calibrate the turbulence statistics and spectral content of the wind field, at the location of interaction with the building in the computational domain. Results for the mean speed, turbulence intensity and longitudinal spectral content match the targets, as measured from wind tunnel experiments. The pressure time series are extracted from equivalent locations as the experimental pressure taps of TPU and treated in the same way as to calculate the peak pressures from each procedure. Peak values corelate very well with the target experiments, and the target level of accuracy is achieved. The method will be expanded soon for more wind directions and for various exposures as to estimate its capacity to simulate all possible conditions needed for design purposes.

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