

Further Measurements of Buffeting Effects of Twin Upstream Buildings

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SUMMARY This study systematically modelled the buffeting effects on a 150 x 37 x 37 m building of upstream twin diamond-shaped buildings with a clear upstream fetch (e.g. water, desert). The results show that the presence of the twin 220 m upstream buildings can increase the dynamic loads by a factor of almost 2.1. Buffeting effects can be significant for distances of 1 km. The maximum buffeting loads would have serious effects on a building designed to the current Australian Wind Code (AS 1170).

1 INTRODUCTION

The buffeting of small, medium and large buildings by upstream buildings has become an increasing problem because:

- Tall buildings have been built upstream of existing structures, particularly on re-claimed land.
- Buffeting of downstream buildings by upstream buildings can and has produced undesirable dynamic motion and loading of the downstream buildings. Habitation has become unpleasant in a number of instances.
- If the upstream building is built after the downstream building has been built, the owners of the downstream building can take legal action.
- Whilst there is proprietary information on buffeting effects from specific projects, little is readily available to the designer of a more general nature.

Saunders and Melbourne (1979), at the last International Wind Engineering Conference, highlighted that the buffeting effects on a medium-sized building near a waterfront or other clear fetch due to upstream buildings or other structures, can produce substantial increases in peak loads and serious dynamic effects. They defined a Buffeting Factor as

$$B_F = \frac{\text{Overturning Moment (upstream structures present)}}{\text{Overturning Moment (isolated building)}}$$

which is simply a measure of the loads produced by the presence of the upstream structure(s) compared to the loads without the upstream structure(s).

The use of a Buffeting Factor allows convenient use with existing design procedures for evaluating peak loads on wind-excited buildings. In particular the approach developed by Saunders (1974, 1975, 1977) for evaluating the cross-wind dynamic response of an isolated building can be easily adjusted for the presence of an upstream building by using a Buffeting Factor.

Saunders and Melbourne (1979) presented wind tunnel results for buffeting factors on a 150mx37mx37m building model due to upstream models with one face perpendicular to the mean velocity. The results

obtained showed Buffeting Factors of up to about 2.1 for critical locations of the upstream buildings. These buffeting effects were significant up to distances of 1 km.

The work presented in this paper further extends this work into investigating the effect of upstream twin diamond-shaped buildings, i.e. the corners are closest together, e.g. similar to the Collins Place Project in Melbourne.

It is hoped that this initial study will promote discussion of this problem and also provide some more generally useful information to planners and designers.

There are a large number of variables present when upstream structures are considered. Therefore, the experimental approach was to keep the model building configuration as simple as possible and search for limit conditions.

High winds can occur at low levels off waterfronts or near deserts. A designer of a medium-size building in using standard wind codes would normally only design for low intensity winds. Standard codes offer little guidance for the effects of buffeting if a large building or twin buildings are upstream of the building.

The effect of an upstream building will be to increase the turbulence intensity. This will broaden the bandwidth of the crosswind force spectrum (Saunders, 1974). If the upstream building is of rectangular section and facing the mean wind, then the pressure distribution on the front face will also tend to induce higher velocity wind to lower levels. Both of these effects will increase the amount of energy available in the high-frequency side-band of the vortex-shedding mechanism. This will substantially increase the crosswind vibration of the downstream building. Saunders and Melbourne (1979) showed that this effect may be further amplified by the presence of twin upstream buildings with both faces of the twin buildings perpendicular to the wind. This study extends this work to a diamond-shaped orientation.

If a downstream medium-size building has been designed fairly economically, the presence of upstream buildings may present a potentially dangerous (or at least expensive) configuration for the downstream building causing excessive dynamic motion, creaking and groaning, and motion-perception by the occupants

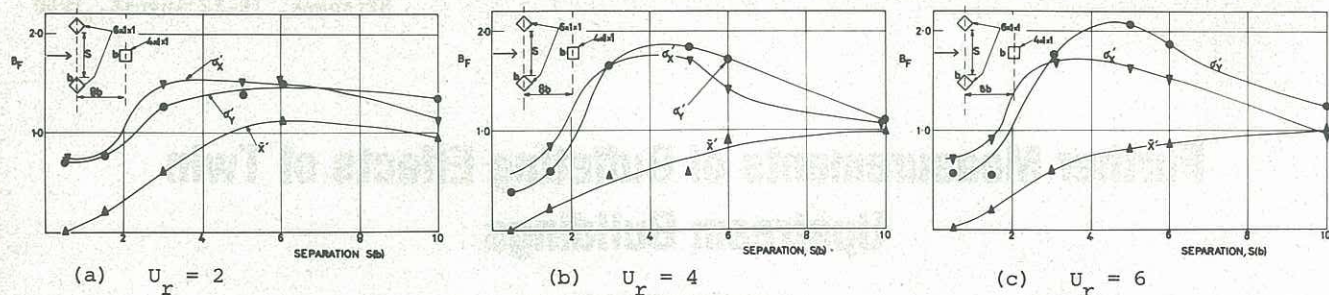


Figure 1 Mean and dynamic alongwind buffeting factors and crosswind dynamic buffeting factors at varying separation and reduced velocity.

of the downstream building.

In the investigations so far, the possible limiting conditions for maximum buffeting of a medium-size building have been assessed as:

- a clear upstream fetch, such as open water, or desert, or open plain;
- an upstream building having the same or greater height, but with the same plan area; and, alternatively
- twin upstream buildings.

2 NOMENCLATURE

| | |
|-------------|--|
| b | breadth of building |
| B_F | buffeting factor |
| S | air space |
| X | upstream displacement |
| \bar{X} | buffeting factor for alongwind mean overturning moment |
| n_o | natural frequency of building |
| \bar{U}_h | hourly mean wind velocity at the top of the building |
| U_r | reduced velocity |
| Y | crosswind displacement |
| σ'_x | buffeting factor r.m.s. alongwind moment |
| σ'_y | buffeting factor for r.m.s. crosswind moment |

3 WIND MODEL

A 1/400 wind model was developed by Melbourne (1977). The tests were conducted using this wind model in the Boundary Layer Wind Tunnel at Monash University. Its characteristics are detailed in Saunders and Melbourne (1979). The wind model used compares quite closely with the Australian Wind Code recommendations for the wind characteristics over sea or desert (AS 1170).

4 DYNAMIC MODEL BUILDING

The characteristics of the 1/400 model building were: proportions hxbxd = 4x1x1; height, h = 375 mm; breadth, b = 92.5 mm; density = 175 kg/m³; natural frequency = 48 Hz and percentage critical damping = 1%. The mode shape of the model building was linear and the overturning moment was measured at the base of the model using strain gauges. RMS and mean plus peak factors were measured.

5 REDUCED VELOCITY RANGE

For the purposes of this paper, the reduced velocity U_r is defined as,

$$U_r = \frac{\bar{U}_h}{n_o b}$$

where the symbols are defined in the nomenclature.

The prime wind design criterion of a building being subjected to buffeting from an upstream building will normally be motion perception by the occupants. A wind return period of less than 5 years would normally be appropriate. For a 5 year return period, a medium-size building will normally operate at reduced velocities up to about 6. If the frequency of motion perception was designed at a return period of less than 5 years, e.g. the building was perceived to move once p.a.; then the relevant reduced velocity would be lower. Therefore U_r was varied from 2 to 6 (9 m/s to 26 m/s).

6 UPSTREAM MODEL BUILDING TYPES

In the original study by Saunders and Melbourne (1979), the types of upstream buildings considered were of 6x1x1, 4x1x1 and 3x1x1 proportions. All models had the same plan area, and the models were simply placed in different locations upstream of the dynamic model. The buffeting factor graphs which resulted from this study contained large amounts of information but were quite complicated and difficult to comprehend. This paper presents the buffeting factor graphs in a simpler manner. The buffeting factor graphs are presented for the 6x1x1 twin models. However, while there was some buffeting due to the 4x1x1 pairs, there was insufficient information to be able to present the same type of graphs as shown in this paper. The response due to the 4x1x1 pairs and the 3x1x1 pairs was lower than the response of the 6x1x1 pairs. The dynamic characteristics of the model tested in isolation are detailed in Saunders and Melbourne (1979).

7 'CRITICAL' SEPARATION OF TWIN UPSTREAM BUILDINGS

The buffeting factors due to twin upstream model buildings were tested to investigate the degree of amplification due to the presence of an additional 'twin' building beside the upstream building.

Tall buildings induce a large downdraft of high velocity air to lower levels. Saunders and Melbourne (1979) conducted tests using 6x1x1 upstream models with the upstream face perpendicular to the wind. As the orientation of buildings can be rotated through 45° for reasons of aesthetics or wind environment, the diamond-shaped plan form was tested in this study.

In this and the previous study, the highest buffeting was found at about 8b downstream. The separation between the models was then varied. The results are shown on Fig. 1 for the various reduced velocities. The highest amplification for the crosswind dynamic buffeting factor occurred at a reduced velocity of 6 and was a value of almost 2.1

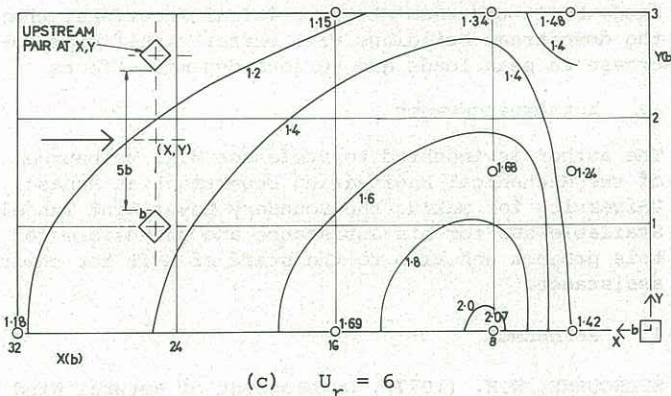
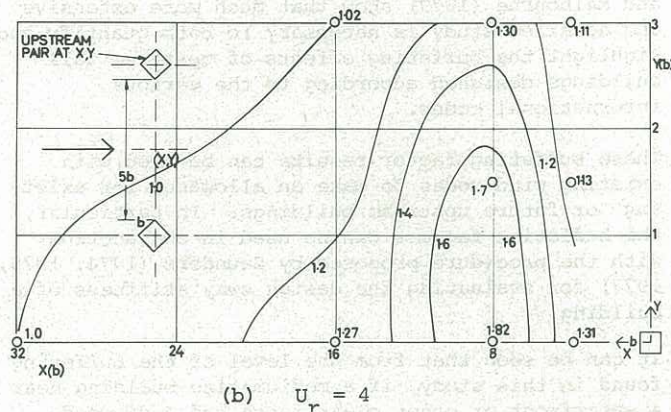
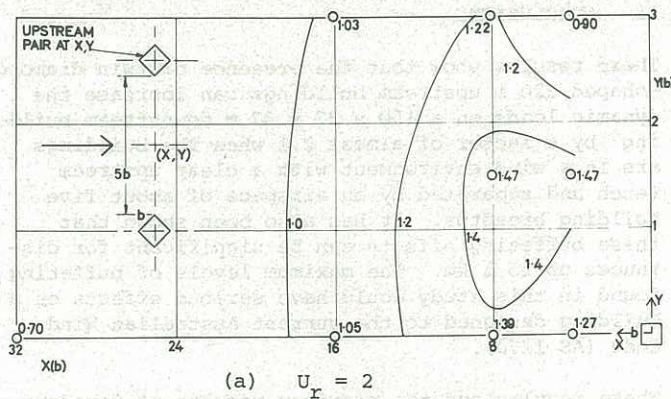


Figure 2 Crosswind r.m.s. buffeting factors

This reduced to about 1.8 at $U_r = 4$. The highest buffeting factor for the alongwind dynamic B_F occurred at $U_r = 4$ at an airspace of about 3-5 and was a value of about 1.7. The buffeting was lower at $U_r = 2$. The shielding effect on the mean alongwind moment is shown as the airspace reduces. This reduces the impact of the alongwind buffeting.

An airspace of 3b-6b produces the most dynamic buffeting at each U_r and the factors are generally above about 1.5 in both directions for $U_r = 4$ & 6.

Saunders and Melbourne (1979) found quite similar results for the square-planform twin buildings but with slightly higher buffeting factors. The tendency of a maximum buffeting factor occurring at a 5b airspace was more pronounced in their results.

Tests were also conducted at the same upstream location with the orientation of the axis between the two buildings set at an angle of attack of 0° and 45° , and also with the separation between the models increased and also decreased. In all cases the buffeting was lower. It was then assumed that

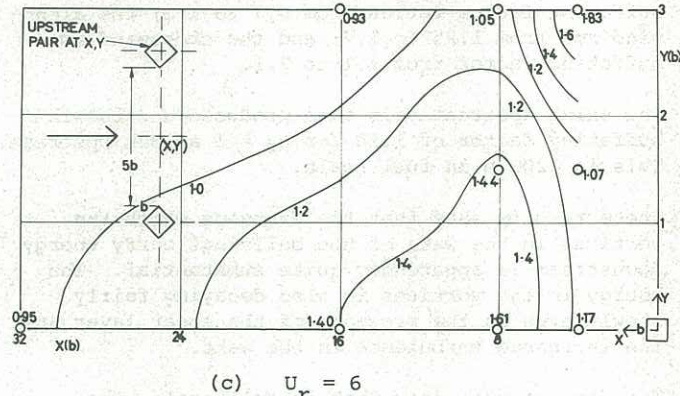
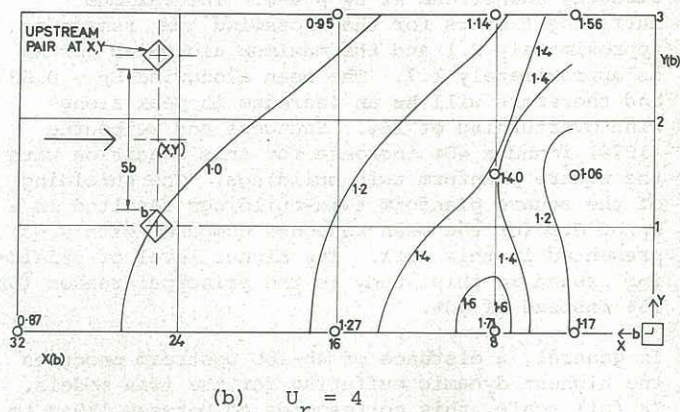
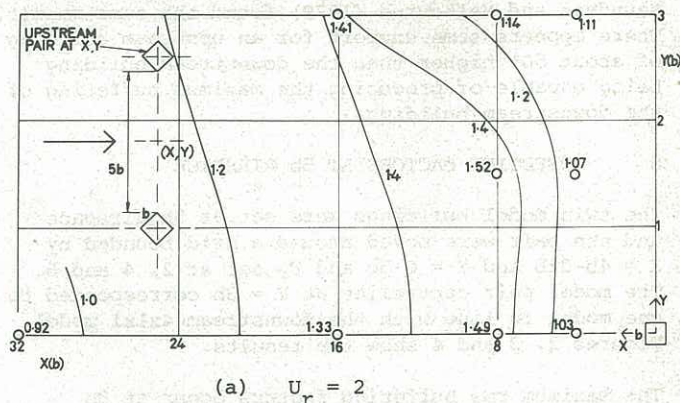
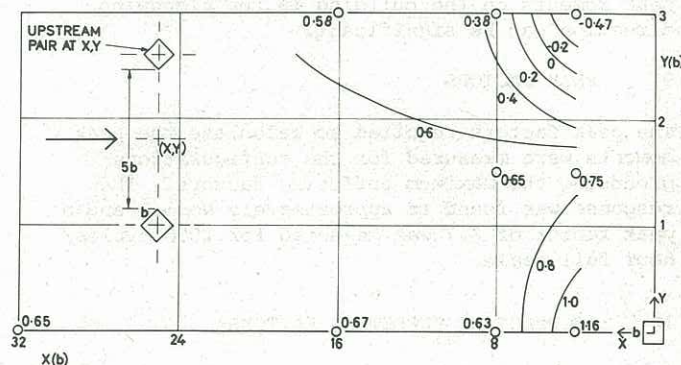


Figure 3 Alongwind r.m.s. buffeting factors



for twin upstream buildings that an airspace of about 5b produced the maximum buffeting effects when the pair were located in varying positions upstream.

Tests of an 8x1x1 upstream produced lower buffeting.

Saunders and Melbourne (1979) found the same result. There appears some support for an upstream building of about 50% higher than the downstream building being capable of producing the maximum buffeting of the downstream building.

8 BUFFETING FACTORS AT 5b AIRSPACE

The twin model buildings were set at 5b airspace and the pair were moved around a grid bounded by $X = 4b-32b$ and $Y = 0-3b$ and U_r set at 2, 4 and 6. The model pair centreline at $Y = 3b$ corresponded to one model in line with the downstream 4x1x1 model. Figures 2, 3 and 4 show the results.

The maximum rms buffeting factors occur at 8b directly downstream at $U_r = 4-6$. The maximum buffeting factors for the crosswind rms remain at approximately 2.1 and the maximum alongwind rms B_f is approximately 1.7. The mean alongwind $B_f = 0.63$ and therefore will be an increase in peak alongwind overturning of 16%. Saunders and Melbourne (1979) found a 40% increase for this condition with the square planform twin buildings. The shielding of the square planform twin-buildings resulted in a B_f of 0.9 for the mean response compared with 0.63 presented in this work. The higher level of shielding found in this study is the principal reason for 16% instead of 40%.

In general, a distance of 4b-16b upstream produces the highest dynamic buffeting for the twin models. In full scale, this corresponds to between 150 m to 600 m upstream. Under these conditions, the mean buffeting factor varies from 0.7 to 1.2; the alongwind rms from 1.25 to 1.7; and the crosswind rms buffeting factor from 1.1 to 2.1.

The 6x1x1 upstream pair also produced a crosswind buffeting factor of 1.18 for $U_r = 6$ at 32b upstream. This is 1200 m in full scale.

These results show that the distance which the vortices in the wake of the buildings carry energy downstream is apparently quite substantial. The energy in the vortices is also decaying fairly slowly even in the presence of the shear layer and the increased turbulence in the wake.

The results also show that in full scale, the dynamic buffeting can produce increases in the motion perception of buildings which can be quite substantial and also the level of increase in the peak moments on the building in the alongwind direction can be significant.

9 PEAK FACTORS

The peak factors required to calculate the peak moments were measured for the configurations producing the maximum buffeting factors. The response was found to approximately Normal and a peak factor of 3.7 was measured for 1000 cycles/hour full scale.

10 ACCURACY OF BUFFETING FACTORS

The accuracy of the buffeting factors measured at reduced velocities of 4 and 6 was assessed to be within 10% and at the lowest reduced velocity of 2 to be within 15% due to lower incident velocity and some background noise from tunnel vibration.

11 CONCLUSIONS

These results show that the presence of twin diamond-shaped 220 m upstream buildings can increase the dynamic loads on a 150 x 37 x 37 m downstream building by a factor of almost 2.1 when the buildings are in a wind environment with a clear upstream fetch and separated by an airspace of about five building breadths. It has also been shown that these buffeting effects can be significant for distances up to 1 km. The maximum levels of buffeting found in this study would have serious effects on a building designed to the current Australian Wind Code (AS 1170).

These results and the previous results of Saunders and Melbourne (1979) show that much more extensive and detailed study is necessary to both quantify and highlight the buffeting effects of upstream tall buildings designed according to the various international codes.

These buffeting factor results can be used with existing wind codes to make an allowance for existing or future upstream buildings. In particular, the buffeting factors can be used in conjunction with the procedure proposed by Saunders (1974, 1975, 1977) for evaluating the design sway stiffness of a building.

It can be seen that from the level of the buffeting found in this study, if a medium-size building near a waterfront or other clear fetch had a diamond-shaped planform twin building as tested in this study built upstream at the critical locations, then the downstream buildings will suffer significant increase in peak loads and serious dynamic effects.

12 ACKNOWLEDGEMENTS

The author is indebted to Professor W.H. Melbourne of the Mechanical Engineering Department at Monash University for making the Boundary Layer Wind Tunnel available and for his assistance and enthusiasm for this project and also to the staff of RMIT for their assistance.

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