Executive Summary

The Bridgewater Place development in Leeds consists of a tall residential tower, with two attached blocks that enclose an atrium space. Since the development was opened, unpleasant and potentially unsafe winds have been reported around the base of the main building, particularly around the North and North-West facades. To address this issue, BRE were commissioned by Bovis Lendlease to undertake wind tunnel testing upon a 1:250th scale model of the Bridgewater development. The aim of this testing was to establish the location and size of wind amelioration measures that produce appropriate wind conditions around the building.

In total, six different model configurations were tested in this investigation. The first test was the 'baseline' configuration which consisted of the Bridgewater Place site as it currently exists. Of the other five configurations, Configuration 'A' showed the most significant improvement to the wind conditions, and details of this configuration are given below. For brevity, details of Configurations 'B-E' and their associated test results have not been included in this report; information about this testing can be provided if required. Configuration 'A' consisted of the baseline model with the addition of a high porous fence, a dense array of porous barriers around North façade, a large canopy above Main North entrance doors, and a vertical barrier along stairway to West of entrance.

Measurements of mean and gust wind speed were made around the site using instruments known as Irwin probes. 45 measurement locations were used in this study. The majority of the measurement locations were concentrated at the wind sensitive locations identified to the North and West of Bridgewater Place. Also, there were a few additional locations chosen to establish the nature of the general wind conditions around the site. The wind conditions around each scheme tested was assessed using the Comfort and Distress Criteria described in the report.

This testing produced the following findings:

- Installing 3.5m barriers is likely to offer good protection against the wind. This height of barrier ensures that almost all of the North Entrance doorways are protected against distressing winds, and these measures also increase the number of locations suitable for Pedestrian Walking. Increasing the barrier height above 3.5m is shown to have only a marginally beneficial effect
- The incidences of the occurrences of distress windspeeds will be reduced significantly by the introduction of the Configuration 'A' wind mitigation measures.
- Introducing barriers of sufficient height is likely to prevent these exceedences of distress windspeeds at most of the North fire exit doorways. However, even with the addition of 4.25m barriers, locations 17 and 23 are likely to experience distress windspeeds once or twice a year in January.
- The area surrounding the existing Bridgewater site has wind conditions that are suitable for Pedestrian Walking (i.e. ambling/strolling) and Business Walking, but are not suitable for Long-

Term Sitting or Entrances. Beyond the vicinity of the Bridgewater building, the Bridgewater development does not affect significantly the general wind conditions.

- The wind conditions everywhere around the existing Bridgewater site are suitable for Business Walking. About a half of the test locations are also suitable for Pedestrian Walking, and about a third of the Pedestrian Walking locations are suitable for Entrances and Long-Term Sitting.
- Compared with the existing situation, introducing wind amelioration devices is likely to improve significantly the wind conditions. However test locations around the exposed North and North-West facade (locations 15, 16, 17, 23 and 24) are not likely to have wind conditions that are suitable for entrance doorways, whatever the height of the wind amelioration devices.
- Introducing barriers more than 3.5m in height is likely to create suitable Pedestrian Walking wind conditions at locations 16, 23 and 24, but locations 15 and 17 would still be unsuitable for Pedestrian Walking (again, irrespective of the barrier heights tested). Note that these two windy locations are still suitable for Business Walking.

Contents

1 Introduction

The Bridgewater Place development in Leeds consists of a tall residential tower, with two attached blocks that enclose an atrium space. Since the development was opened, unpleasant and potentially unsafe winds have been reported around the base of the main building, particularly around the North and North-West facades. To address this issue, BRE were commissioned by Bovis Lendlease to undertake wind tunnel testing upon a 1:250th scale model of the Bridgewater development. The aim of this testing was to establish the location and size of wind amelioration measures that produce appropriate wind conditions around the building.

2 Site and the Model

A model of the proposed development in Bridgewater Place, Leeds, and its surroundings was manufactured at a linear scale of 1:250. A photograph of the model mounted in the wind tunnel is shown in Figure 1.

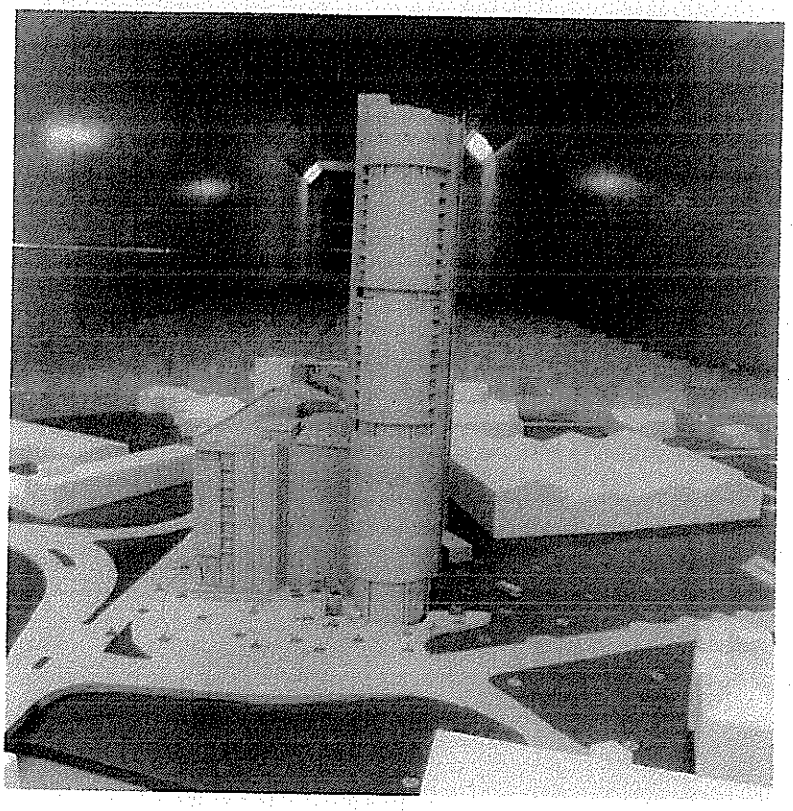


Figure 1. Bridgewater Place Model Mounted in Wind Tunnel (Looking Upstream)

In total, six different model configurations were tested in this investigation. The first test was the 'baseline' configuration which consisted of the Bridgewater Place site as it currently exists (shown in Figure 1). Of the other five configurations, Configuration 'A' showed the most significant improvement to the wind conditions, and details of this configuration are given below. For brevity, details of Configurations 'B-E' and their associated test results have not been included in this report; information about this testing can be provided if required.

Configuration 'A' consisted of the baseline model with the addition of a high porous fence, a dense array of porous barriers around North façade, a large canopy above Main North entrance doors, and a vertical barrier along stairway to West of entrance. These features can be seen in the photographs presented as Figures 2a-c; Figure 5 shows the heights of each of the vertical barriers.

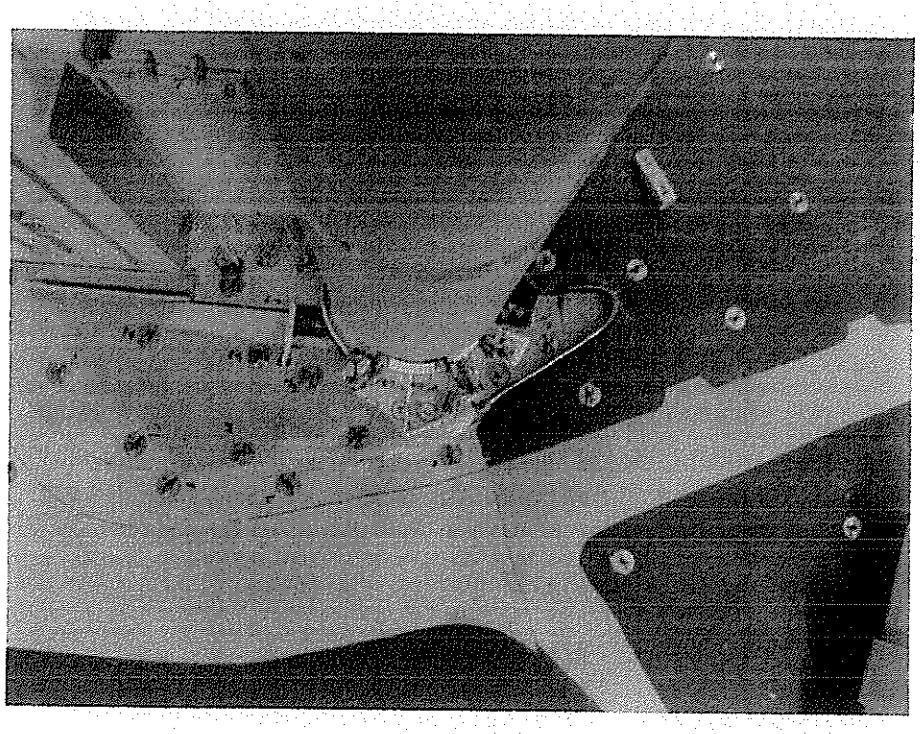


Figure 2a. Details of Configuration 'A' Wind Amelioration Scheme

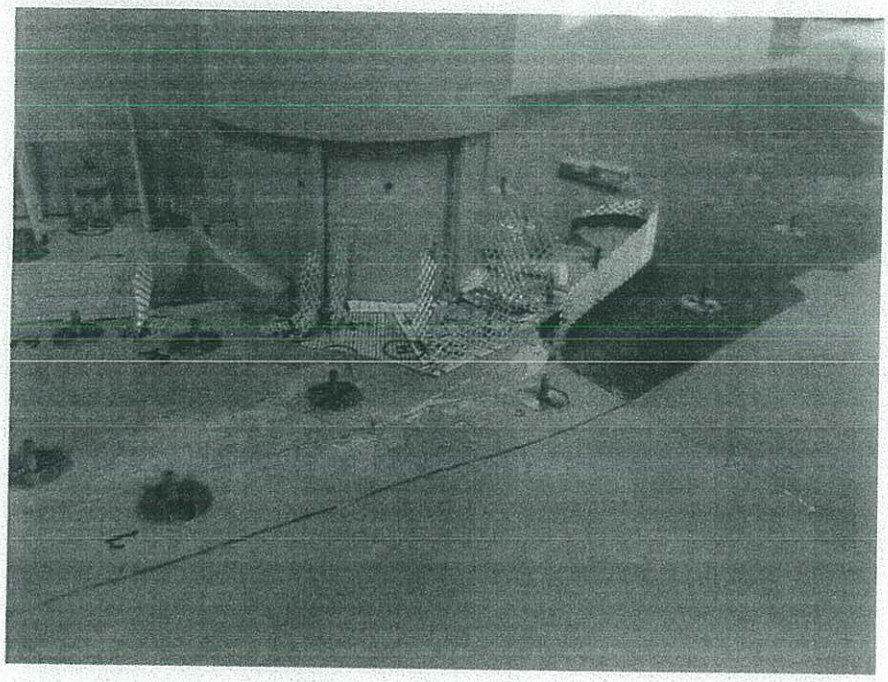


Figure 2b. Details of Configuration 'A' Wind Amelioration Scheme

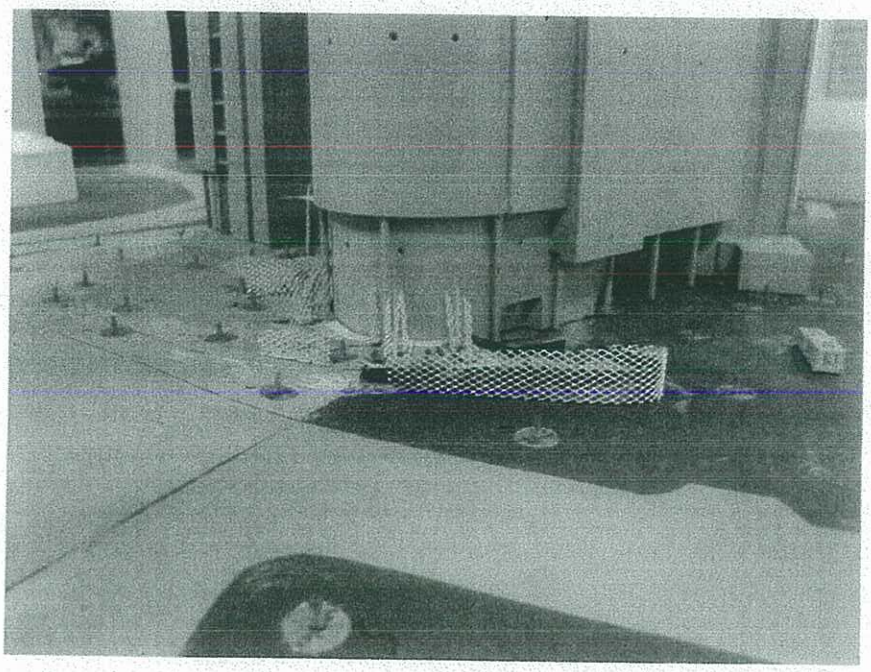
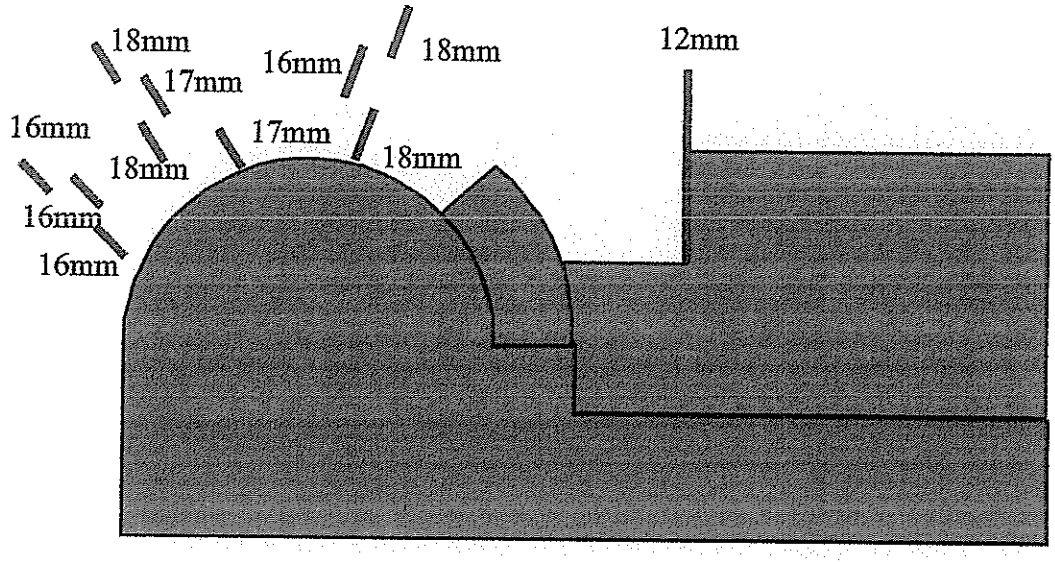


Figure 2c. Details of Configuration 'A' Wind Amelioration Scheme



Average model barrier height = 17mm (4.25m full-scale) – not including 12mm barrier.

Figure 3. Model Configuration 'A' Barrier Heights

To investigate the effect of barrier height, the heights shown in Figure 3 were reduced in 3mm (0.75m full-scale) steps, and the experimental procedure described below repeated.

A plan of the Bridgewater Place building is shown in Figure 4. The direction of North is shown on this figure, and all of the wind directions (or azimuth angles) are quoted in degrees East of North. For example, winds coming from the West have a corresponding azimuth angle of 270°.

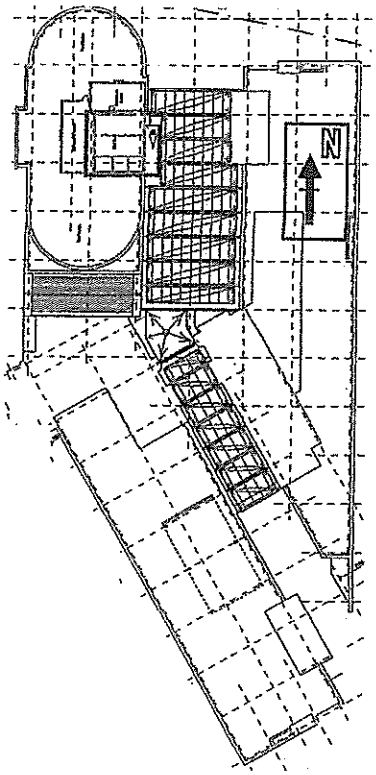


Figure 4. Roof Plan of Bridgewater Place

The site corresponds to Town category terrain as defined in British Standard BS 6399-2:1997 (Ref[1]). An appropriate suburban atmospheric boundary layer was simulated at the appropriate scale using rectangular plate roughness elements to create a mean velocity profile, turbulence profile and turbulence spectra appropriate to the area surrounding the site.

3 Method of Testing and Analysis

3.1 General

The windiness of a given location can be determined by combining measured results from an appropriate wind tunnel test with full-scale meteorological data. This combination is only possible when both sets of readings refer to the same conditions. It is standard practice in wind tunnel studies to use the Meteorological Standard Windspeed (MSW) as the reference condition. The MSW is the wind speed 10m above open level ground with a mean recurrence interval of 50 years, i.e. an annual probability of exceedance of 0.02. This wind speed is commonly referred to as 'the once in 50 year wind speed', and is the wind speed usually used for design purposes in the UK.

Combining long-term meteorological statistics with wind tunnel measurements enables the probability of a given wind speed occurring at a measurement location to be determined. However, this information does not, by itself, provide any information about how people perceive that wind speed. This is because such perception depends not only upon the magnitude of the wind, but upon what the person is doing at the time, and that person's expectations of the wind environment. To accommodate these issues, 'user defined criteria' have been developed over a period of years.

Wind conditions are usually described in terms of the Beaufort Wind Scale. Wind speeds associated with this scale, and a description of observable events that occur at such wind speeds are presented in Table 1. However, the Beaufort Wind Scale is found to be too coarse for environmental wind studies.

3.2 Comfort Criteria

Comfort criteria have been developed for the assessment of pedestrian wind comfort that can be used in conjunction with the results from wind tunnel investigations. The criteria are based on the percentage of time that the wind speed at a location exceeds the Beaufort values shown in Table 1. The criteria provide an indication which can be used to assess whether the wind environment is 'unacceptable', 'tolerable' or 'acceptable', for a given activity, where:

1) *Unacceptable*	Unpleasant conditions for the given activity which should not normally be allowed to occur.
2) *Tolerable*	Conditions, which would be described as 'windy', but which would be tolerated for the given activity.
3) *Acceptable*	Conditions that will elicit no adverse comments about the wind.

Beaufort Scale	Description	Mean wind speed range (m/s) at 10m	Effects
B0	Calm	0 - 0.2	
B1	Light air	0.3 - 1.5	No noticeable wind.
B2	Light breeze	1.6 - 3.3	Wind felt on face.
B3	Gentle breeze	3.4 – 5.4	Wind extends light flag.
B4	Moderate breeze	5.5 – 7.9	Raises dust and loose paper. Hair disarranged, clothing flaps.
B5	Fresh breeze	8.0 – 10.7	Limit of agreeable wind on land.
B6	Strong breeze	10.8 – 13.8	Umbrellas used with difficulty. Force of the wind felt on the body. Wind noisy, frequent blinking.
B7	Near gale	13.9 – 17.1	Inconvenience felt when walking; difficult to walk steadily. Hair blown straight.
B8	Gale	17.2 – 20.7	Generally impedes progress; walking difficult to control. Great difficulty with balance in gusts.
B9	Strong gale	20.8 – 24.4	People blown over by gusts.
B10	Storm	24.5 – 28.4	Seldom experienced inland.

Table 1: The Beaufort wind scale

A location that is rated as unacceptable for a given activity, for example such as long-term sitting, could well be tolerable or even acceptable for another activity such as pedestrian walking. Table 2 shows the criterion numbers and Table 3 shows the threshold wind speeds, in terms of the Beaufort scale, of unacceptable and tolerable wind conditions for people undertaking generic activities. Acceptable conditions are those which fall below the tolerable threshold.

These comfort criteria give a physical description of how the average person will react to the wind conditions present at that location. Different groups of people will have different tolerance levels, for example the very young or very old may be more susceptible to the effects of the wind.

Activity	Lawson Comfort Criteria	
	Unacceptable	Tolerable
Business walking - fast walking from A – B	10	9
Workers around buildings	9	7
Pedestrian walking - slow walking with occasional stops, such as browsing and shopping or ambling/stroling	8	6
Long term sitting – in open-air cafes, parks, etc.	6	4
Entrance doors – specifically for entrances to buildings	6	3

Table 2: Lawson comfort criteria

Criterion number	Threshold wind speeds in terms of the Beaufort scale
1	B1 exceeded for more than 25% of the time
2	B1 exceeded for more than 50% of the time
3	B2 exceeded for more than 4% of the time
4	B2 exceeded for more than 6% of the time
5	B3 exceeded for more than 3% of the time
6	B3 exceeded for more than 6% of the time
7	B4 exceeded for more than 2% of the time
8	B4 exceeded for more than 4% of the time
9	B5 exceeded for more than 2% of the time
10	B5 exceeded for more than 6% of the time
11	B6 exceeded for more than 2% of the time
12	B6 exceeded for more than 4% of the time

Table 3 Threshold wind speeds used for Lawson comfort criteria

The criteria given in Tables 2 and 3 have been developed by Lawson (Ref[2]) for shopping centres in the South of England and are based on a person's perception of the wind conditions.

3.3 Distress Criteria

The Comfort Criteria described above relate the measured wind speeds to a person's perception of the wind conditions. However, there are occasions when wind could create conditions that lead to physical discomfort, distress, or even danger to pedestrians. As described by Lawson (Ref[2]), the exceedence of Beaufort Force 6 (14m/s) can upset a frail old lady, and this windspeed therefore represents the lowest critical windspeed at which an accident can occur.

The Distress Criterion used in this study is that given by Lawson (Ref[2]). This criterion relates to the general public, and is appropriate for locations where frail people or cyclists are not expected. The Distress

Criterion threshold is an hourly average mean windspeed of 20 m/s exceeded for 0.025% of the time for the year, and 0.04% of the time for each month. These conditions relate to a "Once a Year" probability of occurrence.

3.4 Meteorological Data

Meteorological wind data were purchased from the Met Office for the nearest meteorological station which was Church Fenton. The Church Fenton site was identified by the Met Office as the closest and most appropriate site to use for a development in Leeds. The Meteorological data were processed to determine the probability of occurrence of winds from each wind direction. The 'wind roses' presented in Annex A show the number of hours that the wind blows with a given strength from a given direction. These wind roses are therefore a pictorial representation of the site wind behaviour. For each season, and for the year as a whole, the wind records for the Church Fenton site are shown in Annex A. It can be seen that the wind at this site is dominated by westerly winds (240°, 270° and 300°)

It is known that the probability distribution of UK wind speeds, averaged over periods of between about one second to one hour is well represented by the Weibull probability distribution. The Weibull cumulative distribution function (CDF), P is given by:

$$P = 1 - \exp(- (V/c)^k) \qquad (1)$$

where c is the scale parameter, k is the shape parameter and V is the wind speed.

Corrections then need to be applied to account for the differences in terrain, distance from the sea, height of anemometer, etc, at the development site and the meteorological station. Appropriate correction factors were determined using the BRE BREVe computer program which takes account of changes in terrain for distances of up to 200km around a site. This program is fully compatible with the methodology in BS6399-2 (Ref[1]). The BREVe outputs for the development and the meteorological station sites are given in Annex B.

3.5 Wind Tunnel Measurements

Measurements of mean and gust wind speed were made around the site using instruments known as Irwin probes. With the Bridgewater Place model in place, 45 measurement locations were used in this study, and these locations are shown in Figure 5.

The mean and gust wind speeds were measured at a height representative of head height at full-scale and converted to non-dimensional wind speed ratios by dividing by a reference wind speed. This reference wind speed was measured at a reference height of 300mm above the ground in the undisturbed free air stream immediately upwind of the model; equal to 75m in full scale. These ratios are then factored so they are consistent with the meteorological data described in Section 3.4.

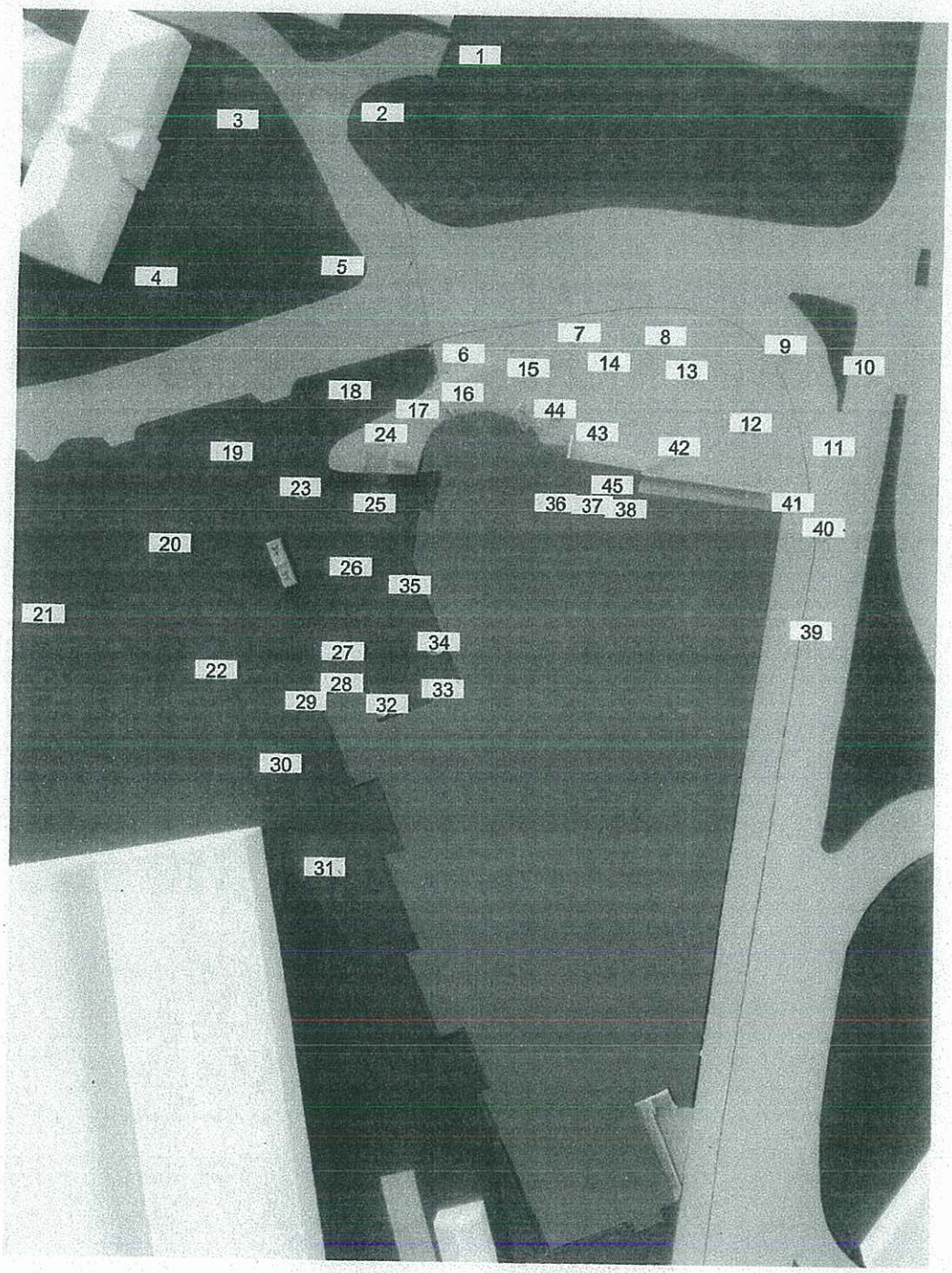


Figure 5. Plan of Bridgewater Place Development Showing Wind Environment Measurement Locations

4 Results

4.1 General

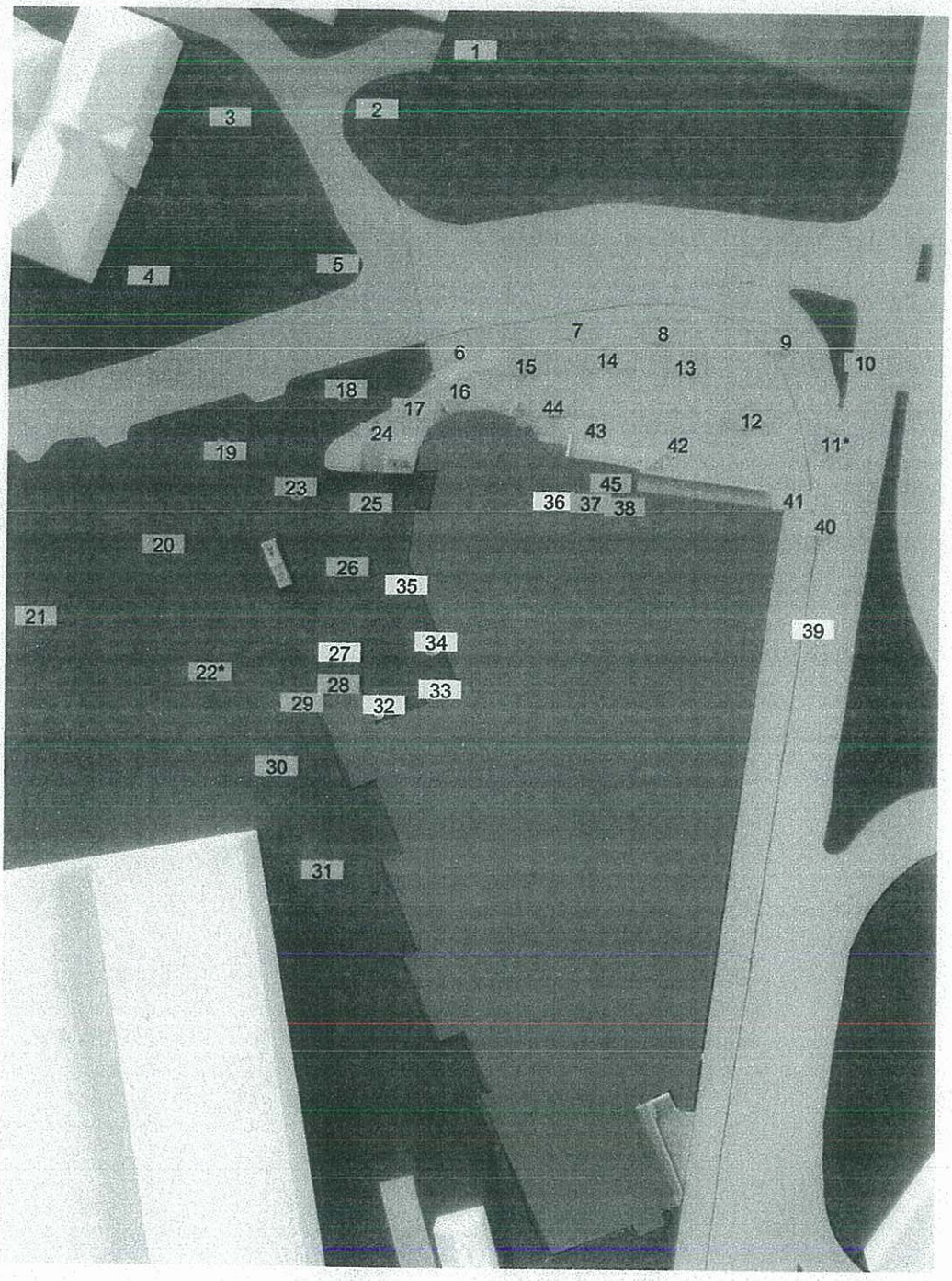
The comfort criteria results presented in Annex C are in terms of the three following criteria: 'unacceptable', 'tolerable' and 'acceptable' for specified activities. If a location is shown to be 'acceptable', then it will elicit no adverse comments about the wind. If a location is 'tolerable', then when the wind is blowing strongly, a typical person carrying out a given activity in that area is likely to think that it is windy, but not sufficiently windy to prevent them carrying out the activity. However, if a location is shown to be 'unacceptable' then wind amelioration measures should normally be incorporated or the intended use of that location be restricted to activities for which the conditions are more suited. The onset of unacceptable conditions depends on the activity. For example, unacceptable conditions for long term sitting are where the wind speeds exceed Beaufort 4 (defined as a moderate breeze) for more than 2% of the time. From Table 1 it can be seen that such a wind speed would raise dust and loose paper.

The information presented in Annex D show the number of times in a given month or year that the distress criteria threshold (defined in Section 3.3) is exceeded. The information provided in Annex D was obtained by combining the wind tunnel test results with the long-term meteorological wind data in the same way as the comfort criteria analysis. Nevertheless, analysing the data in the way described in Section 3.3 provides additional insight into the wind behaviour at a given location.

4.2 Existing Site Conditions

As can be seen in Section D1 of Annex D, in January 15 locations around the existing site are likely to experience 'distress' wind conditions at least once per year. In December five locations, in February four locations, and in March three locations are also likely to experience these conditions.

The wind conditions around the model were assessed for the pedestrian activities of Business walking, Pedestrian walking, Long term sitting and Entrances, according to the Comfort Criteria given in Table 2. For the existing site, Figure 6 shows a summary of the acceptability of the wind conditions at each of the measurement locations. This figure shows the most sedentary activity for which each location is suitable. A location has been taken as suitable for a given activity when it has been assessed as either tolerable or acceptable (see Tables in Annex C).



*The raw test results were assessed this location as being 'tolerable'. However, consideration of the other test results shown above indicates that this initial assessment was not correct.

Key:
White – suitable for any pedestrian activity (including Long-Term Sitting and Entrance Doors)
Green – suitable for Pedestrian Walking and Business Walking
Amber – suitable for Business Walking only

Figure 6. Baseline Configuration: summary of acceptability conditions around the site for the year as a whole.

4.3 Comparison Between Existing Site and Configuration 'A' Results

In this section, the wind conditions at locations 15, 16, 17, 23, 24, 36, 37, 38, (shown in Figures 5 and 6) are considered. These locations correspond with all the fire exit doorways around North facades of Bridgewater Place Building.

4.3.1 Safety of Fire Exit Doors

As can be seen in the results presented in Annex D, for both existing site and Configuration 'A' scenarios for locations 36, 37 and 38 (which are adjacent to Main North Entrance Doors) there are no exceedences of the distress windspeed threshold. Therefore there are no safety issues at these three doorway locations.

For locations 15, 16, 17, 23, and 24, in a given year the likely total number of exceedences of the distress threshold are shown in Table 4. As can be seen by examination of the results presented in Annex D, most of these exceedences are likely to occur in January, with very occasional excedences in December, Februrary - and for the existing site only in March.

Location	Full-Scale Average Barrier Height (m)					
	0 (Existing)	1.25	2	2.75	3.5	4.25
15	8	11	11	7	2	0
16	9	1	0	0	0	0
17	4	2	2	2	2	2
23	2	1	1	1	0	1
24	2	0	0	0	0	0
Total	25	15	14	10	4	3

Table 4. Incidence of Exceedences of Safety Criterion Per Year

From Table 4 it can be seen that for the existing site, locations 15 and 16 have particularly unpleasant wind conditions. The efficacy of introducing the Configuration 'A' wind amelioration measures can be seen clearly in Table 4, with larger barrier heights reducing or preventing the incidences of exceeding the safety windspeed threshold.

It is interesting to note that the lowest barrier heights increase the number in incidences at location 15 (the barriers appear to be moving the wind, thus creating a localised increase of windspeed at this location). Nevertheless, these low barriers have a significant wind amelioration effect at other locations. Note that even with 4.25m barriers, there are still likely to be incidences of the safety criteria windspeed being exceeded at locations 17 and 23 (but only in January).

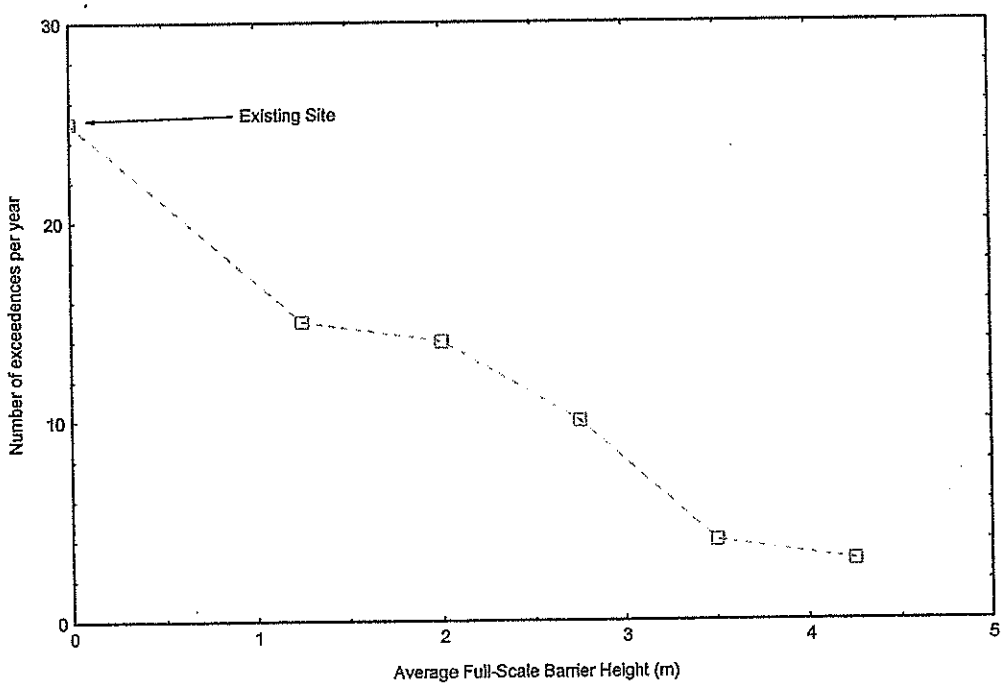


Figure 7. Effect of Barrier Height Upon Exceedences of Distress Criteria

The total numbers of exceedences of the distress criteria per year are plotted against full-scale average barrier height in Figure 7. This figure shows:

- In general, increasing barrier height reduces exceedences.
- Average barrier heights above 1.25m roughly halves the incidences (increasing barrier height has a small beneficial effect)
- Compared with the existing site, average barrier heights above 3.5m reduces incidences 6-fold.

4.3.2 Comfort Criteria

North Main Entrance Doors

For the North Main Entrance Doors (locations 36, 37 and 38), the comfort criteria results are shown in Annex C have been summarised below in Table 5. These results show that:

- Location 36 always has wind conditions that are suitable for its intended purpose.
- At location 37 the wind conditions become unsuitable for average barrier heights between 2m and 3.5m. For barrier heights greater than 3,5m, the wind conditions are suitable, for barrier heights less than 2m, the wind conditions are unsuitable.
- At location 38, any barrier height creates suitable conditions. Note that the lowest barrier height includes the effect of the large canopy over the Main North Entrance Doors. Hence any wind amelioration caused by the small 1.25m barriers is enhanced by the effect of the canopy.

Location	Full-Scale Average Barrier Height (m)					
	0 (Existing)	1.25	2	2.75	3.5	4.25
36	Tolerable	Tolerable	Tolerable	Tolerable	Tolerable	Tolerable
37	Unacceptable	Unacceptable	Tolerable	Unacceptable	Tolerable	Tolerable
38	Unacceptable	Tolerable	Tolerable	Tolerable	Tolerable	Tolerable

Table 5. Comfort Criteria Assessment for North Main Entrance Doors

Other Locations (Locations 15, 16, 17, 23 and 24)

As can be seen from he results presented in Annex C, locations 15, 16, 17, 23 and 24 have unsuitable wind conditions for Entrances (the most onerous windspeed comfort criteria), irrespective of barrier height. Nevertheless, all of these locations are suitable for Business Walking (the least onerous windspeed criteria), irrespective of barrier height.

The efficacy of the Configuration 'A' barriers can be seen in the Pedestrian Walking criteria, which have been summarised in Table 6.

Location	Full-Scale Average Barrier Height (m)					
	0 (Existing)	1.25	2	2.75	3.5	4.25
15	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable
16	Unacceptable	Unacceptable	Tolerable	Tolerable	Tolerable	Tolerable
17	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable
23	Unacceptable	Unacceptable*	Unacceptable	Unacceptable	Tolerable	Tolerable
24	Unacceptable	Tolerable	Tolerable	Tolerable	Tolerable	Tolerable

*The raw test results assessed this location as being 'tolerable'. However, consideration of the other test results shown above indicates that this initial assessment is not correct.

Table 6. Comfort Criteria Assessment for Pedestrian Walking

With regards to the wind conditions, the results in Table 6 show that locations 15 and 17 are unsuitable, and location 24 is suitable for Pedestrian Walking, irrespective of barrier height. Note that location 24 (with no barriers) presently has 'unsuitable' wind conditions, which are ameliorated by the barriers.

From the results shown in Table 6 it can be seen that location 16 is likely to have suitable Pedestrian Walking wind conditions if the average barrier height is more than 2m high. It can also be seen that location 23 is likely to have suitable Pedestrian Walking wind conditions if the average barrier height is more than 3.5m high.

5 Discussion

Firstly, issues concerning pedestrian safety will be considered. The results presented in Annex D show clearly that the incidences of the occurrences of 'distress' windspeeds can be reduced significantly by the introduction of the Configuration 'A' wind mitigation measures. Introducing barriers of sufficient height is likely to prevent these exceedences at most of the North fire exit doorways. However, even with the addition of 4.25m barriers, locations 17 and 23 are likely to experience distressing windspeeds once or twice a year.

It is important to put the number of incidences of 'distress' into a practical context. As can be seen from the information presented in Annex D, for every model configuration tested, almost all of the exceedences occur in January. Indeed, for the larger barrier heights tested, the exceedences are only likely to occur in January. It should furthermore be noted that the number of exceedences per year can occur at night-time, as well as during the day. Therefore, although this testing has shown that wind conditions likely to cause distress can occur, from a fire safety point of view, two wind-related issues that should be considered are:

1) What is the likelihood that an emergency evacuation (e.g. due to fire) occurs during working hours in January?
2) Is the number of exceedences of the distress windspeed in January likely to cause people to fall or stumble, thus hindering an evacuation?

Answering the questions above is outside the experience of the author, and is not within the remit of this wind tunnel investigation. Nevertheless, as can be seen from Figure 7, introducing barriers of height 3.5m or taller reduces the number of distress windspeed exceedences to a very small number of incidences.

With regards to the pedestrian comfort, the test results show that compared with the existing situation, introducing wind amelioration devices is likely to improve significantly the wind conditions. However the test locations around the exposed North and North-West facade (locations 15, 16, 17, 23 and 24) are not likely to be suitable for entrance doorways, whatever the height of the wind amelioration devices. Introducing barriers more that 3.5m in height is likely to create suitable Pedestrian Walking wind conditions at locations 16, 23 and 24, but locations 15 and 17 would still be unsuitable for Pedestrian Walking (again, irrespective of the barrier heights tested). Note that these two windy locations are assessed as being suitable only for Business Walking.

As well as considerations about the efficacy of wind amelioration devices, a decision as whether or not to install such measures depends upon factors (such as cost and aesthetics) that are outside the author's experience. A balance has to be struck between the economics and the potential benefits. The wind tunnel testing has shown that the wind conditions around the Bridgewater Place site are such that it is not practicable to produce pleasant wind conditions everywhere around the site throughout the whole year. Therefore amelioration measures should be introduced with the aim of producing the best possible wind conditions, even though it must be recognised that on very windy days these locations are still likely to experience unpleasant wind conditions.

From a wind engineering perspective, it would appear that installing 3.5m barriers is likely to offer good protection against the wind. This height of barrier ensures that almost all of the North Entrance doorways are protected against distressing winds, and these measures also increase the number of locations suitable

for Pedestrian Walking. Increasing the barrier height above 3.5m is shown to have only a marginally beneficial effect.

6 Conclusions

6.1 Pedestrian Safety

- The results presented in Annex D show that the incidences of the occurrences of distress windspeeds will be reduced significantly by the introduction of the Configuration 'A' wind mitigation measures.
- Introducing barriers of sufficient height is likely to prevent these exceedences of distress windspeeds at most of the North fire exit doorways. However, even with the addition of 4.25m barriers, locations 17 and 23 are likely to experience distress windspeeds once or twice a year in January.

6.2 Pedestrian Comfort

- The area surrounding the existing Bridgewater site has wind conditions that are suitable for Pedestrian Walking (i.e. ambling/strolling) and Business Walking, but are not suitable for Long-Term Sitting or Entrances. Beyond the vicinity of the Bridgewater building, the Bridgewater development does not affect significantly the general wind conditions.
- As shown in Figure 6, the wind conditions everywhere around the existing Bridgewater site are suitable for Business Walking. About a half of the test locations are also suitable for Pedestrian Walking, and about a third of the Pedestrian Walking locations are suitable for Entrances and Long-Term Sitting.
- Compared with the existing situation, introducing wind amelioration devices is likely to improve significantly the wind conditions. However test locations around the exposed North and North-West facade (locations 15, 16, 17, 23 and 24) are not likely to have wind conditions that are suitable for entrance doorways, whatever the height of the wind amelioration devices.
- Introducing barriers more than 3.5m in height is likely to create suitable Pedestrian Walking wind conditions at locations 16, 23 and 24, but locations 15 and 17 would still be unsuitable for Pedestrian Walking (again, irrespective of the barrier heights tested). Note that these two windy locations are still suitable for Business Walking.

7 Recommendations

The wind tunnel testing has shown that the wind conditions around the Bridgwater Place site are such that it is not practicable to produce pleasant wind conditions everywhere around the site throughout the whole year. Therefore amelioration measures should be introduced with the aim of producing the best possible wind conditions, even though it must be recognised that on very windy days these locations are still likely to experience unpleasant wind conditions.

The test results show that installing 3.5m barriers is likely to offer good protection against the wind. This height of barrier ensures that almost all of the North Entrance doorways are protected against distressing winds, and these measures also increase the number of locations suitable for Pedestrian Walking. Increasing the barrier height above 3.5m is shown to have only a marginally beneficial effect.

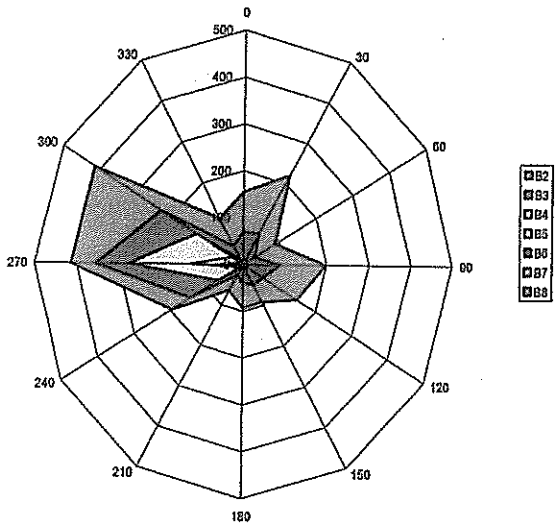
8 References

1. British Standard BS 6399: Part 2: 1997. Loading for buildings. Part 2. Code of practice for wind loads. ISBN 0 580 27447 0.

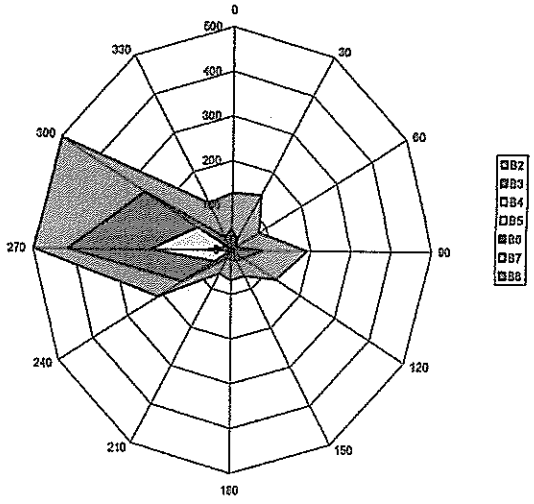
2. Lawson TV. Building Aerodynamics. Imperial College Press, 2001. ISBN 1-86094-187-7

Annex A – Meteorological Wind Data

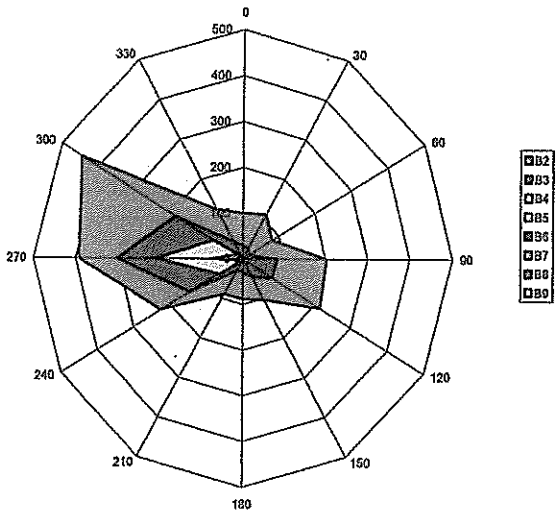
The data used in the wind roses presented below was obtained from the UK Met Office. The data was measured at Church Fenton aerodrome, 10m above the ground. B2, B3 etc are the windspeed ranges of the Beaufort Scale



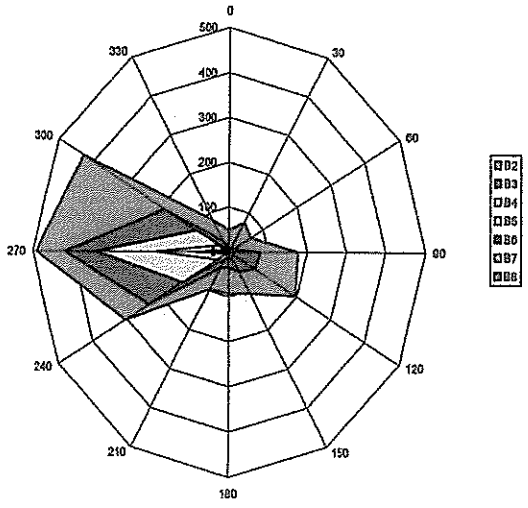
Spring



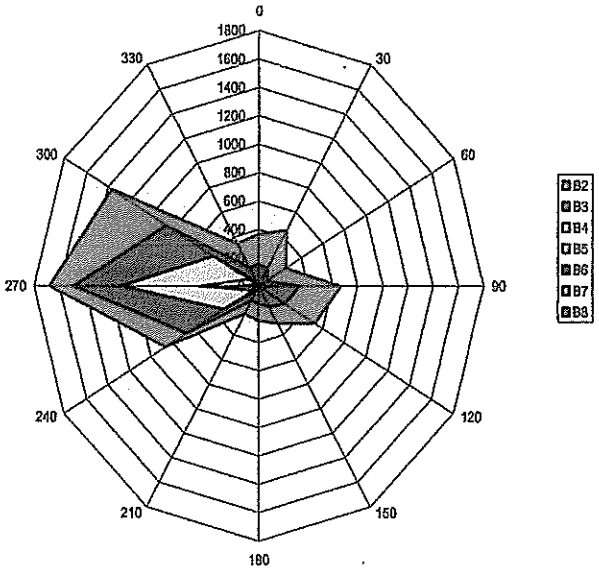
Summer



Autumn



Winter



Year as a Whole

Annex B – Output from BreVe Computer Program

Meteorological Site Conditions – Church Fenton

Provenance

Report generated by BreVe 2.2.1.1, 10/07/2008 08:32:13
SE527377 BreVe 1km resolution site data for SE527377
Design annual risk = 0.02000
Shelter effect from obstructions is included.
Site altitude = 8.0m.
Topographic increment from internal parameters.
Season length is all year.
Using UK direction factors.
Basic wind speed *Vb* = 23.5m/s
Site altitude = 8.0m
Probability factor, *Sp* = 1.000
Seasonal factor, *Ss* = 1.000

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Direction factor, *Sd* :	0.780	0.730	0.730	0.740	0.730	0.800	0.850	0.930	1.000	0.990	0.910	0.820
Topography :												
Crest height (m) :	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Site location (m) :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Upwind length (m) :	50	50	50	50	50	50	50	50	50	50	50	50
Dnwind length (m) :	50	50	50	50	50	50	50	50	50	50	50	50
Base altitude (m) :	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Upwind slope :	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020

BS6399-2 Directional Method - Effective gust plus Mean, gust and turbulence wind speeds

SE527377 BreVe 1km resolution site data for SE527377

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Direction factor, *Sd* :	0.780	0.730	0.730	0.740	0.730	0.800	0.850	0.930	1.000	0.990	0.910	0.820
Dist. to sea (km) :	134.0	73.9	68.0	78.0	200.0	200.0	200.0	200.0	200.0	115.8	200.0	200.0
Dist. in town (km) :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Altitude factor, *Sa* :	1.007	1.007	1.007	1.007	1.007	1.007	1.007	1.007	1.007	1.007	1.007	1.007
Obst. height, *Ho* (m) :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Obst. spacing, *Xo* (m) :	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Displ. height, *Hd* (m) :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Height above ground = 10.0 m												
Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Eff. height, *He* (m) :	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Topog. Incr. *Sh* :	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
Factor *Sc* :	1.004	1.023	1.028	1.020	1.004	1.004	1.004	1.004	1.004	1.004	1.004	1.004
Factor *St* :	0.178	0.178	0.178	0.178	0.178	0.178	0.178	0.178	0.178	0.178	0.178	0.178
Factor *Tc* :	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Factor *Tt* :	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
a = 5.0 m, *gt* :	3.440	3.440	3.440	3.440	3.440	3.440	3.440	3.440	3.440	3.440	3.440	3.440
a = 5.0 m, *Sb* :	1.645	1.677	1.684	1.672	1.645	1.645	1.645	1.645	1.645	1.645	1.645	1.645
a = 5.0 m, *Ve* (m/s) :	30.4	29.0	29.1	29.3	28.4	31.1	33.1	36.2	38.9	38.5	35.4	31.9
Mean factor :	1.032	1.052	1.056	1.049	1.032	1.032	1.032	1.032	1.032	1.032	1.032	1.032
Mean *V* (m/s) :	19.0	18.2	18.2	18.4	17.8	19.5	20.8	22.7	24.4	24.2	22.2	20.0
t = 1s, *Sb* :	1.645	1.677	1.684	1.672	1.645	1.645	1.645	1.645	1.645	1.645	1.645	1.645
1s gust *V* (m/s) :	30.4	29.0	29.1	29.3	28.4	31.1	33.1	36.2	38.9	38.5	35.4	31.9
Turbulence factor :	0.178	0.182	0.182	0.181	0.178	0.178	0.178	0.178	0.178	0.178	0.178	0.178
Turbulence *V* (m/s) :	3.29	3.14	3.15	3.17	3.08	3.37	3.58	3.92	4.22	4.18	3.84	3.46

Site Conditions - Bridgewater Place

Provenance

Report generated by BreVe 2.2.1.1, 10/07/2008 08:38:51
SE300327 BreVe 1km resolution site data for SE300327
Design annual risk = 0.02000
Shelter effect from obstructions is included.
Site altitude = 32.0m.
Topographic increment from internal parameters.
Season length is all year.
Using UK direction factors.
Basic wind speed *Vb* = 23.3m/s
Site altitude = 32.0m
Probability factor, *Sp* = 1.000
Seasonal factor, *Ss* = 1.000

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Direction factor, *Sd* :	0.780	0.730	0.730	0.740	0.730	0.800	0.850	0.930	1.000	0.990	0.910	0.820
Topography :												
Crest height (m) :	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Site location (m) :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Upwind length (m) :	400	400	400	400	400	400	400	400	400	400	400	400
Dnwind length (m) :	400	400	400	400	400	400	400	400	400	400	400	400
Base altitude (m) :	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
Upwind slope :	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020

BS6399-2 Directional Method - Effective gust plus Mean, gust and turbulence wind speeds

SE300327 BreVe 1km resolution site data for SE300327

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Direction factor, *Sd* :	0.780	0.730	0.730	0.740	0.730	0.800	0.850	0.930	1.000	0.990	0.910	0.820
Dist. to sea (km) :	200.0	92.0	88.0	89.6	200.0	200.0	200.0	200.0	200.0	96.0	200.0	200.0
Dist. in town (km) :	7.5	6.5	7.5	2.5	1.5	2.5	2.5	3.5	3.5	17.5	8.5	8.5
Altitude factor, *Sa* :	1.024	1.024	1.024	1.024	1.024	1.024	1.024	1.024	1.024	1.024	1.024	1.024
Obst. height, *Ho* (m) :	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
Obst. spacing, *Xo* (m) :	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Displ. height, *Hd* (m) :	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Height above ground = 75.0 m												
Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Eff. height, *He* (m) :	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0
Topog. incr. *Sh* :	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
Factor *Sc* :	1.347	1.355	1.359	1.358	1.347	1.347	1.347	1.347	1.347	1.351	1.347	1.347
Factor *St* :	0.140	0.140	0.140	0.140	0.140	0.140	0.140	0.140	0.140	0.140	0.140	0.140
Factor *Tc* :	0.916	0.920	0.916	0.946	0.963	0.946	0.946	0.936	0.936	0.897	0.913	0.913
Factor *Tt* :	1.282	1.269	1.282	1.175	1.119	1.175	1.175	1.210	1.210	1.352	1.293	1.293
a = 5.0 m, *gl* :	3.440	3.440	3.440	3.440	3.440	3.440	3.440	3.440	3.440	3.440	3.440	3.440
a = 5.0 m, *Sb* :	2.035	2.047	2.053	2.051	2.036	2.036	2.036	2.035	2.035	2.040	2.034	2.034
a = 5.0 m, *Ve* (m/s) :	37.9	35.6	35.8	36.2	35.5	38.9	41.3	45.2	48.6	48.2	44.2	39.8
Mean factor :	1.271	1.283	1.282	1.322	1.336	1.312	1.312	1.299	1.299	1.248	1.267	1.267
Mean *V* (m/s) :	23.7	22.4	22.3	23.3	23.3	25.1	26.6	28.8	31.0	29.5	27.5	24.8
t = 1s, *Sb* :	2.035	2.047	2.053	2.051	2.036	2.036	2.036	2.035	2.035	2.040	2.034	2.034
1s gust *V* (m/s) :	37.9	35.6	35.8	36.2	35.5	38.9	41.3	45.2	48.6	48.2	44.2	39.8
Turbulence factor :	0.222	0.222	0.224	0.212	0.204	0.210	0.210	0.214	0.214	0.230	0.223	0.223
Turbulence *V* (m/s) :	4.13	3.87	3.90	3.74	3.55	4.01	4.26	4.75	5.11	5.43	4.85	4.37

Annex C - Acceptability Tables for each measurement location

C1. Baseline Configuration

Location	Business Walking	Strolling	Long-term Sitting	Entrance Doors
1	Acceptable	Tolerable	Unacceptable	Unacceptable
2	Acceptable	Tolerable	Unacceptable	Unacceptable
3	Acceptable	Tolerable	Unacceptable	Unacceptable
4	Acceptable	Tolerable	Unacceptable	Unacceptable
5	Acceptable	Unacceptable	Unacceptable	Unacceptable
6	Acceptable	Unacceptable	Unacceptable	Unacceptable
7	Tolerable	Unacceptable	Unacceptable	Unacceptable
8	Tolerable	Unacceptable	Unacceptable	Unacceptable
9	Tolerable	Unacceptable	Unacceptable	Unacceptable
10	Acceptable	Tolerable	Unacceptable	Unacceptable
11	Acceptable	Unacceptable*	Unacceptable	Unacceptable
12	Tolerable	Unacceptable	Unacceptable	Unacceptable
13	Acceptable	Unacceptable	Unacceptable	Unacceptable
14	Acceptable	Unacceptable	Unacceptable	Unacceptable
15	Tolerable	Unacceptable	Unacceptable	Unacceptable
16	Tolerable	Unacceptable	Unacceptable	Unacceptable
17	Tolerable	Unacceptable	Unacceptable	Unacceptable
18	Acceptable	Unacceptable	Unacceptable	Unacceptable
19	Acceptable	Unacceptable	Unacceptable	Unacceptable
20	Acceptable	Unacceptable	Unacceptable	Unacceptable
21	Acceptable	Tolerable	Unacceptable	Unacceptable
22	Acceptable	Unacceptable*	Unacceptable	Unacceptable
23	Acceptable	Unacceptable	Unacceptable	Unacceptable
24	Tolerable	Unacceptable	Unacceptable	Unacceptable
25	Acceptable	Tolerable	Unacceptable	Unacceptable
26	Acceptable	Tolerable	Unacceptable	Unacceptable
27	Acceptable	Acceptable	Tolerable	Tolerable
28	Acceptable	Tolerable	Unacceptable	Unacceptable
29	Acceptable	Tolerable	Unacceptable	Unacceptable
30	Acceptable	Tolerable	Unacceptable	Unacceptable
31	Acceptable	Tolerable	Unacceptable	Unacceptable
32	Acceptable	Acceptable	Tolerable	Tolerable
33	Acceptable	Acceptable	Tolerable	Tolerable
34	Acceptable	Acceptable	Tolerable	Tolerable
35	Acceptable	Acceptable	Tolerable	Tolerable
36	Acceptable	Acceptable	Tolerable	Tolerable
37	Acceptable	Tolerable	Unacceptable	Unacceptable
38	Acceptable	Tolerable	Unacceptable	Unacceptable
39	Acceptable	Acceptable	Tolerable	Tolerable
40	Acceptable	Tolerable	Unacceptable	Unacceptable

Location	Business Walking	Strolling	Long-term Sitting	Entrance Doors
41	Acceptable	Tolerable	Unacceptable	Unacceptable
42	Acceptable	Tolerable	Unacceptable	Unacceptable
43	Acceptable	Tolerable	Unacceptable	Unacceptable
44	Acceptable	Unacceptable	Unacceptable	Unacceptable
45	Acceptable	Tolerable	Unacceptable	Unacceptable

*The raw test results were assessed this location as being 'tolerable'. However, consideration of the other test results shown above indicates that this initial assessment was not correct.

C2. Configuration 'A', Average Barrier Height 4.25m (Full-Scale)

Location	Business Walking	Strolling	Long-term Sitting	Entrance Doors
1	Acceptable	Tolerable	Unacceptable	Unacceptable
2	Acceptable	Tolerable	Unacceptable	Unacceptable
3	Acceptable	Tolerable	Unacceptable	Unacceptable
4	Acceptable	Tolerable	Unacceptable	Unacceptable
5	Acceptable	Unacceptable	Unacceptable	Unacceptable
6	Acceptable	Tolerable	Unacceptable	Unacceptable
7	Tolerable	Unacceptable	Unacceptable	Unacceptable
8	Acceptable	Unacceptable	Unacceptable	Unacceptable
9	Acceptable	Tolerable	Unacceptable	Unacceptable
10	Acceptable	Unacceptable	Unacceptable	Unacceptable
11	Acceptable	Tolerable	Unacceptable	Unacceptable
12	Acceptable	Tolerable	Unacceptable	Unacceptable
13	Acceptable	Tolerable	Unacceptable	Unacceptable
14	Acceptable	Unacceptable	Unacceptable	Unacceptable
15	Acceptable	Unacceptable	Unacceptable	Unacceptable
16	Acceptable	Tolerable	Unacceptable	Unacceptable
17	Tolerable	Unacceptable	Unacceptable	Unacceptable
18	Acceptable	Tolerable	Unacceptable	Unacceptable
19	Acceptable	Unacceptable	Unacceptable	Unacceptable
20	Acceptable	Unacceptable	Unacceptable	Unacceptable
21	Acceptable	Tolerable	Unacceptable	Unacceptable
22	Acceptable	Unacceptable	Unacceptable	Unacceptable
23	Acceptable	Tolerable	Unacceptable	Unacceptable
24	Acceptable	Tolerable	Unacceptable	Unacceptable
25	Acceptable	Tolerable	Unacceptable	Unacceptable
26	Acceptable	Tolerable	Unacceptable	Unacceptable
27	Acceptable	Acceptable	Tolerable	Tolerable
28	Acceptable	Tolerable	Unacceptable	Unacceptable
29	Acceptable	Tolerable	Unacceptable	Unacceptable
30	Acceptable	Tolerable	Unacceptable	Unacceptable
31	Acceptable	Tolerable	Unacceptable	Unacceptable
32	Acceptable	Acceptable	Tolerable	Tolerable
33	Acceptable	Acceptable	Tolerable	Tolerable
34	Acceptable	Acceptable	Tolerable	Tolerable
35	Acceptable	Acceptable	Tolerable	Tolerable
36	Acceptable	Acceptable	Tolerable	Tolerable
37	Acceptable	Acceptable	Tolerable	Tolerable
38	Acceptable	Acceptable	Tolerable	Tolerable
39	Acceptable	Acceptable	Tolerable	Tolerable
40	Acceptable	Tolerable	Unacceptable	Unacceptable

Location	Business Walking	Strolling	Long-term Sitting	Entrance Doors
41	Acceptable	Tolerable	Unacceptable	Unacceptable
42	Acceptable	Tolerable	Unacceptable	Unacceptable
43	Acceptable	Tolerable	Unacceptable	Unacceptable
44	Acceptable	Tolerable	Unacceptable	Unacceptable
45	Acceptable	Tolerable	Unacceptable	Unacceptable

C3. Configuration 'A', Average Barrier Height 3.5m (Full-Scale)

Location	Business Walking	Strolling	Long-term Sitting	Entrance Doors
1	Acceptable	Tolerable	Unacceptable	Unacceptable
2	Acceptable	Tolerable	Unacceptable	Unacceptable
3	Acceptable	Acceptable	Tolerable	Tolerable
4	Acceptable	Tolerable	Unacceptable	Unacceptable
5	Acceptable	Unacceptable	Unacceptable	Unacceptable
6	Acceptable	Tolerable	Unacceptable	Unacceptable
7	Tolerable	Unacceptable	Unacceptable	Unacceptable
8	Acceptable	Unacceptable	Unacceptable	Unacceptable
9	Acceptable	Tolerable	Unacceptable	Unacceptable
10	Acceptable	Unacceptable	Unacceptable	Unacceptable
11	Acceptable	Unacceptable	Unacceptable	Unacceptable
12	Acceptable	Unacceptable	Unacceptable	Unacceptable
13	Acceptable	Tolerable	Unacceptable	Unacceptable
14	Acceptable	Unacceptable	Unacceptable	Unacceptable
15	Acceptable	Unacceptable	Unacceptable	Unacceptable
16	Acceptable	Tolerable	Unacceptable	Unacceptable
17	Tolerable	Unacceptable	Unacceptable	Unacceptable
18	Acceptable	Tolerable	Unacceptable	Unacceptable
19	Acceptable	Unacceptable	Unacceptable	Unacceptable
20	Acceptable	Unacceptable	Unacceptable	Unacceptable
21	Acceptable	Tolerable	Unacceptable	Unacceptable
22	Acceptable	Unacceptable	Unacceptable	Unacceptable
23	Acceptable	Tolerable	Unacceptable	Unacceptable
24	Acceptable	Tolerable	Unacceptable	Unacceptable
25	Acceptable	Tolerable	Unacceptable	Unacceptable
26	Acceptable	Tolerable	Unacceptable	Unacceptable
27	Acceptable	Acceptable	Tolerable	Tolerable
28	Acceptable	Tolerable	Unacceptable	Unacceptable
29	Acceptable	Tolerable	Unacceptable	Unacceptable
30	Acceptable	Tolerable	Unacceptable	Unacceptable
31	Acceptable	Tolerable	Unacceptable	Unacceptable
32	Acceptable	Acceptable	Tolerable	Tolerable
33	Acceptable	Acceptable	Tolerable	Tolerable
34	Acceptable	Acceptable	Tolerable	Tolerable
35	Acceptable	Acceptable	Tolerable	Tolerable
36	Acceptable	Acceptable	Tolerable	Tolerable
37	Acceptable	Acceptable	Tolerable	Tolerable
38	Acceptable	Acceptable	Tolerable	Tolerable
39	Acceptable	Acceptable	Tolerable	Tolerable
40	Acceptable	Tolerable	Unacceptable	Unacceptable

Location	Business Walking	Strolling	Long-term Sitting	Entrance Doors
41	Acceptable	Tolerable	Unacceptable	Unacceptable
42	Acceptable	Tolerable	Unacceptable	Unacceptable
43	Acceptable	Tolerable	Unacceptable	Unacceptable
44	Acceptable	Tolerable	Unacceptable	Unacceptable
45	Acceptable	Tolerable	Unacceptable	Unacceptable

C4. Configuration 'A', Average Barrier Height 2.75m (Full-Scale)

Location	Business Walking	Strolling	Long-term Sitting	Entrance Doors
1	Acceptable	Tolerable	Unacceptable	Unacceptable
2	Acceptable	Tolerable	Unacceptable	Unacceptable
3	Acceptable	Acceptable	Tolerable	Tolerable
4	Acceptable	Tolerable	Unacceptable	Unacceptable
5	Acceptable	Tolerable	Unacceptable	Unacceptable
6	Acceptable	Tolerable	Unacceptable	Unacceptable
7	Tolerable	Unacceptable	Unacceptable	Unacceptable
8	Acceptable	Unacceptable	Unacceptable	Unacceptable
9	Acceptable	Unacceptable	Unacceptable	Unacceptable
10	Acceptable	Unacceptable	Unacceptable	Unacceptable
11	Acceptable	Tolerable	Unacceptable	Unacceptable
12	Acceptable	Unacceptable	Unacceptable	Unacceptable
13	Acceptable	Tolerable	Unacceptable	Unacceptable
14	Acceptable	Unacceptable	Unacceptable	Unacceptable
15	Tolerable	Unacceptable	Unacceptable	Unacceptable
16	Acceptable	Tolerable	Unacceptable	Unacceptable
17	Tolerable	Unacceptable	Unacceptable	Unacceptable
18	Acceptable	Tolerable	Unacceptable	Unacceptable
19	Acceptable	Unacceptable	Unacceptable	Unacceptable
20	Acceptable	Unacceptable	Unacceptable	Unacceptable
21	Acceptable	Tolerable	Unacceptable	Unacceptable
22	Acceptable	Unacceptable	Unacceptable	Unacceptable
23	Acceptable	Unacceptable	Unacceptable	Unacceptable
24	Acceptable	Tolerable	Unacceptable	Unacceptable
25	Acceptable	Tolerable	Unacceptable	Unacceptable
26	Acceptable	Tolerable	Unacceptable	Unacceptable
27	Acceptable	Acceptable	Tolerable	Tolerable
28	Acceptable	Tolerable	Unacceptable	Unacceptable
29	Acceptable	Tolerable	Unacceptable	Unacceptable
30	Acceptable	Tolerable	Unacceptable	Unacceptable
31	Acceptable	Tolerable	Unacceptable	Unacceptable
32	Acceptable	Acceptable	Tolerable	Tolerable
33	Acceptable	Acceptable	Tolerable	Tolerable
34	Acceptable	Acceptable	Tolerable	Tolerable
35	Acceptable	Acceptable	Tolerable	Tolerable
36	Acceptable	Acceptable	Tolerable	Tolerable
37	Acceptable	Tolerable	Unacceptable	Unacceptable
38	Acceptable	Acceptable	Tolerable	Tolerable
39	Acceptable	Acceptable	Tolerable	Tolerable
40	Acceptable	Tolerable	Unacceptable	Unacceptable

Location	Business Walking	Strolling	Long-term Sitting	Entrance Doors
41	Acceptable	Tolerable	Unacceptable	Unacceptable
42	Acceptable	Tolerable	Unacceptable	Unacceptable
43	Acceptable	Tolerable	Unacceptable	Unacceptable
44	Acceptable	Tolerable	Unacceptable	Unacceptable
45	Acceptable	Tolerable	Unacceptable	Unacceptable

C5. Configuration 'A', Average Barrier Height 2m (Full-Scale)

Location	Business Walking	Strolling	Long-term Sitting	Entrance Doors
1	Acceptable	Tolerable	Unacceptable	Unacceptable
2	Acceptable	Tolerable	Unacceptable	Unacceptable
3	Acceptable	Acceptable	Tolerable	Tolerable
4	Acceptable	Tolerable	Unacceptable	Unacceptable
5	Acceptable	Tolerable	Unacceptable	Unacceptable
6	Acceptable	Tolerable	Unacceptable	Unacceptable
7	Tolerable	Unacceptable	Unacceptable	Unacceptable
8	Acceptable	Unacceptable	Unacceptable	Unacceptable
9	Acceptable	Unacceptable	Unacceptable	Unacceptable
10	Acceptable	Unacceptable	Unacceptable	Unacceptable
11	Acceptable	Tolerable	Unacceptable	Unacceptable
12	Acceptable	Unacceptable	Unacceptable	Unacceptable
13	Acceptable	Tolerable	Unacceptable	Unacceptable
14	Acceptable	Unacceptable	Unacceptable	Unacceptable
15	Tolerable	Unacceptable	Unacceptable	Unacceptable
16	Acceptable	Tolerable	Unacceptable	Unacceptable
17	Tolerable	Unacceptable	Unacceptable	Unacceptable
18	Acceptable	Tolerable	Unacceptable	Unacceptable
19	Acceptable	Unacceptable	Unacceptable	Unacceptable
20	Acceptable	Unacceptable	Unacceptable	Unacceptable
21	Acceptable	Tolerable	Unacceptable	Unacceptable
22	Acceptable	Unacceptable	Unacceptable	Unacceptable
23	Acceptable	Unacceptable	Unacceptable	Unacceptable
24	Acceptable	Tolerable	Unacceptable	Unacceptable
25	Acceptable	Tolerable	Unacceptable	Unacceptable
26	Acceptable	Tolerable	Unacceptable	Unacceptable
27	Acceptable	Acceptable	Tolerable	Tolerable
28	Acceptable	Tolerable	Unacceptable	Unacceptable
29	Acceptable	Tolerable	Unacceptable	Unacceptable
30	Acceptable	Tolerable	Unacceptable	Unacceptable
31	Acceptable	Tolerable	Unacceptable	Unacceptable
32	Acceptable	Acceptable	Tolerable	Tolerable
33	Acceptable	Acceptable	Tolerable	Tolerable
34	Acceptable	Acceptable	Tolerable	Tolerable
35	Acceptable	Acceptable	Tolerable	Tolerable
36	Acceptable	Acceptable	Tolerable	Tolerable
37	Acceptable	Acceptable	Tolerable	Tolerable
38	Acceptable	Acceptable	Tolerable	Tolerable
39	Acceptable	Acceptable	Tolerable	Tolerable
40	Acceptable	Tolerable	Unacceptable	Unacceptable

Location	Business Walking	Strolling	Long-term Sitting	Entrance Doors
41	Acceptable	Tolerable	Unacceptable	Unacceptable
42	Acceptable	Tolerable	Unacceptable	Unacceptable
43	Acceptable	Tolerable	Unacceptable	Unacceptable
44	Acceptable	Tolerable	Unacceptable	Unacceptable
45	Acceptable	Tolerable	Unacceptable	Unacceptable

C6. Configuration 'A', Average Barrier Height 1.25m (Full-Scale)

Location	Business Walking	Strolling	Long-term Sitting	Entrance Doors
1	Acceptable	Tolerable	Unacceptable	Unacceptable
2	Acceptable	Tolerable	Unacceptable	Unacceptable
3	Acceptable	Tolerable	Unacceptable	Unacceptable
4	Acceptable	Tolerable	Unacceptable	Unacceptable
5	Acceptable	Tolerable	Unacceptable	Unacceptable
6	Acceptable	Tolerable	Unacceptable	Unacceptable
7	Tolerable	Unacceptable	Unacceptable	Unacceptable
8	Acceptable	Unacceptable	Unacceptable	Unacceptable
9	Acceptable	Unacceptable	Unacceptable	Unacceptable
10	Acceptable	Unacceptable	Unacceptable	Unacceptable
11	Acceptable	Tolerable	Unacceptable	Unacceptable
12	Acceptable	Unacceptable	Unacceptable	Unacceptable
13	Acceptable	Tolerable	Unacceptable	Unacceptable
14	Acceptable	Unacceptable	Unacceptable	Unacceptable
15	Tolerable	Unacceptable	Unacceptable	Unacceptable
16	Tolerable	Unacceptable	Unacceptable	Unacceptable
17	Tolerable	Unacceptable	Unacceptable	Unacceptable
18	Acceptable	Tolerable	Unacceptable	Unacceptable
19	Acceptable	Unacceptable	Unacceptable	Unacceptable
20	Acceptable	Unacceptable	Unacceptable	Unacceptable
21	Acceptable	Tolerable	Unacceptable	Unacceptable
22	Acceptable	Unacceptable	Unacceptable	Unacceptable
23	Acceptable	Tolerable	Unacceptable	Unacceptable
24	Acceptable	Tolerable	Unacceptable	Unacceptable
25	Acceptable	Tolerable	Unacceptable	Unacceptable
26	Acceptable	Tolerable	Unacceptable	Unacceptable
27	Acceptable	Acceptable	Tolerable	Tolerable
28	Acceptable	Tolerable	Unacceptable	Unacceptable
29	Acceptable	Tolerable	Unacceptable	Unacceptable
30	Acceptable	Tolerable	Unacceptable	Unacceptable
31	Acceptable	Tolerable	Unacceptable	Unacceptable
32	Acceptable	Acceptable	Tolerable	Tolerable
33	Acceptable	Acceptable	Tolerable	Tolerable
34	Acceptable	Acceptable	Tolerable	Tolerable
35	Acceptable	Acceptable	Tolerable	Tolerable
36	Acceptable	Acceptable	Tolerable	Tolerable
37	Acceptable	Tolerable	Unacceptable	Unacceptable
38	Acceptable	Acceptable	Tolerable	Tolerable
39	Acceptable	Acceptable	Tolerable	Tolerable
40	Acceptable	Tolerable	Unacceptable	Unacceptable

Location	Business Walking	Strolling	Long-term Sitting	Entrance Doors
41	Acceptable	Tolerable	Unacceptable	Unacceptable
42	Acceptable	Tolerable	Unacceptable	Unacceptable
43	Acceptable	Tolerable	Unacceptable	Unacceptable
44	Acceptable	Unacceptable	Unacceptable	Unacceptable
45	Acceptable	Tolerable	Unacceptable	Unacceptable

Annex D – Locations Exceeding Distress Criterion

Note that # is the expected number of exceedences in a given year

D1. Existing Site Configuration

Dec		Jan		Feb		Mar	
Loc	#	Loc	#	Loc	#	Loc	#
7	1	5	1	7	1	9	1
9	1	7	3	9	1	15	1
15	1	8	2	15	2	16	1
16	2	9	4	16	2		
17	1	12	3				
		13	1				
		14	2				
		15	4				
		16	4				
		17	3				
		19	3				
		20	1				
		23	2				
		24	2				
		44	2				

D2. Configuration 'A', Average Barrier Height 4.25m (Full-Scale)

Dec		Jan		Feb		Mar	
Loc	#	Loc	#	Loc	#	Loc	#
7	2	5	1	7	2	7	1
		7	4				
		8	3				
		10	2				
		14	1				
		17	2				
		19	2				
		20	1				
		22	1				
		23	1				

D3. Configuration 'A', Average Barrier Height 3.5m (Full-Scale)

Jan		Feb		Mar		Nov		Dec		Year	
Loc	#	Loc	#	Loc	#	Loc	#	Loc	#	Loc	#
5	1	7	3	7	3	7	1	7	3	7	2
7	7										
8	2										
9	1										
10	2										
11	1										
12	2										
14	2										
15	2										
17	2										
19	3										
20	2										
22	1										

D4. Configuration 'A', Average Barrier Height 2.75m (Full-Scale)

Jan		Feb		Mar		Nov		Dec		Year	
Loc	#	Loc	#	Loc	#	Loc	#	Loc	#	Loc	#
5	1	7	2	7	2	7	1	7	2	7	1
7	5	15	1	15	1			15	1		
8	2										
10	3										
11	1										
12	2										
14	2										
15	4										
17	2										
19	3										
20	1										
22	3										
23	1										

D5. Configuration 'A', Average Barrier Height 2m (Full-Scale)

Jan		Feb		Mar		Nov		Dec		Year	
Loc	#	Loc	#	Loc	#	Loc	#	Loc	#	Loc	#
7	5	7	2	7	2	15	1	7	2	15	1
8	1	15	2	15	2			15	2		
9	1							19	1		
10	2										
12	2										
14	1										
15	5										
17	2										
19	3										
20	1										
22	2										
23	1										

D6. Configuration 'A', Average Barrier Height 1.25m (Full-Scale)

Jan		Feb		Mar		Oct		Nov		Dec		Year	
Loc	#	Loc	#	Loc	#	Loc	#	Loc	#	Loc	#	Loc	#
7	3	15	2	15	2					7	1		
8	2									15	2		
10	2												
12	2												
14	1												
15	5												
16	1												
17	2												
19	2												
20	1												
22	2												
23	1												
44	1												