Transient Wind Loads on Complex Façades

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1 INTRODUCTION

As the demand for energy efficient buildings increases, a significant number of high performance façades now use ventilated double skins, or include relatively small attachments such as external shading devices. These systems are often bespoke, giving each building its own distinguishing aesthetic, resulting in potentially different surface flow characteristics. There are several instances when the wind induced pressures on such facade elements cannot be obtained from codes of practice, or the façade elements are too small or complex to be included in conventional wind tunnel testing. Since wind-induced pressures often govern the sizing, detailing and performance of a façade, it is pertinent to investigate the wind-façade interaction in further detail.

1.1 Existing Studies

Double skin façades are aerodynamically similar to ventilated rainscreen systems. A number of studies have addressed such rainscreens, particularly Gerhardt and Janser [1] who extended previous research. They assess the sensitivity of pressures to the size of air gap and skin permeability. Other studies more directly related to double skin façades confirm the aerodynamic similarity of these systems, where the importance of closing off the ventilated cavity at building corners is quantified. An attempt at codification has been made within EN1991-1-4:2005 [2], although studies have indicated that these provisions may not always be conservative [3].

External shading locally modifies wind flow over building façades, thereby changing the surface pressures. This also attracts significant loading onto the shading devices, particularly at building edges. Some similarities may be drawn with projecting balconies on a tall building surface, however there is a dearth of research on this topic. Two methods tend to be used for this type of assessment, either a velocity based assessment, or a pressure based assessment. Mans *et. al* [4] propose the use of velocity measurements on the façade surface combined with known drag coefficients, to estimate the loading on external shading elements. Rofail and Vallis [5] note that the presence of such external elements can significantly modify the pressure distribution over the façade surface itself, and propose the calculation of a Sunshade Factor K_s. This is simple a ratio between the net pressure measured across the shading element and the external pressure co-efficient on the façade. Rofail and Vallis suggest values of K_s which could be used for preliminary design however; each different louver type would need to be tested for sufficient accuracy.

1.2 Definition of the problem

A number of important conclusions and guiding principles may be drawn from existing research, however these are often limited to particular design situations. Accurate surface pressures are still very sensitive to building shape, façade system or type of flow within the same façade. There is insufficient published data to develop a comprehensive set of guidelines for desktop calculation of the wind loading on aerodynamically complex façades. Too many variables are involved in the design of such façade systems and it may not be possible to develop a comprehensive codification to cover a majority of design situations.

When carrying out cladding pressure testing in the wind tunnel, the greatest challenge with achieving accuracy lies with modelling and instrumenting the small-scale features in sufficient detail. The availability of cheaper rapid prototyping has opened up further possibilities, particularly for larger façade features. Unfortunately, many significant façade details are in the region of 600mm or less, which poses severe difficulties when instrumenting such features with pressure taps.

The research presented in this paper is the recent progress made by the authors in developing a more generally applicable method by combining the two approaches: (a) wind tunnel results for the entire simplified building surface and (b) Computational Fluid Dynamics (CFD) analysis to account for smaller façade details. The results from wind tunnel testing at a scale of 1:10 are presented which will be used to assess the accuracy of such a method.

2 TESTING

2.1 Test Method

Prediction of the transient load history on complex façade surfaces requires detailed pressure information, which is in turn required for the lifetime prediction of the façade components. This study uses a relatively large model in a scale of 1:10, in contrast to common wind tunnel scales of 1:200 to 1:400. This allows the façade elements to be modelled and instrumented in far greater detail. This work focuses on double skin facades and shading devices however, it is expected that the fundamental nature of the research undertaken in this area should be easily transferable to other façade typologies.

Figure 1, Double Skin Model (left) and External Shading model detail (right).

The tests were based on a simple 6m cube since this has well know pressure distribution and full scale test results are available from the Silsoe Cube [6]. The boundary layer used was matched to the open fetch at Silsoe. A single adjustable model was used for the tests, shown in Figure 1. The double skin model was built with an adjustable cavity as well as adjustable ventilation openings. The external shading was constructed as an add-on to the cube with aerofoil louvers which had an adjustable angle. All pressure tubing was concealed within the model to avoid flow obstruction. Pressure measurements were taken simultaneously at a total of 450 locations concentrated around the façades.

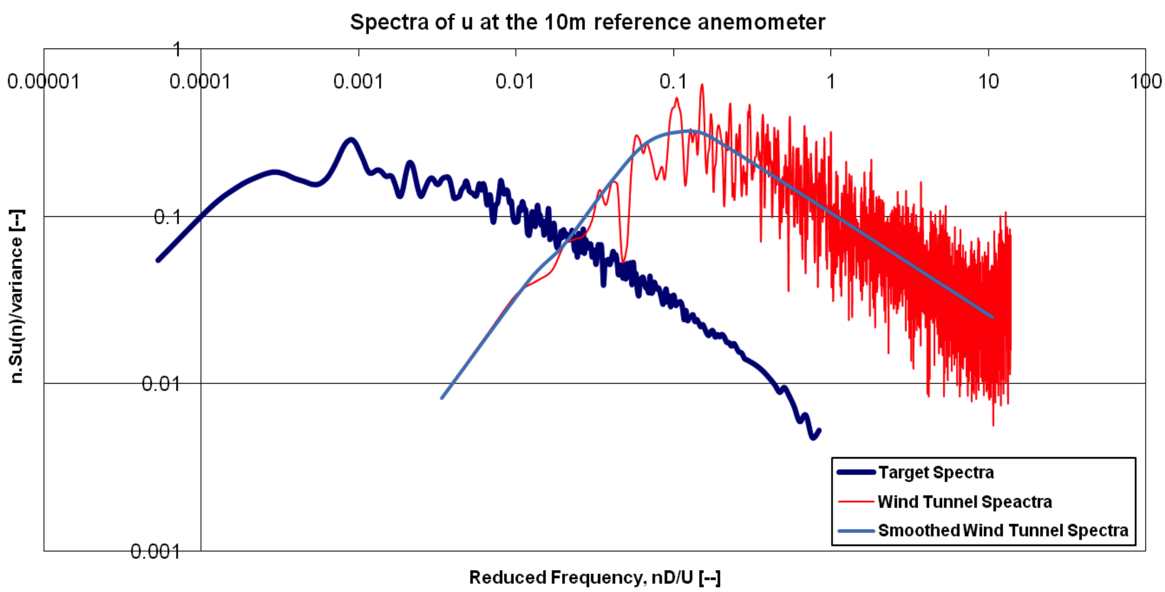

Figure 2, Spectral Shift between full scale and 1:10 scale wind tunnel test.

In comparison with the full scale target boundary layer, a shift in the spectrum of the incoming flow was deteceted as shown in Figure 2. This was a result of the relatively large scale of the model, where the wind tunnel walls were constraining the development of larger vortices. Comparisons between the full scale results and model scale results were therefore limited to mean values.

2.2 Results

Results show how the local wind flow on external elements affects façade surface pressures, highlighting potentially significant effects on design. Net pressure coefficients for the façade elements are given in Tables 1 and 2, in relation to external surface pressures measured without the façade features present.

Table 1, Absolute values of Double Skin Façade Pressure Coefficients

Test Conditions		Mean Pressure Coefficients		
Ventilation Opening	*Distance between Skins*	*External Surface*	*Inner Surface of External Skin*	*Internal Skin*
50mm	100mm	0.65	0.48	0.48
50mm	1000mm	0.65	0.45	0.45
150mm	100mm	0.66	0.53	0.52
150mm	500mm	0.66	0.54	0.53
150mm	1000mm	0.66	0.52	0.52

Table 2, Absolute values of Shading Louvre Pressure Coefficients

Test Conditions	Net Mean Pressure Coefficients		
Shading Angle	*External Surface*	*Max Louver*	*Min Louver*
0°	0.72	1.15	0.61
15° *1	1.06	1.25	1.06
30° *1	1.05	1.27	1.05
45°	0.71	1.06	0.60
Louvers Removed	0.70	N/A	N/A

3 CFD-AUGMENTED WIND TUNNEL DATA

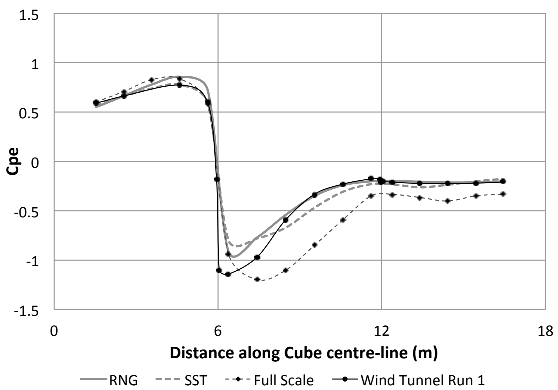

Figure 3, CFD vs Wind-Tunnel Pressure Cpe.

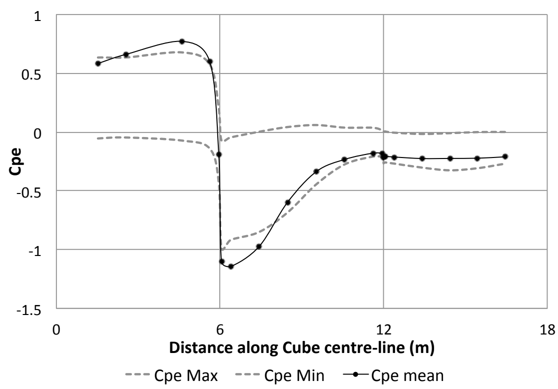

Figure 4, Mean vs Peak Pressure Cpe.

CFD analyses have been carried out for the same models tested in the wind tunnel. The purpose of CFD in this study is to assess the applicability of readily available CFD software to augment wind tunnel data. In order to avoid issues with defining boundary conditions and maximise speed of analysis, Reynolds Averaged Navier Stokes (RANS) turbulence modelling has been used to calculate the mean pressures over the different façades.

Preliminary results show good agreement with the wind tunnel pressures, particularly for the Renormalisation Group *k*- ε (RNG) and Shear Stress Transport (SST) turbulence models. Figure 3 shows the mean external pressure coefficients along the centre line of the cube with the front face perpendicular to the wind.

Figure 4 shows that a strong relation between mean pressures and the envelope of maximum and minimum peak pressures can be identified in certain cases. This indicates that a quasi-steady approach to analysis may be appropriate.

4 CONCLUSIONS

The estimation of surface pressures over intricate façades is an ideal application for CFD used to augment wind tunnel testing. This capability is relevant for day-to-day design of façades, as it can provide an accurate an efficient means of sizing façade elements. It is envisaged that such a combined method could be used where it is impractical to model intricate facade details in the scaled wind tunnel models. The computational basis also presents the façade designer with a cost-effective tool for parametric design optimisation or assessment of design variations.

The preliminary results presented in this paper indicate that it may be possible to validate CFD models for façade mean pressure computations and combine these with measurements of mean and peak pressures from wind tunnel testing using quasi-steady theory.

The wind tunnel spectra of fluctuating pressures measured acting across the façade elements are being compared to those measured on the external cube surfaces. The latter pressures are those measured in the same location on the simple cube model with no special façade elements present. It is hoped that consistently strong coherence can be identified between these spectra. Once a correlation is established, this could be used to define the peak pressures over local façade surfaces as a of function the local mean pressure data calculated from CFD analysis and the mean and peak pressures measured from wind tunnel testing.

This research is focused on double skin facades and shading devices. It is however, expected that the fundamental research undertaken in this area should be easily transferable to other façade typologies.

ACKNOWLEDGMENTS

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