Wind-induced building interference: increase of wind loads on existing buildings after erection of new high-rises

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ABSTRACT

INTRODUCTION

Because cities grow denser nowadays, new buildings more often have adverse effects upon the wind loading on existing buildings. It contributes to this effect that new buildings tend to get higher and higher at the same time. Figure 1 shows how a new building (left) can change the wind loading upon an existing building: the wind is forced around the building corners, thus generating turbulent eddies.

Wind loading upon buildings is determined according to Building Codes like the Eurocode or by conducting measurements in boundary layer wind tunnels. It mostly concerns the wind loading upon buildings under design, whereas the effect of existing buildings in the environment is sometimes taken into account as well. This paper will show that the opposite can sometimes be of paramount importance.

The above-described mutual influence is called wind interference in international literature on wind. The extent of wind interference depends on the shape and size of the buildings, the distance between them and the roughness of the surrounding terrain.
There are several parties that might be interested in wind interference:
- construction engineers, because the wind forces and moments acting upon the main bearing structure or cladding might be augmented;
- architects, since their design freedom is impaired if building parts are less slender or more expensive;
- building users, for new buildings might cause undesirable movements as a result of turbulent eddies, as shown in figure 1;
- building owners and municipalities, because of the juridical and financial consequences of for example damage cases.

It is evident that nobody can ignore this phenomenon. Therefore it is not surprising that proper and well-established knowledge regarding wind interference is needed.

This paper discusses the practical and theoretical knowledge that can be found in scientific literature. Most of this knowledge has been acquired by wind tunnel experiments regarding scale models. Some case studies performed at Peutz Ltd. will be discussed as well and the findings of these experiments will be compared to literature data. It will be shown that more research is desirable on wind interference with respect to local dynamic pressures in particular.

**SCIENTIFIC LITERATURE ON WIND INTERFERENCE**

As Khanduri (1998) mentions, little attention is paid to wind interference in Building Codes. This is not surprising, for the following reasons:
- the phenomenon is very complicated and cannot easily be described by rules of thumb;
- little experimental data are available;
- common intuition says that additional buildings will have a favourable shielding effect.

Bailey & Vincent (1943) already carried out pioneer research on the subject during the Second World War for several building shapes. Thereafter, it kept silent for two decades. When three large cooling towers collapsed soon after they were built in Ferrybridge in the UK in November 1965, the interest in wind interference increased substantial. The collapsed cooling towers were positioned on the leeward side of the row that was still erect, which seems to be a favourable position. However, it turned out the forces and moments acting upon the collapsed row were increased by a factor three as a result of the erection of the upwind row. Many scientific studies regarding wind interference have been performed since.

![Figure 2: flow around solitary building (a) and around a pair (b), wind coming from the left side.](image)

Based upon flow visualisations (Fig. 2) from Khanduri (1998), the physical mechanism underlying wind interference will be discussed. The wind is coming from the left side in both visualisations of figure 2. Turbulent eddies separate from the upwind building at the corners and edges of this building and hit the existing downwind building. Wind is accelerated by presence of
the new building and hits the front facade of the existing one, yielding increased overpressures.

When the buildings are not positioned right behind each other, like in figure 1, the flow that is released from the new building can be forced through the space between the buildings, thus yielding increased suction at the flank of the existing one. This can result in a crosswind force. The partial shielding caused by the new building can cause torsion moments around the vertical centre line of the existing downwind building as well. If the height of the new building is considerable, wind from higher layers can be forced downwards, so-called downwash, which causes a further increase of the wind loads acting upon the downwind building. This illustrates the fact that several effects cooperate with respect to wind interference.

Mean pressures and forces tend to decrease as a result of shielding by a new upwind building, though the peaks might increase considerably because of the turbulent eddies. The wind interference will disappear when the mutual distance between the buildings increases. The existing building then behaves as a solitary building again. It is mentioned that at very small mutual distance the wind interference could be small as well, because the vortex shedding of the upwind building is disturbed by the influence of the downwind one. The flow becomes less organised and large eddies do not have the time fall apart into smaller ones, which would have a higher angular velocity. Thus, higher peaks cannot come into existence.

Dedicated experimental results

One might question what theories and wind tunnel experiments have produced throughout the years. First of all a definition: wind interference is mostly quantified by the interference factor, IF, which is defined as follows:

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IF = \frac{\text{wind load upon building in group}}{\text{wind load upon solitary building}}
\]  

Forces and moments acting upon the main bearing structure as well as local pressures acting upon facade elements can be described by the IF as shown. Besides, average wind loading and fluctuating components as well as peak values can be distinguished. It is stressed that even when peak design loads do not increase, an augmented contribution of the fluctuations can at its own yield uncomfortable vibrations in the downwind building or cause material fatigue in facade cladding systems.

Many researchers used an experimental set-up as shown in figure 3. The position of the new building (coloured grey) is varied along the X and Y axis and the existing one is fixed at the origin of the axis system. For each position of the new building, expressed as the ratio of X or Y over the building width B, the interference factor, IF, is measured. Local pressures are measured with dynamic pressure sensors through small tubes mounted in the facades of the scale model. The forces and moments are measured with a piezo-electrical 6-component balance to which the scale model is attached.
Main bearing structure
A good example of the effect of wind interference on the main bearing structure is the work of Taniike (1992), who measured the forces parallel to the wind direction, called ‘drag’, at the main bearing structure of a building with height to width ratio of 1:4 as a function of the position of a new identical building. The interference factor is plotted for each location of the new building in figure 4.

The left plot in figure 4 reveals to what extent the mean force can decrease as a result of shielding by the new building, for the values of the contours are less than unity. The fluctuating forces can however be doubled as shown in the right plot. The consequence for the peak forces will be discussed in the following.

A more recent example is the work of Xie & Gu (2007), who studied the effect of two new upwind buildings upon an existing high-rise building. Since there are many possible combinations of positions of two buildings, they performed as many as 2500 measurements. Besides, they tried to find an effective way to comprehensibly present the results.
Two of their plots are shown in figure 5, the left one shows the interference factor for mean moments and the right one shows the fluctuating component. Building C represents the existing one at a fixed position and building A has a fixed determining position as well. The position of building B has been varied. The contours show the interference factor for the combined effect of buildings A and B.

![Figure 5: IF for mean (left) and fluctuating (right) moments acting upon building C. One new building, A, is fixed and the position of B has been varied.](image)

The right graph of figure 5 reveals that the dynamic component of the wind can be augmented six times, what can yield uncomfortable vibrations in the building, while the mean component can decrease by a factor five at the same time and position. It is interesting to know what the consequences for the peak wind loads are, which often are determining for the design. One can consider the peak loads as a quasi-static load as described in Building Codes, computed by a linear combination of mean and dynamic components.

The findings of Taniike (1992) show an increase of the peak forces parallel to the wind by 20% as a result of the presence of one new building. The results discussed above show an increase of 120% as a result of the presence of two new buildings. This means a doubling of the design load.

As well, some wind tunnel measurements have been performed regarding drag and lift for different upwind building shapes, like for instance the work of Thoroddsen, Cermak and Peterka (1985).

![Figure 6: IF for fluctuating crosswind moments acting upon rectangular downwind building with varying shape of upwind building.](image)

They found that mainly the fluctuating part of the crosswind bending moments is highly influenced by the shape of the upwind building. In particular, triangular upwind buildings can have
adverse effects at other buildings. The contribution of the fluctuating part of the forces and bending moments has significance, because it can yield uncomfortable vibrations or material fatigue. The mean bending moments as well as the moments parallel to the wind happened to be less sensitive to upwind building shape.

Local pressures

The forces and moments acting upon the main bearing structure have been discussed in the above, but the effect of new buildings upon the local pressures at facade elements of the existing ones is at least as important.

Cladding can be subjected to an additional load when a new building forces the wind towards this building or when more turbulent eddies are produced. Unfortunately, scientific literature contains few data in this scope, except the comprehensive work of Sun & Gu (1995) regarding cylindrical buildings and the work of Taniike (1992). Sun & Gu found that extreme local pressures could increase by 60% at a centre-to-centre distance of twice the diameter. This is not a large distance, but nevertheless these findings are something to keep in mind. It can attribute to both increased suction at the sides of the downwind cylinder and to increased pressure fluctuations.

Taniike (1992) found a considerable increase of fluctuating pressures, with an increase of $C_p'$ from 0.2 to 0.4 as can be seen in the right plot of figure 7, and as a result of this an increase of local peak pressures at a centre-to-centre distance of four times the width. When comparing the left plot of figure 6 with the previous ones, one can see that a striking difference between local pressures and forces and moments is that mean local pressures can be augmented considerably as well. Apparently, wind interference caused by rectangular buildings plays a more important role than that caused by cylindrical buildings. Presumably, at the sharp edges of the rectangular buildings where the boundary layer is shed off at one location, more severe turbulence is generated.

Thus, since the pioneer work of Bailey & Vincent (1943) and the collapsed cooling towers in Ferrybridge, much research on wind interference has been carried out. However, it must be stressed that retrieving dedicated and quantitative design data on behalf of specific cases is not straightforward. It is furthermore hard to predict the interference factor for buildings with odd shapes, especially with respect to local pressures. It is interesting to know how some case studies performed by the author compare to the discussed data.
CASE STUDIES

Peutz Ltd. have undertaken several wind tunnel studies regarding wind interference, all of which are specific case studies for building plans. A picture of the wind tunnel of Peutz Ltd. is shown in figure 8. It is a closed boundary layer wind tunnel with a cross section of 3.2 x 1.8 m² and it can generate a mean wind speed in excess of 25 m/s.

When studying wind loading, the model scale varies from 1:150 to 1:400. Measurement on facade parts require a model scale of at least 1:150, because the size of the smallest eddies in the artificial 'atmospheric boundary layer' amounts to several millimetres. It is therefore deemed useless to model smaller details.

Up to twenty-four wind directions are considered during the experiments.

The mean and fluctuating pressures are measured simultaneously at up to 128 taps using pressure sensors of SensorTechnics HCL series, see figure 8, with a sampling frequency of 1000 Hz. Tubing with an internal diameter of 1.8 mm and a length of 1 m is applied. The amplitude and phase distortion of the tubing have been measured extensively and a digital filter is applied to every tap in order to correct the dynamic pressure signals.

![Figure 8: SensorTechnics HCL series dynamic pressure sensors.](image_url)

Mean and fluctuating forces and bending moments are measured with a dynamic piezo-electrical 6-component balance of Kistler, see figure 9. The scale models are very rigidly fixed to this balance, including the use of steel all threads from the top of the model down into the balance surface, which itself is placed upon a very solid basement.

![Figure 9: Kistler dynamic piezo-electrical 6-component balance.](image_url)
The measurements as well as the following extreme value analysis and the interpretation of the findings are carried out conforming to the Dutch CUR Recommendation C 103: Wind tunnel measurement of wind loads on (high-rise) buildings and construction parts (2005).

New residential high-rise next to the Amsterdam ArenA stadium
Wind tunnel experiments are carried out in order to determine the effect of a new residential tower upon the local peak pressures on the roof of the Amsterdam ArenA stadium. This has been done on behalf of the Amsterdam ArenA and the commissioner of the high-rise. The tower was believed to considerably increase the wind loading on the giant roof of the stadium. To this end, both the current situation as well as the future one with the tower present were studied and compared to each other.

![Figure 10: scale model of the Amsterdam ArenA and a new residential tower.](image-url)

The construction engineers of ARCADIS have applied all simultaneously measured time series of fluctuating pressures to a ESA Win finite element model of the steel roof construction, see figure 11. In this manner, they could simulate the forces and reactions in any part of the steel structure.
The forces that the roof is imposing upon the large concrete pylons at the corners of the stadium could be determined by means of this model as well, and were shown to be limited. However, an increase of local pressures at the envelope of the roof in excess of 30% has been revealed by this experiment. This made several modifications to the roof cladding and the supporting structure necessary.

Nevertheless, the difference between the situations with and without presence of the new tower, i.e. the value of IF, is somewhat smaller than expected based on data of Taniike (1992). This can be explained by the large amount of turbulence in the approaching wind that is already generated by the dense buildings in the surroundings of the stadium. As shown by Taniike and others, a high level of turbulence in the approaching wind will disturb the mechanism of wind interference. Besides that, it already yielded high-pressure peaks at the roof in the current situation.
New high-rises around the ABN AMRO head office

Purpose of a wind tunnel study on the wind loading of the ABN AMRO head office was to determine the effect of new high-rise buildings upon the main bearing structure and the facade cladding. Several upwind high-rise buildings have recently been built to the Southwest (the prevailing wind direction in the Netherlands) of this head office and some more will be constructed in the near future.

The construction of these high-rise buildings that are part of the large developments Mahler 4 and Amsterdam Symphony are shown in figure 12. Wind from the prevailing wind direction (Southwest) is forced through the canyons between the buildings and additional turbulence is generated. Currently, this effect can be felt in the ABN AMRO head office, whereas this seemed not to be the case in the past.

![Figure 12: aerial view of head office ABN AMRO seen from Southwest.](image)

Regarding the main bearing structure, the experiments have revealed that only the torsion moment around the vertical centre line has somewhat been increased as a result of the construction of the Mahler 4 towers. It was shown that wind coming from the Southwest is partly shielded and partly accelerated, which results in an asymmetrical wind load at the ABN AMRO head office, similar to the discussion in the section on scientific literature in the above.

However, local pressures at the upper half of the facades increase considerably as a consequence of the construction of the Mahler 4 towers. At one measurement position the peak suction has risen from 2000 to 3500 Pa. Many other measurement positions benefit from the shielding effect caused by the new buildings. The favourable shielding effect increases in particular with the added Amsterdam Symphony development.

The influence of the new buildings upon the maximum local pressures matches quite well with the findings of Taniike (1992). The centre-to-centre distance of the buildings approximately amounts to four times the diameter and the maximum increase of local pressures amounts to approximately 70 %.

The effect upon the main bearing structure as reported by Xie & Gu (2007), an increase of 120 %, is not at all confirmed by this case study, although the resemblance of this configuration and that of figure 5 is evident. In figure 5 however, the relative height of all buildings was one and a half times higher and there were some large additional buildings to the west of the Mahler 4 development in the case study, which possibly had a favourable effect.

A clear similarity between either result is that the mean forces and moments tend to decrease whereas the fluctuating parts are augmented, yielding more vibrations in the building. We can thus conclude that the feelings of ABN AMRO about the effect of the new high-rise buildings were confirmed by this study.
These findings agree with the fact that more dense upwind buildings are favourable with regard to forces and moments on the main bearing structure, but unfavourable regarding local pressures.

CONCLUSIONS

The first conclusion that can be drawn from the matters discussed in the above is that the impact of wind interference can be considerable, but that the extent might differ greatly among different situations.

One can state that in the case studies and in line with the cited literature findings, the local pressures on an existing building tend to be augmented by an increase of building density in the vicinity, whereas the peak forces and bending moments tend to benefit from the shielding effect caused by new upwind buildings. However, not only peak values are important. The contribution of fluctuating components is significant as well, because they can yield uncomfortable vibrations or material fatigue. These fluctuating components of forces and bending moments tend to increase as a result of an increase of building density in the vicinity.

It is not simple to deduce dedicated design data from the scientific literature. Besides, it is hard to predict the wind interference caused by varying building shapes, particularly with respect to local pressures acting upon facade cladding systems. Therefore, case studies are deemed necessary for many building plans.

As a rule of thumb one can state that when the mutual distance between buildings is less than ten times the diameter of the upwind building, the wind interference can be significant, Khanduri (1998).

Furthermore, supplementary systematic scientific research is desirable to gather more generalised data, particularly on local peak pressures on the facades. This systematic scientific research should comprise the interference from upwind buildings of different shapes and heights.

Long lasting on-site measurements regarding wind interference are of paramount importance in order to improve the reliability of wind tunnel experiments on wind interference. Such a comparison is always vital in establishing confidence in the research, as pointed out by Davenport (2002).

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