Effects of environmental conditions on pressures measurement via tubing systems: Experimental study

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SUMMARY:
Accurate measurement of pressures on a structural model in wind tunnel testing is fundamentally critical for estimating accurately wind loads on the structure. Owing to space limitation in a model used in the wind tunnel tests, a tubing system is widely employed to connect the pressure taps on the model to pressure transducers, which results in distorting fluctuating pressures measured via the tubing system. Much research has been performed to investigate the pressure distortion due to configuration of tubing systems under assumption of no effects of environmental changes (e.g., atmospheric pressures and ambient temperature). This study experimentally investigates the effects on the environmental conditions on pressures measured in pressure transducer-tubing systems. Tubing responses were measured in two environmental conditions (i.e., in a hot and cloudy day during the summer and a cold and sunny day during the winter). Wind tunnel testing was also performed to measure pressures on a high-rise building model using the tubing system in the first environmental condition. The results show such differences of environmental conditions can lead to appreciable differences in the transfer functions of amplitude ratio and phase lag. The study shows a dynamic calibration procedure without accounting for different environmental conditions between measurement times of tubing response and pressures on a building model could result in noticeable errors in the characteristics of its corrected pressures (e.g., their standard deviations and peaks).

Keywords: Environmental condition, Pressure measurement, Tubing response

1. INTRODUCTION

Accurate measurement of pressures on a structural model in wind tunnel testing is fundamentally critical for estimating accurately wind loads on the structure. Owing to space limitation in a model used in the wind tunnel tests, a tubing system is widely employed to connect the pressure taps on the model to pressure sensors, which results in distorting fluctuating pressures measured via the tubing system as forms of e.g., resonances, damping, shift of pressure signals. To correct the measured dynamic pressures, calibration procedures are employed as a post-processing technique and/or restrictors in tubes were used as air filters during measurement.

Much research has been performed to investigate the effects of pressure measurements via tubing systems on characteristics of the measured dynamic pressures (Gumley 1983; Holmes and Lewis 1987; Letchford et al. 1992; Yoshida et al. 2001; He et al. 2019). Especially, contributions of configurations of tubing systems to the pressure distortion have been mainly studied under assumption of no effects of environmental changes (e.g., atmospheric pressures and ambient temperature). However, pressure waves propagating within a tubing system experience frequency-dependent distortions are caused not only by dimensions of tubes (i.e., their lengths and inner diameters) but also by the properties of air including the atmospheric pressure, temperature, speed of sound, specific heat, and relative humidity. Since environmental conditions cannot be easily controlled in most wind tunnel testing facilities, variations of the environmental conditions affect thermophysical properties of the air in the tubing system and, consequently, change frequency response of the fluctuating pressures. The National Institute of Standards and Technology (NIST) numerically investigated the effects of changes in atmospheric pressure, temperature, and humidity on the transfer functions (Kovarek et al. 2018). As shown in Figure 1, the study confirmed that variation of atmospheric pressure and temperature can noticeably influence on the amplitude transfer function while the effect of humidity is negligible. However, their impact on pressures were not investigated.

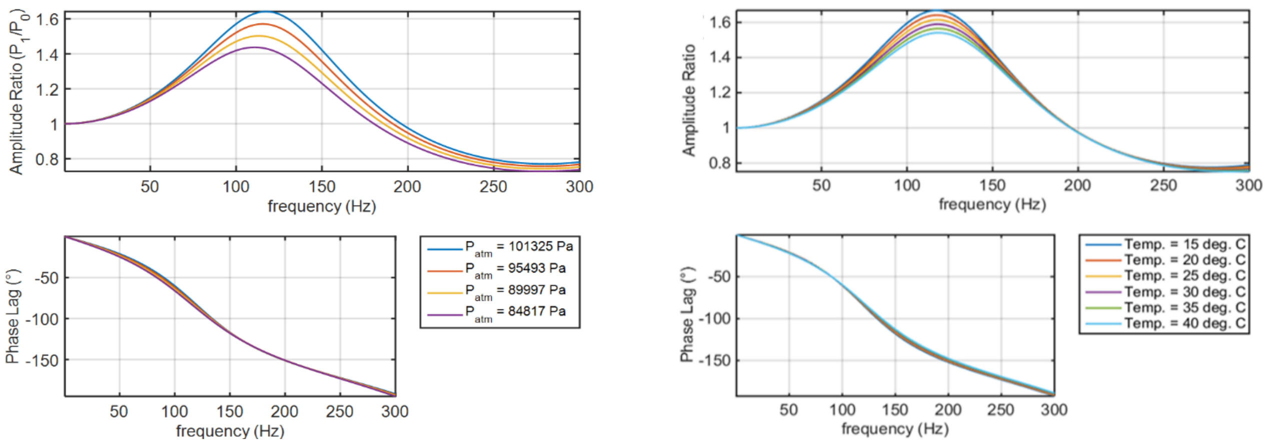

Figure 1. Effects of variation of atmospheric pressure and temperature (Kovarek et al. 2018).

In the present paper, we investigate the effects of environmental conditions on experimental transfer functions of tubing systems and, ultimately, on pressures on a building model measured through the tubing systems. The paper first describes details of the experiments for measurements of tubing response and pressures on a building model in two different environmental conditions. We then present comparison of the two sets of transfer functions estimated in the two environmental conditions and their influence on the pressures measured through pressure transducer-tubing systems.

2. EXPERIMENT SETUP

Pressures on a building model under a suburban approach flow were measured via tubing systems in the open-circuit wind tunnel testing facility of Tokyo Polytechnic University (TPU) whose testing section sizes are 2.2 m in width, 1.8 m in height and 19 m in length. We used a high-rise building model with pressure taps, multi-channel pressure scanners, and tubing systems connecting pressure transducers to the pressure taps on the building model. The building model in a 1:400 length scale (Figure 2) has 98 mm in width (W), 65.3 mm in length (L), and 760 mm in height (H) whose ratio is W:L:H = 1.5:1:11.64. It has total 304 taps on the surfaces of the model, consisting of 95 taps (= 19 rows × 5 columns) on the faces with a larger surface area ($W \times H$) and 57 taps (= 19 rows × 3 columns) on the faces with a smaller area ($L \times H$). The multi-channel pressure scanners (model: ZOC23B-OG, manufacturer: Scanivalve and Other Giken) simultaneously measured 64-channel pressures at the sampling frequency of 800 Hz. As shown in Figure 3(a), tubing systems were employed to connect pressure transducers of the scanners to pressure taps on the building model's envelope. Figure 3(b) shows the components of the tubing system: a pressure tap tabulation, an outer tube, a coupler, and an inner tube. The half the coupler, the inner tube and the pressure transducer were enclosed by the thermal control unit (TCU).

The environmental conditions used in the measurement of tubing responses are (i) a low atmospheric pressure and a high temperature on a hot and cloudy day during the summer and (ii) a high atmospheric pressure and a low temperature on a cold but sunny day during the winter, as summarized in Table 1. Note that the pressure measurement was performed in the environmental condition of Test 1.

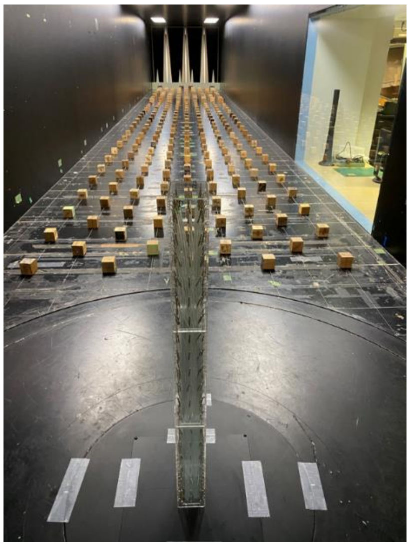

Figure 2. Building model.

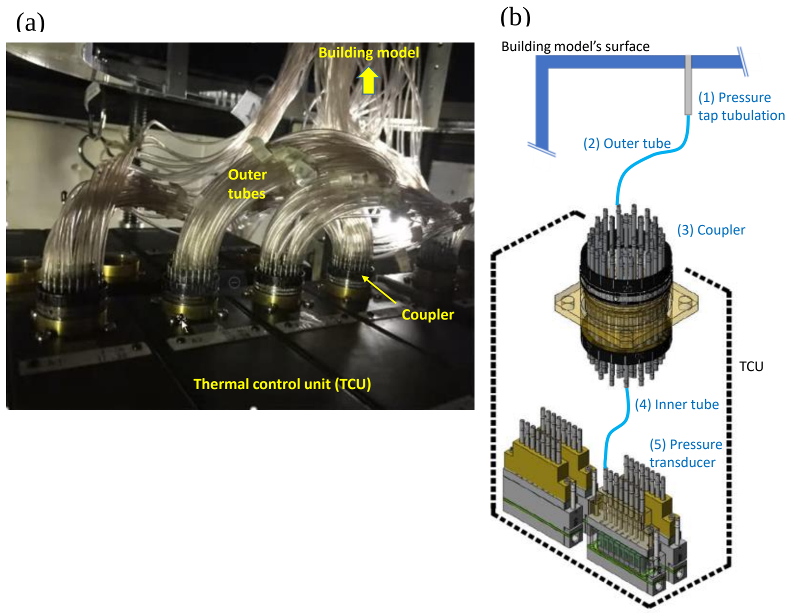

Figure 3. Tubing systems (Courtesy: Scanivalve for the TCU drawing in (b)).

Table 1. Environmental conditions in tests for transfer functions.

	Test 1	Test 2
Measurement date	August 12, 2021	January 19, 2022
Atmospheric pressure [Pa]	100,480	100,995
Ambient temperature [°C]	29.35	12.65

3. TRANSFER FUNCTIONS

The experimental transfer functions of amplitude ratio and phase lag were respectively determined from all 304 channel tubing systems. Deviations among the transfer functions are noticeable as the frequency is higher than ≈ 50 Hz. Figure 4 shows the mean and +/- standard deviations of the transfer functions in the environmental conditions of Tests 1 and 2. The comparison plots confirm that environmental conditions can lead to appreciable differences in the time-averaged transfer functions. The difference of the amplitude ratio is as high as 0.12 at low frequencies (≈ 50 Hz). In contrast, the difference of the phase lag is the largest (19 °) at high frequencies (≈ 360 Hz).

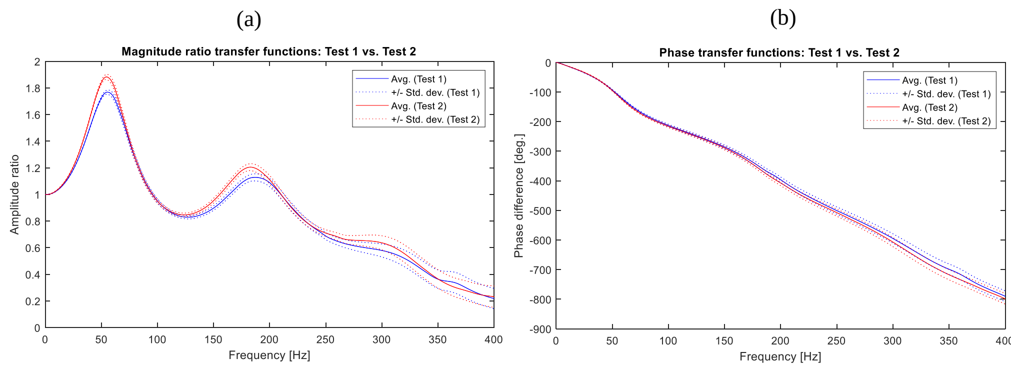

Figure 4. Comparison of experimental transfer functions between Tests 1 and 2.

4. RESULTS

This study found that variations of environmental conditions can result in noticeable distortion of frequency response (i.e., transfer functions) of pressure transducer-tubing systems and, subsequently, the measured pressures. While the differences in phase lags generally become larger with higher frequencies, the differences of amplitude ratios are the highest at low frequencies. Such differences in the transfer functions affects fluctuating pressures the most strongly on the side walls of a building, intermediately on the leeward wall, and then most weakly on the windward wall when the wind approaches the windward wall in the direction normal to the wall. The preliminary results imply that pressure data corrected from a dynamic pressure calibration ignoring environmental conditions could result in noticeable errors of their dynamic characteristics (e.g., standard deviations and peaks). Comprehensive analysis is still in progress and the associated results will be provided in the final paper.

ACKNOWLEDGEMENTS

This research was supported by the FY2021 Joint Usage/Research Center of Wind Engineering in the Wind Engineering Research Center, Tokyo Polytechnic University (No. 21213003). The authors would like to thank engineers from Scanivalve and Ohte Giken for providing the details of tubing systems of the pressure scanner and its TCU.

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