BBAA VI International Colloquium on:
Bluff Bodies Aerodynamics & Applications
Milano, Italy, July, 20-24 2008

THE USE OF THE PROPER ORTHOGONAL DECOMPOSITION FOR SIMULTANEOUSLY ANALYZING THE PRESSURE FIELDS ON TWO STRUCTURES

Rafael Flores-Vera[1], Guy L. Larose[2], Hiroshi Tanaka[3]

[1,3] Department of Civil Engineering
University of Ottawa, 161 Louis Pasteur, Room A106, Ottawa K1N 6N5, Canada
e-mail [1]: rflor037@uottawa.ca,
e-mail [3]: htanaka@uottawa.ca

[2] Aerodynamics Laboratory
National Research Council, 1200 Montreal Road, Building M2, Ottawa K1A 0R6, Canada
e-mail: guy.larose@nrc.gc.ca

Keywords: Proper Orthogonal Decomposition, unsteady pressure measurements, vortex shedding, hanging roof.

Abstract: *The Proper Orthogonal Decomposition technique (POD) was applied to study the pressure field on a long span hanging roof model for two cases : (1) on the isolated building in smooth flow, and (2) for the roof model immersed in the vortex trail of a square prism. In the latter case, the POD was used to analyze simultaneously the vortex generation around the prism and the effects of the vortices impinging on the roof. In both cases the wind speed ranged from 15 m/s to 40 m/s, equivalent to a Reynolds number range of 91,400<Re<242,000 based on the height of the building. From the first case, the use of the POD showed that the turbulence generated by the leading edge of the roof did not cover the whole structure with a particular dominant mode. However, the second case showed that vortices shed from the square prism created very distinct wind loading modes over the roof. These experiments validated previous studies on square prism in cross-flow and are going a step further by analyzing how the turbulence created by the prism affects a structure located in its vortex trail.*

1 INTRODUCTION

Suppose it is possible to visualize the air particles that surround any object. If the air mass starts to move slowly, the formation of a steady flow could be seen around the object. If the wind speed increases a bit further, soon it would be possible to visualize regions –usually near the sharp edges of the object, where the flow starts to show some unsteadiness. At greater wind speeds, those regions increase their level of unsteadiness and their size and most likely, some regions are superimposing with others. At some point, the flow pattern would be too complex that no human eye could distinguish any regular flow pattern. The proper orthogonal decomposition technique (POD) has been used to extract flow patterns (also called structures or modes) from turbulent flows to help the study of various phenomena. The physical meaning of each structure is still a topic of debate, but in many instances, certain modes strongly suggest the representation of aerodynamic phenomena, such as fluctuating lift and drag forces due to vortex structures.

Several applications of the POD used to analyze wind loads on structures can be found in the literature. The wind flow around rectangular prisms is studied in Refs. [1] and [2]. Both papers show how the POD extract mode shapes that describe with high accuracy the vortex shedding phenomena as well as the fluctuating drag forces in high-rise buildings. The POD has also been studied in Refs. [3] and [4] for the case of low-rise buildings where the description of the pressure field on the roof is of major importance.

The present work shows a combination of the previous cases, i.e., the POD is used to analyze the dynamic pressure distribution on a hanging roof model when it is immersed in a smooth flow with low turbulence and also when it is immersed in the vortex trail of a square prism. Simultaneous pressure measurements on the roof model and the square prism were performed, allowing the application of the POD for both, the square prism and the roof model at the same time.

2 THE ROOF MODEL AND THE EXPERIMENTAL CONDITIONS

It was required to study the dynamic pressure field over the hanging roof of a sports facility. A rigid model was built in acrylic at a geometrical scale of 1:200. The footprint of the model covered approximately a square area of 50 cm per side. The height at the centre of the model was 11.6 cm. It should be noted that the vertical wall in the XZ-plane (see Figure 1) over passed the parabolic edge, which brought a slight asymmetry to the building and in the resulting surface pressure field.

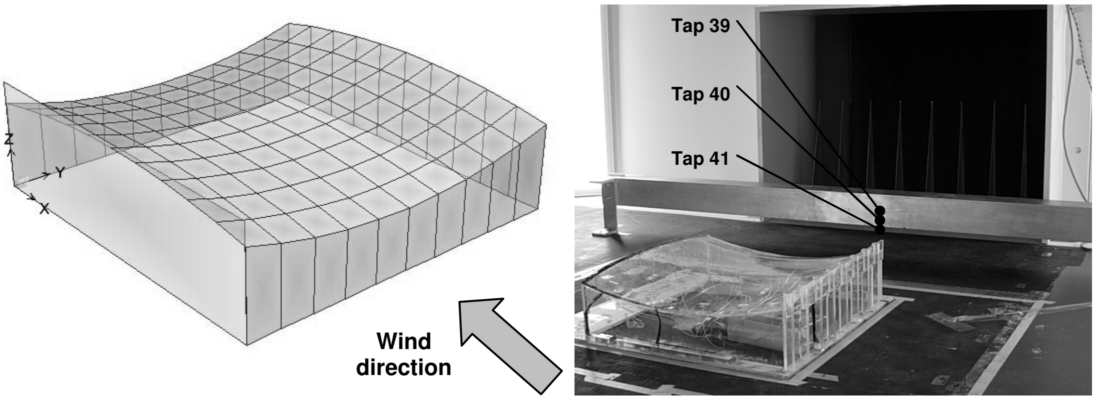

Figure 1 Roof model configuration (left). The roof model and the square prism inside the wind tunnel (right)

The model was tested in the Pilot Wind Tunnel of the National Research Council Canada. The tunnel has a nozzle that is 1.0m-wide and 0.8m-high. The air in the test section travels from the upstream nozzle to a downstream collector. The test section has larger dimensions than the nozzle forming a large plenum. The model was placed 70 cm downstream of the nozzle. Two configurations were studied: 1) the roof model immersed in smooth flow, and 2) the roof model immersed in the vortex trail of a square prism. For configuration 2, a square prism of 10 cm per side was located horizontally between the nozzle and the roof model. Figure 1 (right) shows a view of the model and the square prism inside the wind tunnel.

Unsteady pressure measurements were carried out at 44 pressure taps, 32 of them on the surface of the roof and 12 around the mid-section of the prism. The sampling frequency was set to 400 Hz for a sampling time of 90 seconds. Corrections for the tubing frequency response and time delay between channels were made using the method described in Ref. [5]. A single orientation of the roof was studied with velocities ranging from 15 to 40 m/s. The square prism was located in three vertical positions at 5, 10 and 15 cm from the floor of the wind tunnel.

3 ROOF MODEL IMMERSED IN SMOOTH FLOW

The mean pressure coefficients obtained during this study were found to be similar in magnitude and shape to the values reported in Ref. [3] for flat rectangular roofs. As it is commonly observed for bluff body shapes, higher suction values occur near the leading edge, Figure 2 (left) in the separation bubble.

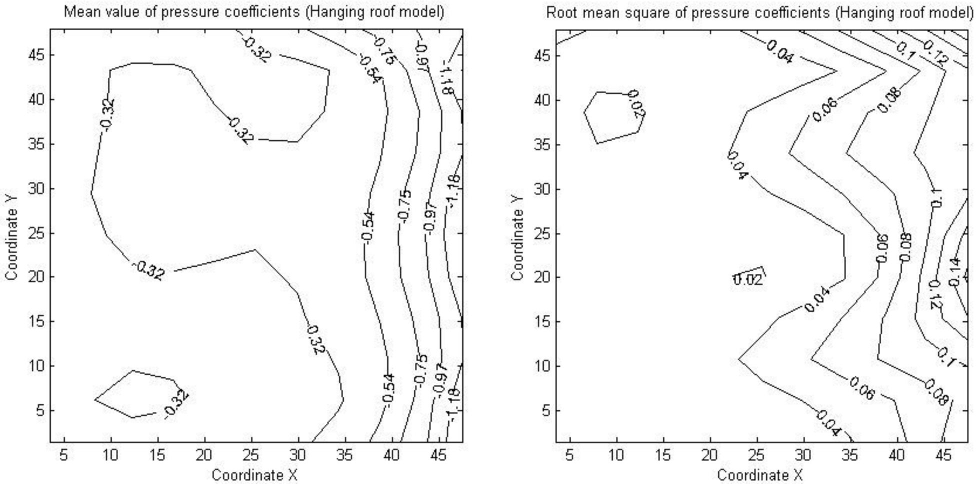

Figure 2 Iso-contour of mean pressure coefficients (left) and root mean square of pressure coefficients (right).

The root mean square value (RMS) of the pressure coefficients is an indicator of the level of unsteadiness in the flow field thus turbulence level, Figure 2 (right). There is a very important difference between the RMS values reported here and those reported in Ref. [3], the former are much lower than the latter. The levels of turbulence of the oncoming flow should be mainly responsible for this difference. Other factors could be attributed to the curved shape of the hanging roof which promote reattachment and to the models' surface roughness.

Since the turbulence levels obtained for the hanging roof are small, it is assumed that the characteristics of the turbulence observed is mainly local, i.e., the eddies created by the leading edge are small and/or do not travel coherently along the roof. Consequently the POD is unable to detect a dominant mode.

4 ROOF MODEL IMMERSED IN THE VORTEX TRAIL OF A SQUARE PRISM

It was observed for this configuration that the vortices shed from the square prism create dominant modes on the prism itself and on the roof model. The vortex shedding phenomena concentrates most of its energy at a specific frequency, which can be estimated very accurately in dimensionless form by the Strouhal number, Ref. [6]. The eigenvalues obtained from the POD are indicators of the amount of energy related with every mode. The cumulative distribution of eigenvalues is shown in Figure 3 and a thorough identification of the vortex impact on the roof will be presented in the full paper.

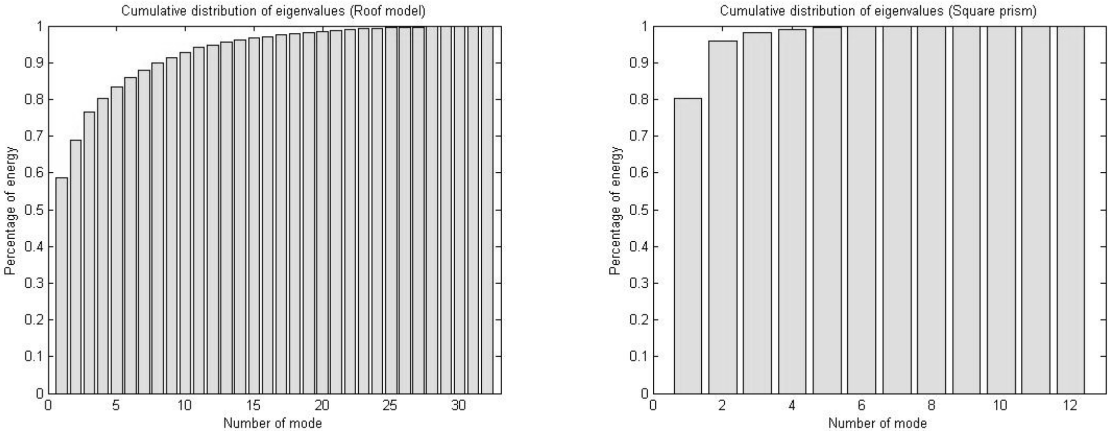

Figure 3 Cumulative distribution of the POD eigenvalues for a large roof in the wake of a square prism.

5 CONCLUSIONS

- For the case of the hanging roof immersed in smooth flow, two interesting results were obtained:
  - (a) The mean pressure coefficients of the hanging roof are very similar to those obtained for flat surfaces,
  - (b) The turbulence generated by the leading edge of the hanging roof has local characteristics, which implies the inexistence of a dominant mode. Such result differs greatly from the case of a flat surface, where a dominant mode was present.
- The vortices shed from the square prism create dominant modes for both, the prism itself and the roof model.

ACKNOWLEDGEMENTS

The first author acknowledges the financial support from the Consejo Nacional de Ciencia y Tecnología of Mexico (CONACYT) to carry out his Ph. D. studies in Canada.

REFERENCES

[1] N. Consentino, A. Benedetti. Use of Orthogonal Decomposition Tools in Analyzing Wind Effect on Structures. *Structural Engineering International*, **15**, 264-270, 2005

[2] H. Kikuchi, Y. Tamura, H. Ueda, K. Hibi. Dynamic Wind Pressures acting on a tall building model –proper orthogonal decomposition. *Journal of Wind Engineering and Industrial Aerodynamics*, **69-71**, 631-646, 1997.

[3] B. Bienkiewicz, Y. Tamura, H.J. Ham, H. Ueda, H. Hibi. Proper orthogonal decomposition and reconstruction of multichannel roof pressure. *Journal of Wind Engineering and Industrial Aerodynamics*, **54-55,** 369-381, 1995.

[4] Y. Tamura, H. Ueda, H. Kikuchi, K. Hibi, S. Suganuma, B. Bienkiewicz. Proper orthogonal decomposition study of approach wind-building pressure correlation. *Journal of Wind Engineering and Industrial Aerodynamics*, **72**, 421-431, 1997.

[5] G.L. Larose, A. D'Auteuil. On the Reynolds number sensitivity of the aerodynamics of bluff bodies with sharp edges. *Journal of Wind Engineering and Industrial Aerodynamics*, in press, 2007.

[6] Da-hai Yu, A. Kareem. Numerical Simulation of flow around rectangular prism. *Journal of Wind Engineering and Industrial Aerodynamics*, **67-68**, 195-208, 1997.