CRITERIA FOR FAÇADE ELEMENT TESTING

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Abstract

Discussion of possible techniques for the estimation of incident wind speeds on porous façade appurtenances such as sunshade louvres and wind-break fins on high-rise buildings.

Background

Recent trends towards high-rise residential towers have focused efforts in the reduction of building energy consumption and increased natural ventilation. Also in demand are outdoor "living" areas at ground level, on podium rooftops and on balconies with an emphasis on pleasant wind climate.

To meet the demands of energy consumption and wind climate there has been an increase in the use of externally mounted façade items such as sunshade louvres to reduce solar heat loads and vertical wind-break fins on podium and tower facades to reduce wind conditions in occupied areas.

Commercial, full-scale wind tunnel noise and vibration studies have been conducted on a number of these façade items, many of which are being manufactured using aluminium and are relatively light and flexible. Fatigue of these elements is an issue in some cases.

Discussion

Basic structural design of facade appurtenances is being hampered by the lack of guidance for the determination of wind loads on these structures. The Australian Wind Code gives no specific guidance to the structural engineer as to, for example, surface velocity multipliers which might be used in the determination of a design velocity. Indeed there is very little experimental data on which the Wind Code might base such guidance. The surprising fragility and/or lack of damping of some proposals indicates the wider engineering community is unaware of the likely loads these structures must withstand and their dynamic response to wind action.

Model scale wind tunnel tests of differential pressures across solid appurtenances such as canopies and fins are regularly made, invariably as part of pressure cladding tests. These provide clear data on which to base load design but the determination of wind loads and wind induced noise and vibration for porous items are best conducted in full scale.

Wind tunnel analysis of the noise and vibration performance of full scale porous appurtenances is regularly conducted, however, the difficulty facing such tests is the modeling of the velocity and turbulence characteristics of the incident flow as there is very little published data on the subject.

Experimental Data

Whilst there is a great deal of experimental data on façade surface pressures, few experiments have been directed at surface or near-surface velocities and turbulence intensities. A brief model-scale study undertaken at Vipac on a 1/100 scale model of a 100m tower in Terrain Category 2-3 indicated that in the centre of the upstream face at the top of the tower the ratio of local peak velocity to building height peak velocity was approximately 1.3, i.e.

$$\frac{\hat{V}_{local}}{\hat{V}_{bh}} = 1.3$$

where $\hat{V}_{local}$ was measured approximately 1m in full scale from the edge of the roof and the façade, as shown in Figure 1.

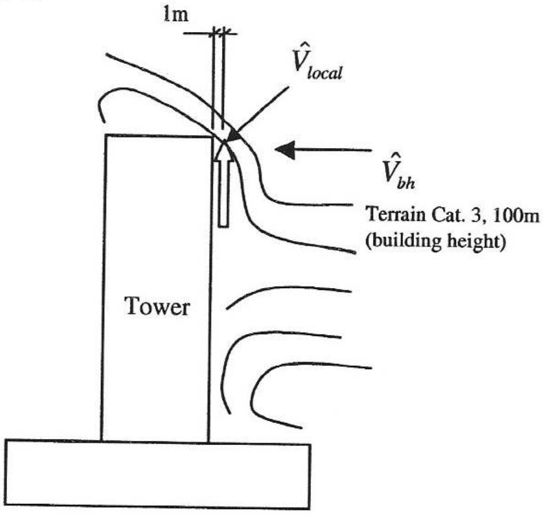

Figure 1 Local surface flow velocity as measured on an example model scale tower with no appurtenances.

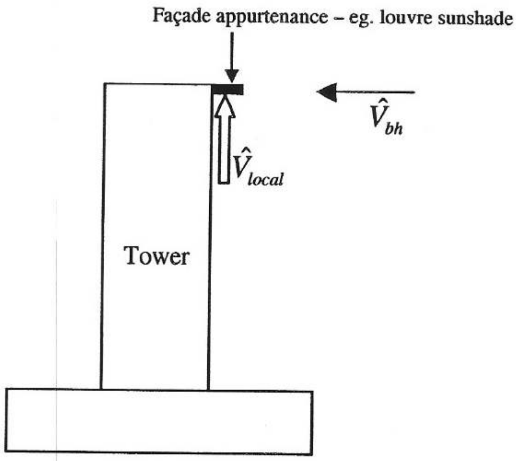

Figure 2 Scenario where a high value $\hat{V}_{local}$ is directly incident on a façade appurtenance.

It should be noted that a thermistor was used for this test and it is likely that, whilst both $\hat{V}_{local}$ and $\hat{V}_{bh}$ would have been underestimated by this instrument, with a higher turbulence intensity likely at the top of the building than in the approach flow, $\hat{V}_{local}$ may have been underestimated more than $\hat{V}_{bh}$, i.e. $\hat{V}_{local}/\hat{V}_{bh}$ is most likely higher than 1.3. Using the means recorded during the experiment and the measured incident σ_v =0.17 and assuming a local σ_v = 0.2, would yield $\hat{V}_{local}/\hat{V}_{bh}$ =1.5.

Possible Techniques for Estimation of Surface Design Wind Speeds

In many cases there will be numerous appurtenances on a building. For example, most high-rise residential towers tend to repeat any sunshades on each level and podium façades tend not to have isolated wind-break fins. The presence of numerous appurtenances will most likely decrease façade surface velocities and increase turbulence intensity.

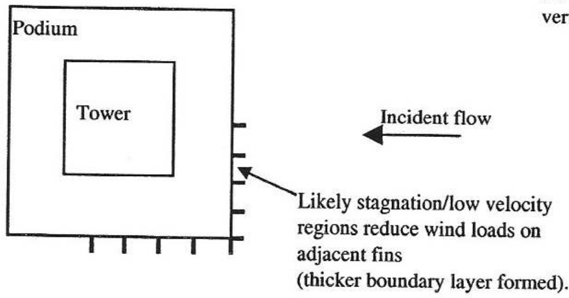

Figure 3 Plan view of a podium-tower configuration with multiple wind-break fins on the podium façade reducing surface velocities.

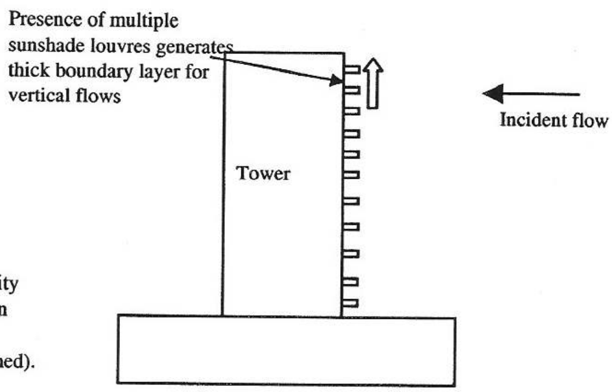

Figure 4 Elevation of a podium-tower configuration with multiple sunshade louvres on the tower façade reducing surface velocities.

As well as the effects on surface velocity and turbulence due to adjacent appurtenances are the effects of building geometry, surrounding developments and topography, all of which would probably reduce the usefulness of a single maximum speed up factor.

Clearly it would be very useful if these variables could be reasonably accounted for using a technique already widely practised. The use of cladding pressures to estimate surface velocities using Bernoulli's theorem has been suggested by Dr. J. D. Holmes. Whilst most regions of interest on a building will not strictly meet the criterion for the use of the Bernoulli theorem of inviscid and irrotational flow [1] it has been suggested this method may provide at least a useful approximation of surface velocities given the local cladding pressure.

The following is an attempt to estimate the ratio of the local peak velocity and the reference peak velocity. As before, the point of interest will be the centre of the upstream façade at the edge of the roof and the wall of the building.

From Bernoulli –

$P_{TOTAL,\ UPSTREAM\ (U.S.)} = P_{TOTAL,\ LOCAL\ (L)}$ eqn.1

$P_{TOTAL\ U.S.} = P_{DYN\ U.S.} + P_{STAT\ U.S.}$ eqn.2

$P_{TOTAL\ L} = P_{DYN\ L} + P_{STAT\ L}$ eqn.3

combining eqns 1, 2 & 3

$P_{DYN\ L} = P_{DYN\ U.S.} + P_{STAT\ U.S.} - P_{STAT\ L}$

where $P_{DYN\ U.S.} = 1/2.\rho.V_{bh}^2$

$P_{STAT\ L} = P_{TAPPING} - P_{STAT\ U.S.}$

$P_{DYN\ L} = 1/2.\rho.V_L^2$

and $P_{TAPPING} = 1/2.\rho.V_{bh}^2.C_P$ (assume C_P= -2 [3])

then rearranging gives

$$\frac{V_L}{V_{bh}} = \sqrt{(1 - C_p)}$$

Using the Australian Wind Code [2], assume C_P= -2 for a roof edge. This gives,

$$\frac{\hat{V}_{local}}{\hat{V}_{bh}} = 1.7$$

which is in fair agreement with the estimate made from the measurements.

Suggestions For Future Research

The study of a characteristic high-rise building using hotwire anemometry to determine local surface gust wind speeds (having first determined the local flow patterns) would seem to be of some urgence. Of interest would be the pressure tapping of the same model to compare data from the hotwire anemometry to verify whether Bernoulli's theorem, if not completely valid, is at least useful in estimating surface velocities. Ideally such a study would include the effects of adjacent buildings and the addition of a number of appurtenances.

Conclusions

Full scale testing of porous façade appurtenances is the only suitable way of testing their acoustic and vibration performance however, little has been published regarding the type of flow conditions that represent a reasonable model of the surface flow on building façades. Presently there is no criteria for incident wind speed and turbulence for such items hence various laboratories are left to simply test these elements to the limit of their facilities. There is little in the wind code to guide the structural designer regarding design velocities incident on building appurtenances. Obviously there is a significant increase in the velocities adjacent to a high-rise development over the reference velocity due to the distortion of the flow around the structure. However, in many cases it may be overly conservative to assume these elevated velocities are directly incident on the external elements since velocities at the building façade surface with significant numbers of fins, balconies etc. may be relatively low due to a thick boundary layer generated by the external elements themselves.

Due to the increased use of façade appurtenances it would seem appropriate that some effort be directed into researching building surface velocities and turbulence characteristics with the objective of developing some generalised scenarios where speed-up factors could be recommended. In addition, it would be useful if such a study could attempt to determine whether surface pressure data might be useful in determining likely surface velocities.

References

[1] Wind Loading of Structures, Dr. J.D. Holmes p69
[2] AS1170.2:2002, p26-35