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Wind loads on temporary stage decks

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- A review of available data and design recommendations

Temporary stages used for outdoor events are generally free-standing structures with a flat timber deck supported on system scaffolding or other proprietary systems. General guidance on the design, use and procurement of these structures is given in Temporary demountable structures ^[1], published by the Institution of Structural Engineers, but it does not include guidance for wind loads on temporary stage decks. This Digest provides a procedure for designing temporary stage structures for wind loads that follows BS 6399-2 Code of practice for wind loads



photo courtesy Star Events group

What affects wind uplift?

The general procedure for calculating the wind uplift on temporary stage decks is:

- 1 Determine the appropriate design wind speed.
- 2 Calculate the effect of the wind on the structural form, ie determine the net pressure coefficient.
- 3 Calculate the resistance of the decking to the uplift load, which may be the result of deadweight alone or in combination with other fixings.
- 4 Apply appropriate partial (safety) factors to allow for uncertainty in the design parameters.

1 Design wind speed

Design wind speeds for buildings in the UK are determined from BS6399-2. All discussion of specific parameters here refers to that Standard.

The effective gust wind speed V_e at a particular site is determined from an equation of the form:

$$V_e = V_b \times S_a \times S_d \times S_s \times S_p \times S_b \quad (1)$$

where:

- V_b = a basic wind speed for standard terrain, obtained from a map
- S_a = altitude factor accounting for the effects of altitude and topography
- S_d = direction factor accounting for the effects of wind direction
- S_s = seasonal factor accounting for sub-annual periods of exposure
- S_p = probability factor accounting for different design risks
- S_b = terrain and building factor accounting for terrain roughness and height above ground

The map wind speed V_b and the factors for altitude and topography, direction and terrain roughness, S_a , S_d and S_b , are determined by the site and are not affected by the type of structure. The S_s and S_p factors are generally less well understood.

Seasonal factor The seasonal factor S_s is a reduction factor used to ensure that structures exposed for a short time only, and at known times of the year, have the same overall annual level of risk as a permanent structure: normally 2% risk of exceedence per annum. The seasonal factor should normally be used for temporary stage structures and, since the majority of events where these structures are used fall within the summer months, there are significant advantages to doing so. BS6399-2 gives S_s values for individual months of the year and for two, four and six-month periods, with reducing benefit as the period is extended.

Where a generic structural form is used, which uses the same components in different locations without alteration throughout the year, the seasonal factor should be taken as 1.0. This is because the structure will have to be designed for the worst exposure period, for which the value of S_s will be very close to 1.0. However, where the structure can be modified, for example, with additional deadweight or with fixings, the seasonal factor will allow lighter or less well fixed structures to be used in the summer months.

Probability factor The probability factor was used in the previous wind code (CP 3 : Chapter V : Part 2: 1972), to allow for reduced exposure periods of temporary structures. In BS6399-2, this function is covered by the seasonal factor and the probability factor is used only to change the level of design risk. The standard level of design risk in the UK, and the one mandated by Building Regulations for permanent structures, is 2% per annum. This means that there is a 2% risk of the specified design wind speed being exceeded in every year for which the structure is exposed. This is exactly equivalent to the previously used 'once-in-50-year return period'. Designers are at liberty to specify a different level of risk, where there is no statutory or other limitation, but to do so they must take account of the risk to users of the structure and to the general public. Generally, they will need to agree any such change with the appropriate licensing authorities.

The reason for this caution about the use of S_p can be illustrated by reference to two structures in close proximity, one of which is permanent and the other temporary. If the temporary structure is designed to a value of $S_p < 1$ (higher risk of exceedence), in any given wind storm the risk of wind damage will be higher than for its permanent neighbour. This means that users of the structure and members of the public, who may be in the vicinity of the structure, are placed at greater risk of injury. This is acceptable only in certain circumstances: for example when the temporary structure is sited well away from public access to minimise the risk of injury in case of a failure, or where the site is carefully controlled and actively managed to include wind speed monitoring so that it can be evacuated if the wind speed exceeds a certain threshold. Note, however, that it is not sufficient merely to evacuate users (for example, by cancelling an event and removing staff). The safety of the public must also be ensured by establishing and enforcing an exclusion zone so that any debris resulting from a failure is unlikely to cause injury. These conditions are quite onerous because they imply a high degree of active site management. However, the benefits in terms of reduced design loads and therefore the structure's weight and complexity are significant. Reference ^[1] gives more information on operations management when using this option.

2 Net pressure coefficients

Monopitch canopies are the closest analogy to temporary stage decks and are, in principle, a good source of data. However, most of the published data for blockage under monopitch canopies was derived using solid blocks that stack from the ground up. There are no known studies of typical stage structures, where there is a general distributed blockage arising from the structural members.

BS6399-2 gives local and overall net pressure coefficients for monopitch canopies. Local coefficients apply to specific edge or central regions of the deck and the overall coefficients give the averaged net effect on the whole deck. The maximum local coefficient for 0° pitch and zero blockage is -2.2, compared with a maximum overall coefficient of -1.2.

If the deck is constructed so that it always acts structurally as a single unit, the overall coefficients may be used to determine the wind uplift on the deck. However, to be able to treat a deck as a single unit the decking sheets would have to be mechanically fixed to each of the support units with sufficient fixings to provide the necessary resistance in the edge regions of the deck. A reduced level of fixings would be justified in the central areas but still with adequate fixings into every support unit to resist the general area uplift load and to maintain the integrity of the deck as one unit.

3 Resistance to uplift

The resistance of a stage deck to uplift is provided by its deadweight and any additional mechanical fixings. These are usually well defined, given the chosen design of deck. However, one way to increase the uplift resistance is to add weight, either by increasing the weight of the individual deck components, or by hanging additional weight (such as sandbags) under the deck. Provided this weight is securely attached and distributed over the deck area, it would have the same effect as using heavier decking. For example, hanging weights equivalent to 10 kg/m^2 of deck area would be the same as changing a 30 kg/m^2 deck for a 40 kg/m^2 deck. It may also be possible to take advantage of the weight of items placed on top of the deck, such as PA systems, equipment boxes, rostrums. However, they may be included in the resistance only if they are fixed and/or restrained so that they are not blown away at a wind speed below the design speed for the deck. They should also be reasonably distributed across the deck. If they were all at one side, their effect in resisting a wind on to the other (clear) side would be minimal. Nevertheless, in principle, fixing these items offers a simple way to increase resistance although they may add to the drag load and contribute to the overturning moment.

4 Partial factors

In limit state design, partial factors are used to account for variability and uncertainty in the input parameters on both sides of the equation: the applied load and the resistance. The size of these factors is a matter of judgement for the industry concerned in consultation with the appropriate licensing authorities. In normal construction, it is common to apply a factor 0.9 on the resistance (mainly deadweight for stages), while a factor of 1.4 to 1.5 is commonly applied for wind loads. Naturally, these factors have a large effect on the acceptability of a design.

Procedure for stage decking

This recommended simplified procedure for determining the net wind uplift force F on a stage deck or part of a stage deck is based on the standard method in BS6399-2. Reduced wind loads will be given by the directional method in BS6399-2 but since this will considerably increase the calculation effort, the directional approach is best implemented using a computer program, such as BREVe^[6], to calculate q_s .

$$F = C_{p, \text{net}} \times q_s \times C_a \times A \quad (2)$$

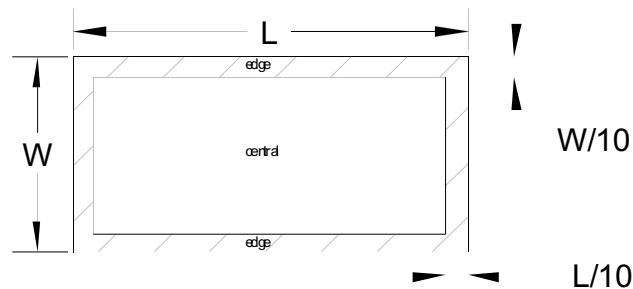
where

- q_s = dynamic pressure = $0.613 V_e^2$
- V_e = effective gust windspeed (see equation 1)
- $C_{p, \text{net}}$ = the net wind pressure coefficient
- C_a = the size effect factor
- A = the surface area of the decking under consideration

Now compare the calculated wind uplift with the resistance offered by deadweight and fixings, applying partial factors as agreed by the licensing authorities. For safe operation:

$$F_{\text{lift}} \cdot \gamma_f \leq (R_{\text{weight}} \cdot \gamma_m) + (R_{\text{fixings}} \cdot \gamma_x) \quad (3)$$

Net pressure difference coefficients $C_{p, \text{net}}$ on flat stages, no sheeting to sides



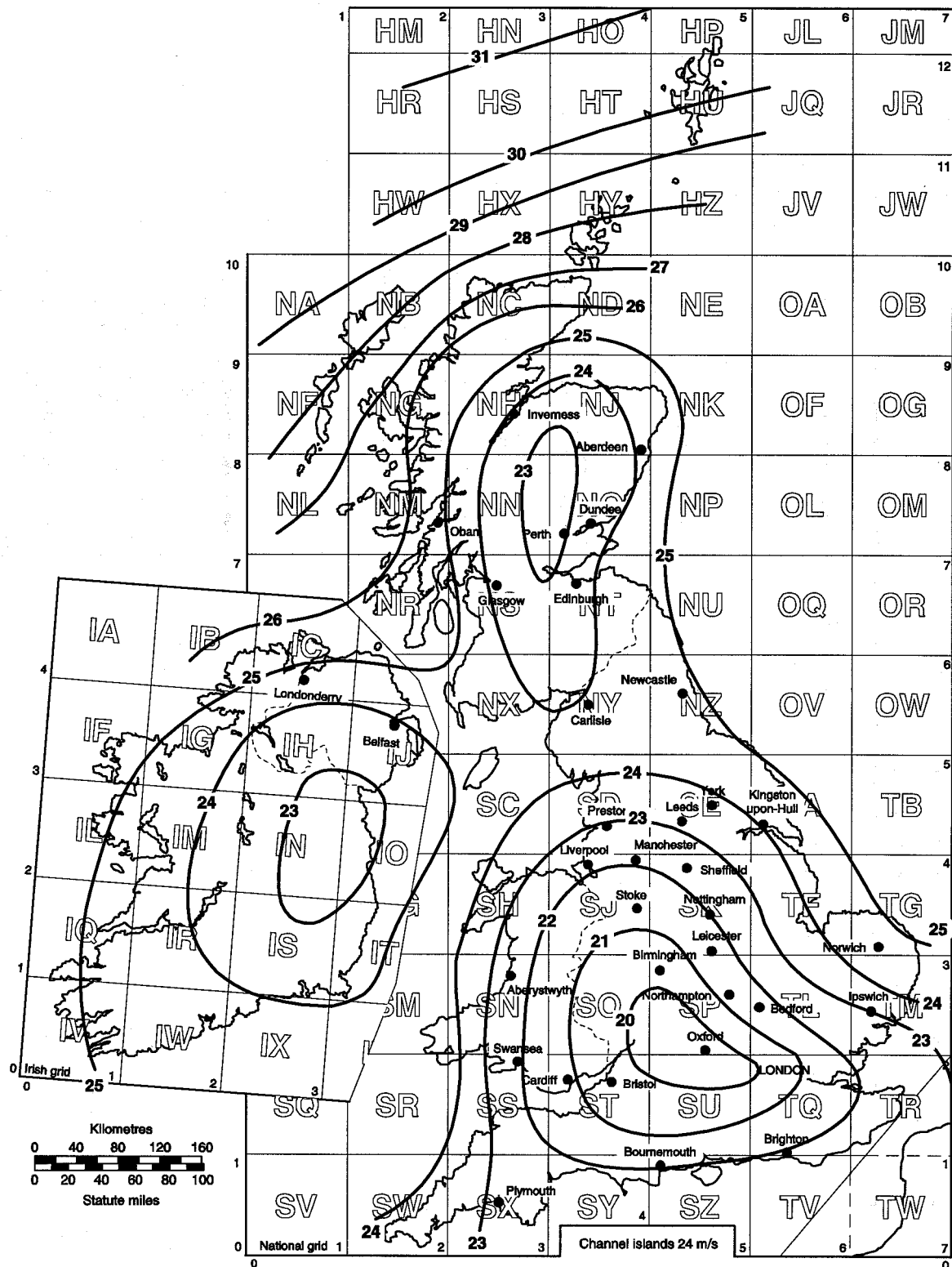
Load case	Blockage	Overall $C_{p, \text{net}}$	Central $C_{p, \text{net}}$	Edge $C_{p, \text{net}}$
Downforce	All	+ 0.2	+ 0.5	+ 1.8
Uplift	0%	- 0.5	- 0.6	- 1.4
Uplift	5%	- 0.54	- 0.64	- 1.43
Uplift	10%	- 0.57	- 0.67	- 1.46
Uplift	20%	- 0.64	- 0.74	- 1.52
Uplift	30%	- 0.71	- 0.81	- 1.58
Uplift	50%	- 0.85	- 0.95	- 1.70
Uplift	100%	- 1.2	- 1.3	- 2.2

The overall $C_{p, \text{net}}$ may only be used where it can be demonstrated that the elements comprising the deck act as a single structural unit and that the fixings that hold it together are able to resist the loads given by the local $C_{p, \text{net}}$ values. Where the deck does not act as one unit, the local $C_{p, \text{net}}$ values for the central and edge regions must be used.

The blockage ratio is defined as the projected area of blockage beneath the stage decking (standards, cross beams, etc) divided by the open area of the stage (the height to the decking multiplied by the stage width). Where the blockage ratio is < 0.05 (5%), it can be ignored and the blockage ratio can be taken as zero.

Increasing the blockage ratio substantially increases the net pressure coefficients so is best avoided. Ensure also that, if the design is based on an assumed low level of blockage, management procedures are in place, and enforced, to inform other users of the site and to prevent the blockage being increased by others.

Figure 1 Basic windspeed map for the UK



Net pressure difference coefficient, $C_{p,net}$ on flat stages, with sheeting to sides

Where the side walls of the stage are sheeted, either with an air permeable covering such as netting or with air impermeable covering such as sheeting or boards, the stage should be treated as an open-sided building. The net uplift coefficients must be determined by summing the internal pressure coefficients and the external coefficients. For example, consider the maximum local edge coefficient on a stage with sheeting on three sides:

the internal coefficient is 0.85

the local edge external coefficient is -2.0

giving a net edge pressure coefficient of -2.85.

This value is very high and likely to be rather conservative for netting. Nevertheless, it indicates that partial sheeting of some of the sides of the stage should, if possible, be avoided.

Worst case internal pressure coefficients on flat stage decks with one or more side walls sheeted

Number of sides sheeted:

One	Two	Three	All
0.60	0.77	0.85	0.2 (-0.3)

External pressure coefficients on flat stage deck

Local edge coefficient	Local central coefficient	Overall coefficient
-2.0	-0.7	-0.8 (estimated)

Basic Wind Speed – V_b

The basic wind speed is obtained from Figure 1.

Altitude factor – S_a

It is assumed that temporary stages are positioned on relatively flat sites and less than halfway up any significant hills (defined as having an upwind slope steeper than 1 in 20). In these circumstances, topography may be ignored and the altitude factor is given by:

$$S_a = 1 + 0.001 \Delta_s$$

where Δ_s is the site altitude in metres above sea level.

If topography is significant, the rules of BS 6399-2 must be followed instead.

Direction factor – S_d

Use $S_d = 1$ for any design where the orientation of the stage is not known or where a conservative design is required. For directional S_d factors see BS 6399-2.

Seasonal factor – S_b

Use the seasonal factor to account for the reduced risk associated with short-term exposure of the stage on a site during particular times of the year. The duration must be fixed and enforced; if not, the effective risk of failure will increase, perhaps substantially.

Start month	1-month period	2-month period	4-month period
Jan	0.98	0.98	0.98
Feb	0.83	0.86	0.87
Mar	0.82	0.83	0.83
Apr	0.75	0.75	0.76
May	0.69	0.71	0.73
Jun	0.66	0.67	0.83
Jul	0.62	0.71	0.86
Aug	0.71	0.82	0.90
Sep	0.82	0.85	0.96
Oct	0.82	0.89	1.00
Nov	0.88	0.95	1.00
Dec	0.94	1.00	1.00

Annual risk of exceedence	S_p
2% (standard value)	1.00
5%	0.95
10%	0.90
20%	0.85

Diagonal dimension (m)	C_a
up to 5	1.00
10	0.96
15	0.93
20	0.91
25	0.90
30	0.89
40	0.87

Probability factor - S_p see Table left

Use $S_p = 1$ unless there are well-defined and enforced safety management protocols to ensure the safety of workers and the public in the event of strong winds.

Where such protocols exist, the value of S_p may be determined from the table below according to the level of design risk agreed with the appropriate licensing authorities:

Size effect factor - C_a see Table left

The value of size effect factor depends on the exposure of the site as well as the diagonal dimension of the loaded area. For simplicity, a table is given of C_a for the most exposed terrain. This introduces a small degree of conservatism. To calculate with greater accuracy, use BS6399-2. For storage decks, the loaded area is defined here as the largest element that acts as a single structural unit. Where the whole deck acts as a single unit, the diagonal of the whole deck is used. Where this is not true and local edge or central values of $C_{p,net}$ are being used, the diagonal is that of the sub-unit (for example, an 8 x 4 deck sheet).

Terrain and building factor - S_b see Table below

The value of S_b depends on the distance to the sea, the height of the stage deck and whether the site is in country or town terrain. Town terrain includes suburban areas where the general roof height is about 5m or more above ground level (typical two-storey domestic housing).

Country terrain is all other terrain.

Height of stage deck (m)	Site in country or up to 2 km into Town Closest distance to sea upwind (km)			Site over 2 km into town Closest distance to sea upwind (km)		
	2	10	≥ 100	2	10	≥ 100
2	1.48	1.35	1.26	1.18	1.15	1.07
5	1.65	1.57	1.45	1.50	1.45	1.36
10	1.78	1.73	1.62	1.73	1.69	1.58

Obstructions around the stage

Take account of specific beneficial sheltering effects of upwind surrounding obstructions, including permanent obstructions (such as buildings, walls and trees) or temporary obstructions, such as Portakabins or toilet blocks. If the obstruction is the same width as the stage and at least as high, and no more than twice its height away from the stage, take account of the shelter effects by taking a reduced effective height for the stage deck. Seek specialist guidance. Upwind obstructions lower than the stage deck could increase the wind loads on the deck so should be sited at a distance of at least three obstruction heights away from the stage.

Obstructions on top of the stage

Provided the obstructions (such as lighting or sound boxes) are small in comparison to the stage itself, they may be ignored when calculating the uplift load on the deck. Where these obstructions are firmly fixed to the deck, their extra weight (subject to the appropriate partial factor) may be allowed for when calculating the resistance to uplift. If they are fixed, the horizontal wind load acting on them will add to the overall load on the deck.

If the obstructions are not fixed to the deck, their deadweight must not be included in the calculation of uplift resistance.

Reducing wind uplift or increasing resistance

These notes are general guides to methods of reducing wind uplift but you should seek advice and/or carry out tests before relying on them. Other factors such as handling and access safety of performers must also be considered.

☐ **Porous decking** Clearly, making the deck more porous is beneficial because it will reduce the magnitude of pressure difference across the deck and so reduce its load. This is likely to be particularly beneficial around the edges of the deck where the greatest loads occur.

☐ **Adding parapets** Parapets are known to reduce edge suctions on flat roofs and may have a similar effect on decks. However, they would have to be significantly high and be applied to all four edges to be fully effective; this is probably not acceptable for stage decks. Handrails will have little effect unless sheeted. Parapets increase the horizontal wind load.

Trial calculations

Calculations of wind uplift forces on temporary stage decks for 9179 postcode sector centroids throughout Great Britain were carried out to determine a limiting value of V_e to overcome deadweight resistance only.

$$V_e = \sqrt{\left(\frac{R_{weight}}{0.613 \cdot C_a \cdot A \cdot C_p} \right) \cdot \left(\frac{\gamma_m}{\gamma_f} \right)} \quad (4)$$

This limiting value of V_e was then compared with the calculated value of $V_{e,site}$ at each of the 9,179 locations using equation (4). These values of $V_{e,site}$ were obtained using the software package BREVe2, which has an ordnance survey database of terrain levels, as well as a BRE database of terrain roughness to 1 km resolution.

Calculations were performed for many combinations of parameters but only a selection are described here to illustrate the effect of different assumptions. The results are presented in two ways: histograms that show the percentage of the 9179 sites for which the deck has acceptable deadweight resistance (abbreviated to %OK) plotted against various input parameters, or as geographic plots showing the location of acceptable and unacceptable sites.

General assumptions used in the calculation

- ☐ Sites above 200 m altitude were omitted from the analysis.
- ☐ The effects of shelter from upwind obstructions were ignored.
- ☐ Topography rules in BS6399-2 were not applied.
- ☐ The site altitude was taken as halfway between the lowest and highest points in the 1 km square.
- ☐ The full directional analysis of wind speed was carried and then the single worst value of V_e was taken for any direction. This is the 'Hybrid method' described in BS6399-2.
- ☐ The seasonal factors for each individual month were used.
- ☐ A single stage deck height of 3 m was used

Figures 2 and 3 show the effect of different deck weight using the local and general net pressure coefficients. The blockage is set to 5%, the probability factor to 1.0 and the partial factors to 1.0 for these two cases, so they represent the baseline case for comparison; this is the best estimate (within the accepted limitations of the BS6399-2 data) of the actual design loads. Using the general coefficients, more than 90% of sites would be acceptable for the use of a 3 m high stage with 40 kg/m² decking, 100% of sites are acceptable between February and October. At 30 kg/m², 90% of sites are acceptable from February to October, and 100% between April and August. A 20 kg/m² deck gives a substantially worse result.

The geographical distribution of the sites that are deemed 'OK' in this analysis for the intermediate deck weight of 30 kg/m² is shown in Figure 4 (local coefficients) and Figure 5 (overall coefficients).

When partial factors of $\gamma_f = 1.4$ and $\gamma_m = 0.9$ are used, the number of acceptable sites reduces significantly. Using the local coefficients, there is nowhere in the UK where a 30 kg/m² deck weight would be acceptable. Using the overall coefficients, however, the number of sites that are acceptable for a deck weight of 40 kg/m² is 90% or more from April to August, and 80% or more from February to October. For a 30 kg/m² deck weight, 90% or more are acceptable only in June and July, 80% or more from May to August and 70% or more from April to August – Figure 6. The geographical distribution of these for a 30 kg/m² deck weight is shown in Figure 7.

Figure 8 shows the effect of assuming a reduced return period of five years (equivalent to an S_p value of 0.85). The caveats associated with such a choice have been discussed but it does improve the percentage of sites that would be deemed acceptable for a 3 m-high, 30 kg/m² deck. The results would be better for a heavier deck.

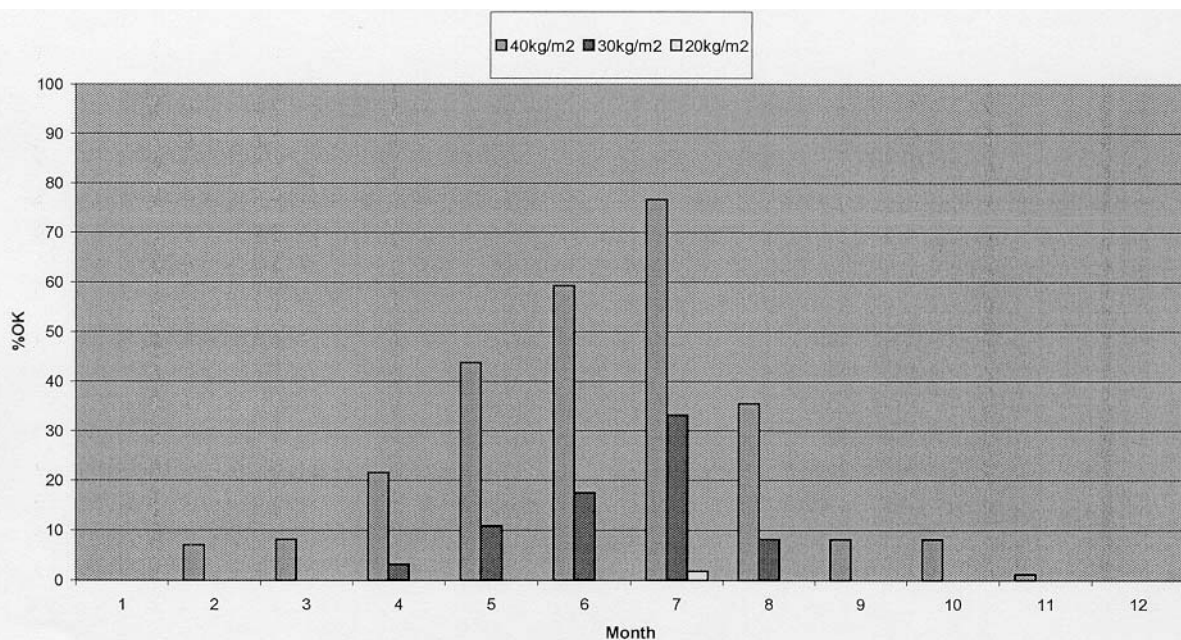


Figure 2 - Effect of deck weight (no partial factors, local coefficients, 5% blockage)

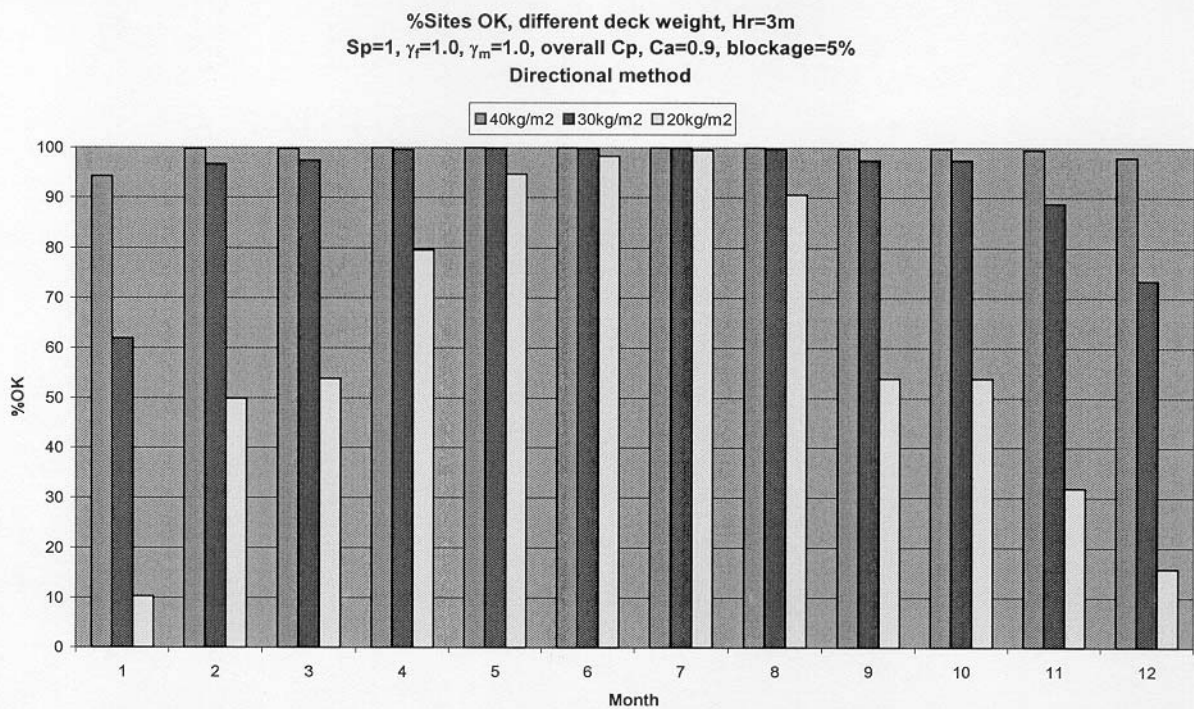


Figure 3 - Effect of deck weight (no partial factors, general coefficients, 5% blockage)

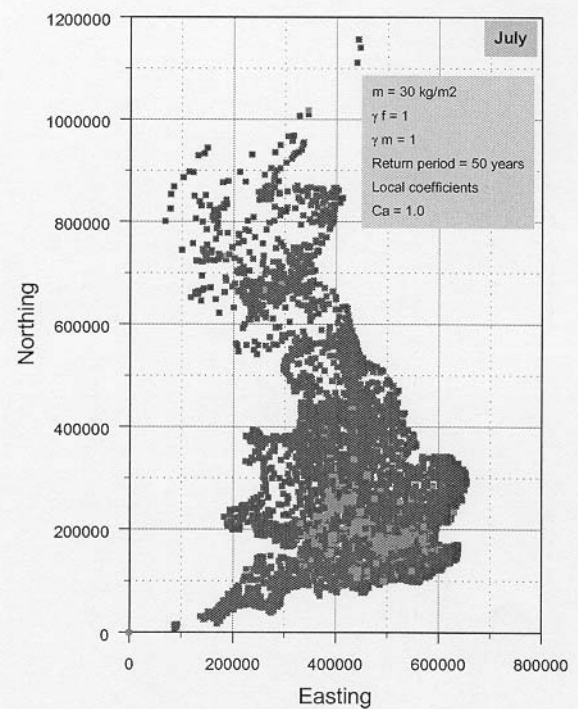
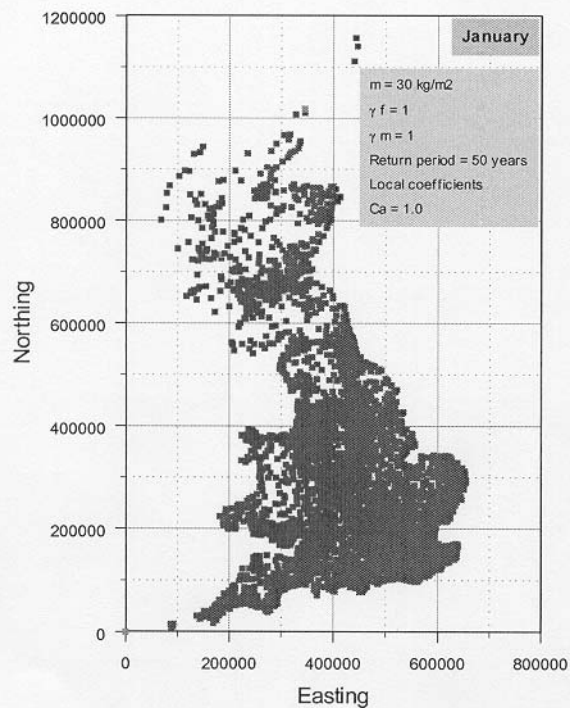


Figure 4 – Distribution of OK sites [no partial factors, local coefficients, RP=50yrs]

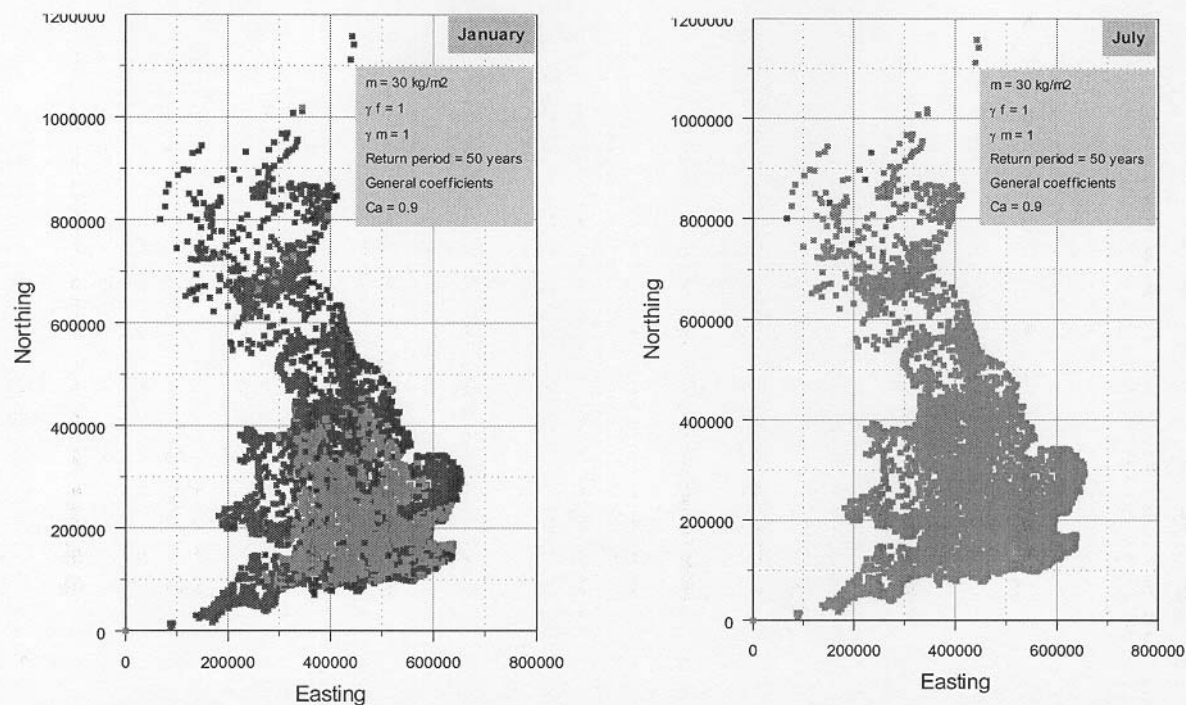


Figure 5 - Distribution of OK sites [no partial factors, general coefficients, RP=50yrs]

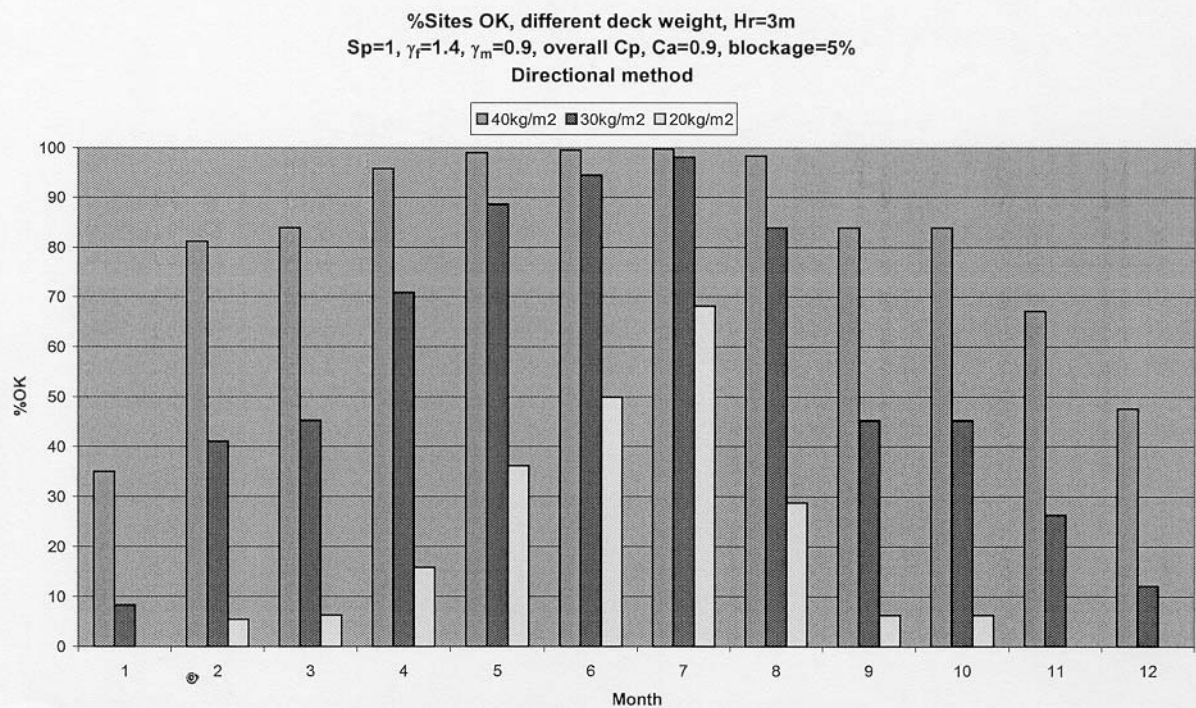


Figure 6 - Effect of deck weight (general coefficients, 5% blockage)

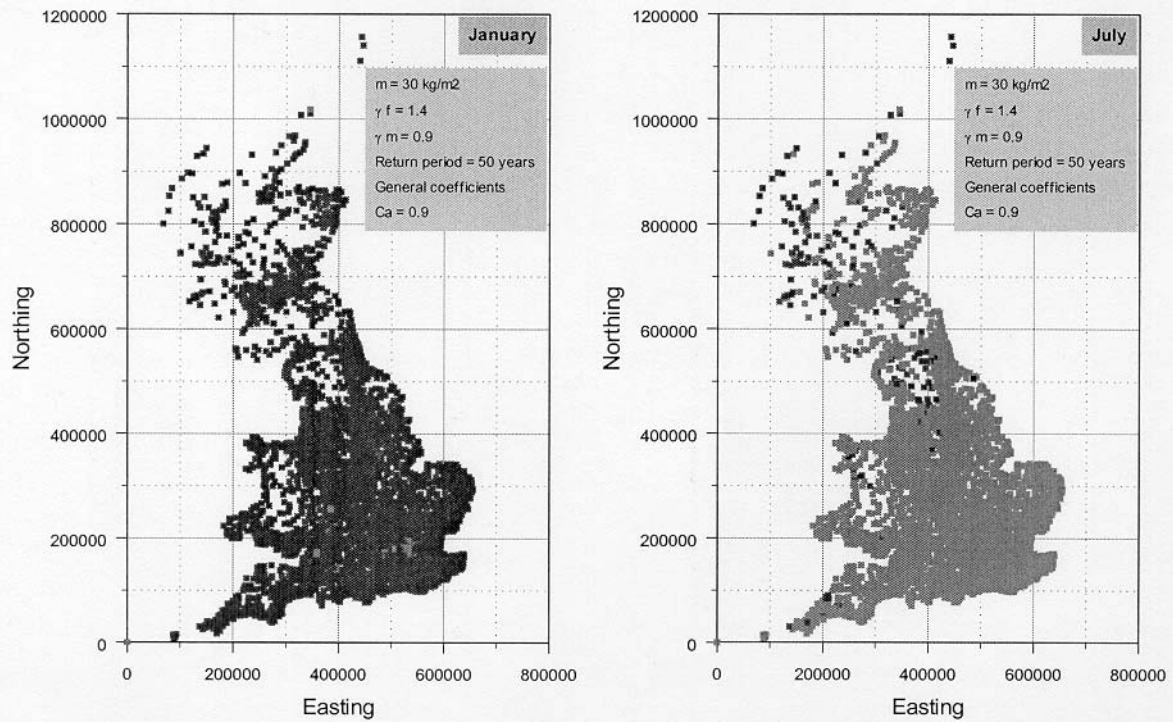


Figure 7 - Distribution of OK sites [with partial factors, general coefficients, RP=50yrs]

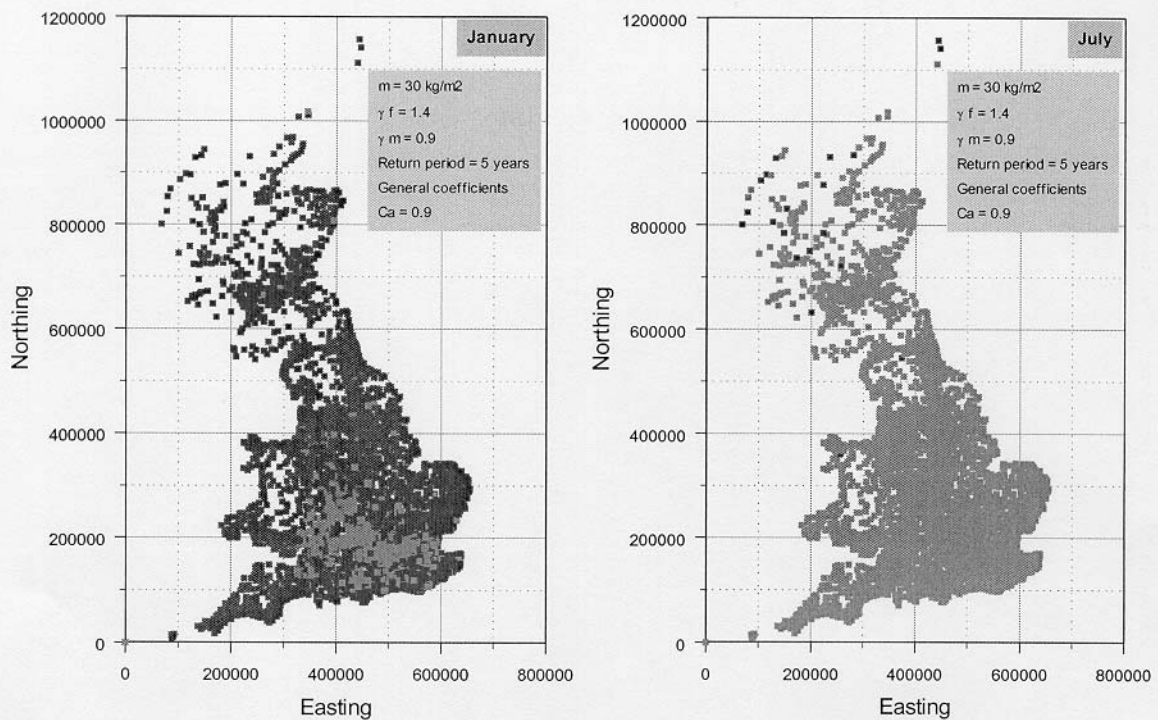


Figure 8 - Distribution of OK sites [with partial factors, general coefficients, RP=5yrs]

Literature Review

A literature review of all major engineering and agricultural databases revealed there was no specific guidance for wind uplift on temporary stage structures. Searches were carried out for seven subject areas:

- ☐ wind effects on flat stages (no blockage or obstructions);
- ☐ wind effects on stages with blockage beneath;
- ☐ wind effects on stages with partially or fully sheeted edges;
- ☐ effects of obstructions on top of stages (hand rails, rostrums, seating, additional tiers, etc);
- ☐ effects of blockage in close proximity to stages (vehicles, temporary offices, storerooms, etc);
- ☐ effects of air permeable decking;
- ☐ wind loads on individual elements (decking, planks, etc).

Relatively little relevant information was found; most of the references retrieved related to wind effects on pitched roof canopy structures, such as Dutch barns. Measurements by Ginger and Letchford^[2, 3, 4] provided some useful data on wind effects on blocked and unblocked canopy roofs, which have similar aerodynamic behaviour to stage decks. These data, which have been incorporated into the Australian/New Zealand wind code^[5], suggests that perhaps the net pressure coefficients given in BS 6399-2 for canopy roofs could be conservative by over 20% for overall loads.

It was concluded that there is limited published data available on wind effects on flat, free-standing structures such as temporary stages, and much of the data that does exist tends to be conflicting. There are also large gaps in knowledge concerning the effects of shelter, the aerodynamic effects of objects placed on top of stages, and the effectiveness of measures for reducing wind uplift by, for example, modifying the edge detail of the stage or adding porosity.

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British Standards Institution

BS 6399 Part 2: 1997 Code of practice for wind loads