EIGENVECTOR MODES OF FLUCTUATING EXTERNAL AND INTERNAL PRESSURES ON A LOW-RISE BUILDING MODEL

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INTRODUCTION

Pressure fluctuations on bluff bodies, such as buildings in natural turbulent boundary-layer flows produced by strong winds, have a very complex temporal and spatial structure, resulting from unsteady and turbulent flows in the approaching wind and near flow separations on the body. The representation of these fluctuations by use of proper orthogonal decomposition, i.e. by the eigenvectors of the covariance matrices of the pressure fluctuations, was first suggested by Armitt [1]. The main advantage of this method is that it can lead to a simplified time/space description of a pressure field as a combination of a few of the highest 'modes'. Published work on eigenvector methods for bluff bodies up to 1988 was reviewed by Holmes [2]. Further applications of the approach for structural design have been discussed by Holmes [3], and Davenport [4]. Letchford and Mehta [5] analysed fluctuating pressures on the Texas Tech Building, and associated the principal eigenvectors with longitudinal and lateral turbulence in the oncoming flow. Bienkiewicz *et al.* [6] carried out a detailed analysis of the pressure fluctuations on a flat-roofed building model, using a multi-channel pressure measurement system.

In the present paper, the eigenvector modes for external and internal pressures recorded on a model of an agricultural building in a boundary-layer wind tunnel are presented.

BUILDING MODEL AND BOUNDARY-LAYER FLOW

The wind-tunnel model in question was a 1/50 scale reproduction of an agricultural building of length 24 metres, width 12 metres and height to eaves of 4.2 metres with a 12.5 degree pitch gable roof. The main purpose of the model was to derive structural frame loads for a commercial client - however, those results will not be presented in this paper. Pressure tappings were installed in tributary areas appropriate to the central frame and the first inboard frame of the supporting structure of the building. The pressure-tapped zones were divided into a number of panels on the roof and walls as shown in Figure 1, which also indicates the panel numbering system. Guttering was modelled by lengths of brass channel section attached at the eaves.

Each panel had ten pressure tappings, which were connected to a manifold, which was in turn connected to a 'Scanivalve' electro-mechanical scanner by a length of tubing containing a small diameter restrictor. The measurement system had a near-flat amplitude frequency response up to about 400 Hertz. The fluctuating panel pressures were sampled in pairs to enable matrices of correlation and covariance coefficients to be assembled for various wind directions. A removable side wall and end wall was provided for the model, to enable cases with dominant openings to be studied. In these cases, the internal pressures were measured by a single pressure tapping located on the floor of the model.

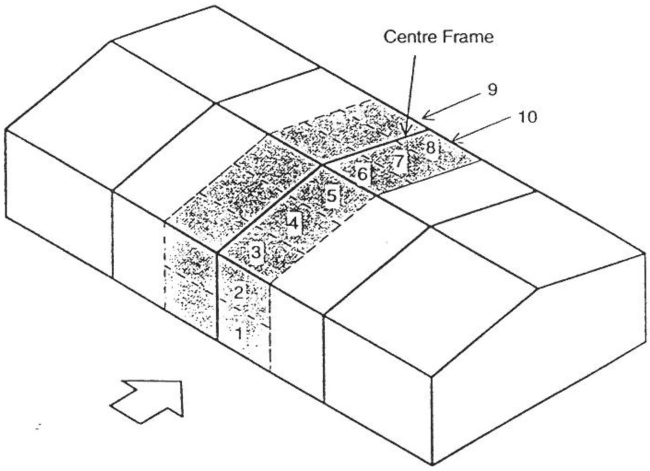

Figure 1. Pressure measurement panels

Tests were carried out in the boundary-layer wind tunnel at James Cook University, Townsville, which has a test section 17 metres long, 2.5 metres wide and about 2.0 metres high (adjustable). A turbulent boundary-layer flow was generated by a 400 mm barrier spanning the test section and followed by 14 metres of carpet roughness up to the turntable on which the model was mounted. The resulting flow was a good representation of a turbulent boundary-layer in synoptic strong winds, over open country terrain with a roughness length of 30 mm (full scale).

CLOSED BUILDING EIGENVECTORS

Figure 2 shows the first three modes for the centre bay of the closed building, for the case of 0 degree mean wind direction, i.e. normal to the ridge line. The mode shapes are shown for two cases:

(i) Wall and roof pressures (panels 1 to 10);
(ii) Roof pressures only (panels 3 to 8).

Thus the eigenvectors for case (ii) were derived from a sub-set of the full matrix of covariances used to derive the eigenvectors for case (i). For mode 1, the roof components of the mode shape for case (i) are nearly identical to the mode shape for case (ii), and they are both similar to the mean pressure coefficients (Figure 4). This is not the case for modes 2 and 3, which are quite different for cases (i) and (ii), despite the fact that the building geometry and flow are the same for the two cases. However, a closer inspection of Figure 2 reveals that mode 3 for case (i) is very similar to mode 2 for case (ii). The requirements of orthogonality with mode 1 mean that it is not mathematically possible for mode 2 of case (ii) to contain all positive components.

EIGENVECTORS FOR CASES WITH WALL OPENINGS

In Figure 3, the eigenvectors are again shown for case (i), as described in the previous section, but now they are compared with those for the following additional cases:

(iii) Side wall open (panels 3 to 10, 12);
(iv) End wall open (panels 1 to 10, 12).

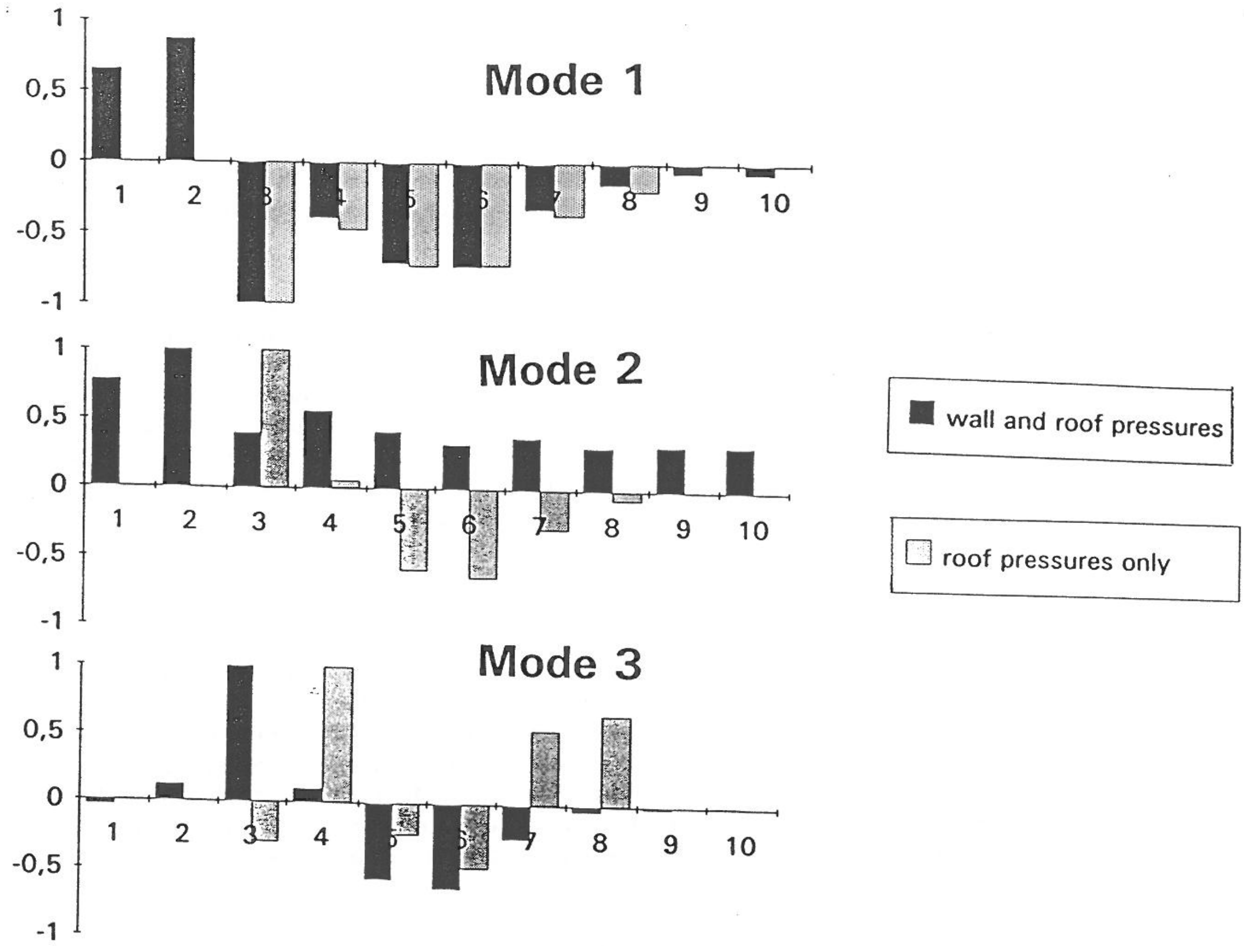

Figure 2. Mode shapes – closed building

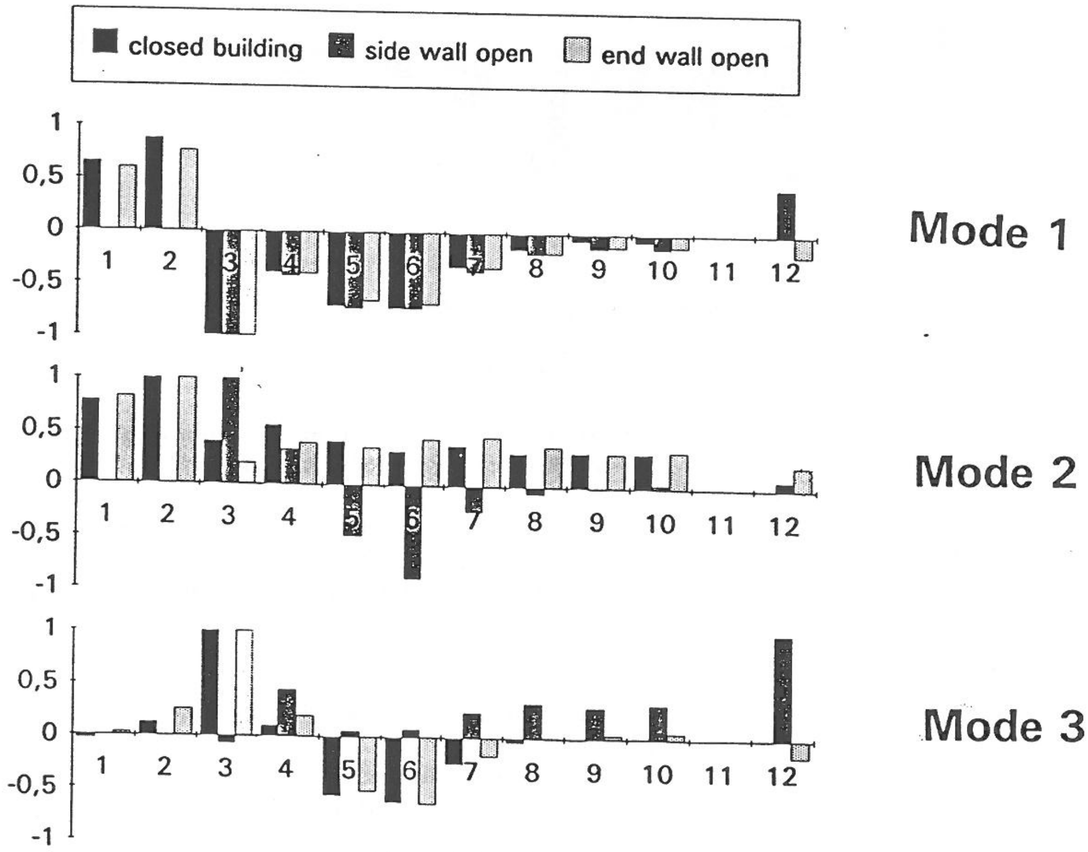

Figure 3. Mode shapes – closed and open wall cases

Again the centre bay panels have been analysed, and the wind direction is normal to the ridge. 'Panel' 12 is used to denote the internal pressure. Thus cases (iii) and (iv) represent different building geometries with consequent changes to the flow producing the pressure fluctuations.

The shapes of mode 1 are similar for all three cases, with the addition of an internal pressure component for cases (iii) and (iv), and these shapes match well the mean pressure distributions shown in Figure 4. In all three cases, the first mode accounts for about 62% of the total mean square pressure fluctuation. The shapes of modes 2 and 3 for cases (i) and (iv), i.e. closed building and end wall open, are also very similar to each other, with the addition of an internal pressure component for case (iv). However the second and third modes for case (iii), side wall open, are not similar to the other two cases. Again, the mathematical requirements play a part, as modes 2 and 3 are required to be orthogonal to mode 1.

CONCLUSIONS

Eigenvector mode shapes have been shown for the centre of a low-rise building with the wind normal to one wall, for four different cases. In two of these cases, contributions from internal pressures have been included. It has been shown that the shapes of the higher modes are constrained by the requirements of orthogonality, and hence physical interpretation of these modes may be misleading. However, the first mode shape is very similar to the mean pressure distribution in all cases, implying that the major source of the pressure fluctuations is the upwind longitudinal turbulence through a quasi-steady mechanism.

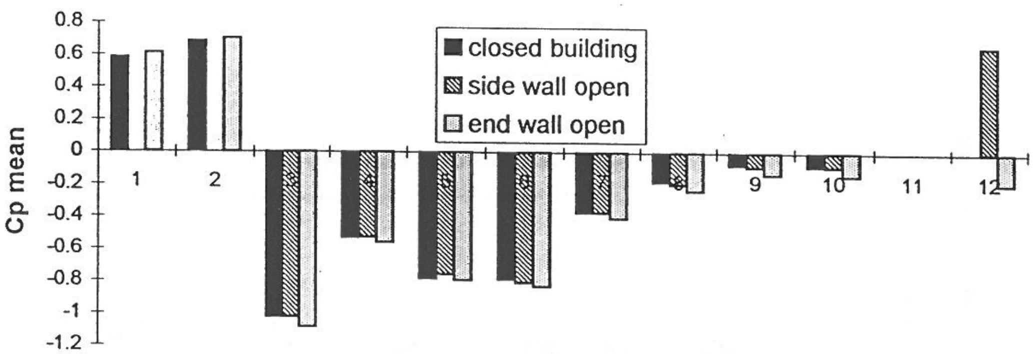

Figure 4. Mean pressure distributions

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