Improving Roof Reliability:
Lessons From Wind Damage Reports

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ABSTRACT

Technical investigation reports on wind damage can provide a wealth of useful information. Several case studies from investigations of wind-damaged roofs in the UK and Ireland are presented, collectively exploring alternative causation theories and developing options for strengthening and repair. Roof elements include lightweight metal cladding, waterproofing membranes, and roof overhangs.

By sharing feedback in an independent and constructive way, we can improve our understanding of failure mechanisms, enabling us to design and build more reliable building envelopes that are better able to withstand the extremes of changing weather patterns in whatever country in which we practice.

 SPEAKER

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KEITH ROBERTS is principal of Roberts Consulting, an independent firm of consulting engineers. He is a chartered civil and structural engineer who has undertaken more than 50 roof investigations of wind-damaged buildings throughout the UK and Ireland over 25 years. He has presented in London at the Institution of Civil Engineers and at RCI conventions. Roberts has published in Interface since 1996 and was chairman of the CIB International Roofing Committee that examined roof reliability.
IMPROVING ROOF RELIABILITY: LESSONS FROM WIND DAMAGE REPORTS

INTRODUCTION
Technical investigation reports on wind damage to roofing and cladding can provide a wealth of useful information relevant to designers, researchers, manufacturers, contractors, and building owners. It is common to find multiple failures within roof systems, and often the challenge is to identify which link in the assembly broke first. The forensic investigations demand a methodical approach, piecing together the available evidence of the initial point of failure, which is often hidden from view.

Several case studies of investigations of wind-damaged roofs in the UK and Ireland are presented, exploring alternative causation theories and developing options for strengthening and repair. Roof types include aluminium standing seam, waterproofing membrane, and cantilever roof brackets. This paper presents an introduction to the European wind-loading standard.

The paper describes some of the experiences of the author, who has investigated wind damage to more than 50 roofs in the UK and Ireland over the past 25 years, identifying the causes of the failures and working with the parties to agree on practical forms of repair or replacement.

It is hoped that by sharing feedback from wind damage reports in an independent and constructive way, we can improve our common understanding of failure mechanisms, enabling us to design and build more reliable building envelopes that are better able to withstand the extremes of changing weather patterns in whatever country in which we practice.

EUROPEAN WIND-LOADING STANDARD
Extreme Wind Events
Situated on the edge of the North Atlantic Ocean, the islands of the United Kingdom experience storm-force winds with gust speeds of 30-40 m/s (70-80 mph) occurring several times each season. Major storms can result in personal injuries and significant financial losses. In an average year, 200,000 buildings are damaged by high winds, although the majority of insurance claims are for minor losses of ridge tiles on older properties. The prevailing wind direction in the UK and Ireland is from the southwest, as frontal depressions track across the North Atlantic. Winds blowing from the north and east tend to be less severe and cause less structural damage.

Over the past three years, there have been several significant wind events in which recorded wind speeds in isolated locations have been greater than could be expected to occur once in 50 years. If these events were to occur again, then our basic wind speed maps might need to be revised. However, at present, no plans have been published to update the relevant standards and to modify the basic wind map.

It is understood that the increase in extreme wind events is related to changes in the paths of the jet stream, with broader meander patterns and increased velocities. Various explanations for these changes have been offered, although at present there does not appear to be a broad consensus.

There is uncertainty in the longer-term forecasting of weather patterns and predicting maximum wind speed data for future building design. What is predicted with a high degree of confidence is that more extreme weather events will occur.

European Standardization
Over the past 25 years, there have been three different standards used for calculating design wind pressures on buildings in the UK, each with its own factors, assumptions, and methodology. The changes in codes have led to confusion within the roofing and cladding industry and, on occasion, mistakes and oversight. The changes have had a negative effect, and it is not unusual to find during a wind damage investigation that no party has actually calculated the design wind pressures on the roof and checked the attachment strength.

The standard now used throughout Europe is EN 1991, Part 1.4, which was first introduced in 1999. This comes in two parts: the basic standard that is common across all 29 member countries of the European Union (EU), and a separate National Annex, which is specific for use in individual countries. Each member country has developed its own variations, often introducing significant differences and the requirement for local knowledge and experience. The designer has to use the two documents together and cross-reference both at the same time, adding complexity.

The original aspiration in setting the EU directive was that the Eurocodes would be common standards that apply in all countries, making it easier to trade across borders. This has not happened in reality.

Basic Theory
The basic theory behind the calculation of design wind pressures acting on a building envelope is the same in Europe as in North America. The applied pressure on the surface of the building envelope is the result of the change in momentum in the package of air moving around the surface. The pressure is expressed in the basic equation (see Equation 1).

The significant differences between European and North American practice are in the identification of design wind speeds and design factors.

Basic Wind Velocity
In Europe, the basic wind speeds are the ten-minute mean wind velocity, sometimes referred to as the “sustained wind speed,” with an annual probability of exceedance of 2%. The basic wind map for the UK, based on recorded wind speeds over the period 1970 to 1999, is given in Figure 1. These basic wind speeds are 10 m (33 ft.) above ground in open country terrain.

The basic wind velocity is calculated by

\[ q = \frac{1}{2} \rho \cdot v^2 \]

where:
- \( q \) = peak velocity pressure
- \( \rho \) = air density, taken as 1,226 kg/m³ (76.5 pcf)
- \( v \) = basic wind velocity

Equation 1
multiplying the map velocity by a number of factors (see Equation 2).

It is recognized that strong winds are less common blowing from the north and east. The standard allows for reductions in design wind speeds from these directions with values of $c_{dir}$ of less than 1.0. As a consequence, it is common practice in the UK for four different sets of wind speeds and pressures to be calculated. This can ultimately lead to more efficient designs.

**Peak Velocity Pressure**

Determining the peak velocity pressure for a site follows the equivalent static pressure approach. For a country terrain where orography is not significant, the simplified expression may be seen in Equation 3.

**Wind Pressure**

The basic equation for calculating the wind pressure acting on a roof formed from impermeable skins is shown in Equation 4.

Within the European standard, there are recommendations for pressure coefficients on loaded areas of roofs and walls. A series of figures shows the extent of wind zones, and accompanying tables give two sets of values for external pressure coefficients for loaded areas of up to 1m$^2$ and for large panels of more than 10m$^2$.

**Comparison of Wind Pressures**

The output is to provide the wind suction pressures acting on the different zones of the building envelope. A comparison between design pressures used in the UK with those of North America is summarized in Table 1.

**Design Check on Attachment Strength**

Having determined the design wind pressures, there is a need to ensure that the permissible strength of the roof assembly is greater than the applied pressure. See Equation 5.

**Equation 2**

$$V_b = V_{b, \text{map}} \cdot C_{alt} \cdot C_{dir} \cdot C_{season} \cdot C_{prob}$$

where:
- $V_b$ = basic wind velocity
- $V_{b, \text{map}}$ = basic wind velocity taken from map
- $C_{alt}$ = altitude factor, for large-scale topography
- $C_{dir}$ = directional factor
- $C_{season}$ = seasonal factor, for temporary structures
- $C_{prob}$ = probability factor

**Equation 3**

$$q_p = c_c \cdot 0.613 \cdot 10^{-3} \cdot v_b^2$$

where:
- $q_p$ = peak velocity pressure
- $c_c$ = exposure factor
- $v_b$ = basic wind velocity

**Equation 4**

$$w = q_p (c_{pe} - c_{pl})$$

where:
- $w$ = design wind pressure
- $q_p$ = peak velocity pressure
- $c_{pe}$ = external pressure coefficient
- $c_{pl}$ = internal pressure coefficient

**Table 1 – Comparison between design wind pressures acting on roofs in UK and USA.**

\[ W < \frac{f}{\gamma} \]

where:
- \( w \) = design wind pressure
- \( f \) = characteristic strength
- \( \gamma \) = factor of safety

**Equation 5**

In the UK, the factors of safety used for checking the attachment strength of profiled metal and single-ply membrane roof fasteners are 2.0 for pullout from steel or aluminium, 3.0 for pullout from timber, and 4.0 for pullout from masonry/concrete.

Wind suction forces acting on the upper weathering skin of a roof are transferred from layer to layer, down through the roof construction into the structural framework. Each fastener transfers the upward load to the next layer down. A useful analogy is that of a chain anchoring the upper weathering skin down to the support structure. If one link in the chain were to break, then potentially the outer sheets could become detached from the roof. Calculations should be prepared to estimate the design wind suction loads acting on the different links in the chain and then compared with the characteristic strength of the fasteners to determine their factors of safety. (See Figure 2.)

**Figure 2 – The chain analogy for the attachment strength of a multilayer roof system.**

**CASE STUDIES: WIND DAMAGE INVESTIGATIONS**

**Case Study A: Standing Seam Roof**

On New Year’s Day, 2005, a strong gale blew across southern Ireland from a southwesterly direction, resulting in an extensive area of lightweight aluminium standing-seam roofing becoming detached from the windward verge and causing consequential impact damage to roof cladding and skylights downwind. The aquatic center and adjacent gym were evacuated safely without injury to members of the public or staff. See Table 2.

My instructions were to examine the evidence relating to the wind damage and to identify causation. The instructions were received three months after the wind event, such

**Table 2 – Basic data for Case Study A.**

<table>
<thead>
<tr>
<th>Location</th>
<th>Dublin, Ireland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building use</td>
<td>Aquatic center</td>
</tr>
<tr>
<td>Altitude, site exposure, topography</td>
<td>+74 m (240 ft.) severe, rural</td>
</tr>
<tr>
<td>Roof area</td>
<td>5,700 m² (61,000 sf)</td>
</tr>
<tr>
<td>Roof slope</td>
<td>Barrel vault 62 m wide, slope up to 20º</td>
</tr>
<tr>
<td>Roof type</td>
<td>Aluminium standing seam</td>
</tr>
<tr>
<td>Roof substructure</td>
<td>Halters fixed to top hat rails, to saddles, through liner into purlins</td>
</tr>
<tr>
<td>Basic wind speed (hourly mean)</td>
<td>23 m/s (52 mph)</td>
</tr>
<tr>
<td>Recorded peak speed (hourly mean)</td>
<td>14 m/s (31 mph)</td>
</tr>
<tr>
<td>Design wind suction pressure in damage zone</td>
<td>-2.0 kN/m² ↑ (42 psf)</td>
</tr>
<tr>
<td>Extent of detachment</td>
<td>300 m² (3,200 sf) of standing seam</td>
</tr>
<tr>
<td>60 m (200 ft.) of parapet capping</td>
<td></td>
</tr>
<tr>
<td>Estimated financial loss</td>
<td>£10 million</td>
</tr>
</tbody>
</table>

**Figure 3 – Detachment of aluminum standing-seam roofing from windward verge.**
that on arrival on site, much of the original roof construction and original damage had been disturbed. Consequently, the color photographs taken immediately after the storm became a vital record. The site inspection confirmed the as-built arrangement of the roof assembly and the details of the fasteners used.

The wind damage photographs showed that there had been a detachment between the steel top hat rail and the aluminum saddle at 900 mm (3 ft.) centers. In addition, there was upward distortion in the wide top plate of the saddle. Calculations were prepared to check the strength at each of the connections, and the conclusions are summarized in Table 3.

The calculations found that the local bending stress in the crown of the aluminum saddle was excessive and that the factor of safety against the top hat rail to saddle fixing pulling out was 1.1, significantly less than the recommended minimum of 2.0. This is the same weakest link as observed in the photos of wind damage.

The adjacent verge cappings also became detached in the storm, and their means of attachment was closely examined. The aluminum capping had been held in place with rivets that had pulled through. The spacing of the rivet holes through the supporting cladding rail was measured, and the distances were found to be greater than the recommended 450 mm (18 in.). This was a further weakness in the roof assembly.

The original roofing contractor undertook to replace the area of detached roofing, to make good the downwind isolated impact damage, and to strengthen the top hat rail to saddle and purlin connection by installing additional long screw fixings through the top hat rail directly into the steel purlin below. This repair scheme had a number of disadvantages, including puncturing the vapor control layer. Those advising the building owners considered the future condensation risks to be acceptable.

### Case Study B: Single-Ply Membrane

On September 28, 2013, St. Jude’s Day, a fast-moving, vigorous Atlantic depression brought very strong winds and heavy rain to southeast England, with winds gusting up to 36 m/s (80 mph). One modern building that suffered wind damage was a hotel in Chelmsford, to the northeast of London. Lengths of roof edging and single-ply membrane roofing became detached from the western side of the second floor roof and

<table>
<thead>
<tr>
<th>Element</th>
<th>Material</th>
<th>Design wind pressure kN/m² (psf)</th>
<th>Area loaded m²</th>
<th>Number fastener no.</th>
<th>Load/fastener kN (lbf)</th>
<th>Fastener strength kN (lbf)</th>
<th>Factor of safety</th>
<th>Satisfactory?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing seam</td>
<td>0.9-mm Aluminum</td>
<td>-2.0 ↑ (42)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-5.0 kN/m² (105 psf)</td>
<td>2.5</td>
<td>✓</td>
</tr>
<tr>
<td>Halter</td>
<td>Aluminum</td>
<td>-2.0 ↑ (42)</td>
<td>0.64</td>
<td>2</td>
<td>0.64 (144)</td>
<td>3.35 (753)</td>
<td>5.2</td>
<td>✓</td>
</tr>
<tr>
<td>Top hat rail</td>
<td>1.25-mm Galvanized Steel</td>
<td>-2.0 ↑ (42)</td>
<td>1.89</td>
<td>2</td>
<td>1.89 (424)</td>
<td>2.1 (472)</td>
<td>1.1</td>
<td>X</td>
</tr>
<tr>
<td>Saddle</td>
<td>2.0-mm Aluminum</td>
<td>-2.0 ↑ (42)</td>
<td>1.89</td>
<td>4</td>
<td>0.95 (213)</td>
<td>18 (4047)</td>
<td>19</td>
<td>✓</td>
</tr>
<tr>
<td>Purlin</td>
<td>10-mm Steel Flange</td>
<td>-2.0 ↑ (42)</td>
<td>1.89</td>
<td>4</td>
<td>0.95 (213)</td>
<td>18 (4047)</td>
<td>19</td>
<td>✓</td>
</tr>
</tbody>
</table>

**Table 3 – Summary of factors of safety for the Competition Pool roof assembly.**
peeled back, resulting in debris falling to ground level (Figure 5). This led to the closure of the public highway immediately to the east of the building for a period of several days.

An independent inspection of the roof was commissioned two months after the storm to investigate the evidence of damage, to identify causation, and to advise on remedial work to remaining roofs. The roof system comprised a TPO single-ply membrane that was adhered to a tissue-faced mineral fiber insulation board, which in turn was screw-fixed through the vapor control layer into a galvanized steel deck (Table 4).

At the time of the inspection, temporary remedial work had been completed to enable the hotel to reopen. Much of the debris had been removed by the repair contractor and, fortunately, had been kept for examination in his local yard. The samples were closely examined to reveal an inadequate thickness and spacing of the adhesive bonding. Samples of the mineral wool insulation showed that the top tissue facing readily detached from the fibrous core and was not the specified insulation board with a “single-ply adhered facing.” The wrong product had been supplied, which had not been identified by the roofing contractor, the supplier, or the other surveyors initially inspecting the wind damage.

The wind damage photos also showed that the roof edge became detached. There were no record drawings of the initial construction, and so the as-built assembly was drawn up based on site measurements, the opening up examination, and inspection of the debris in the contractor’s yard. A short parapet had been constructed using two channel sections with an internal stud and no fixings joining the channels together. Under wind uplift pressure, the capping and support could lift upwards. From this, it was possible to determine the probable sequence of detachment along the western edge of the central roof in which a Z-section flashing rotated upwards, increasing the wind uplift pressure acting on the underside of the flashing and entering the upstand detail. This, in turn, caused the perimeter channel and studs to lift upwards, allowing the single-ply membrane to peel back readily with the lack of adhesive restraint (Figure 6).

Within a month of the initial inspection, the second-floor roof was fully replaced with a new mechanically attached PVC single-ply membrane system. The third- and fourth-floor roofs were investigated and found to be of a similar construction, with areas of debonded single-ply membrane adjacent to the western edge. It was recommended that a new mechanically fixed PVC single-ply membrane should be applied over the existing membrane, with a new secure perimeter detail developed.

There were delays in carrying out this work, during which the extent of the delaminated zone increased over a six-month period, ultimately resulting in extensive rucking or wrinkling. This evidence of further progressive damage persuaded the parties to mechanically fasten and overlay the third- and fourth-floor roofs, with work satisfactorily completed in the summer of 2014.

![Figure 5 – Second-floor roof membrane rolled back from western edge.](image)

<table>
<thead>
<tr>
<th>Location</th>
<th>Chelmsford, England</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building use</td>
<td>Hotel</td>
</tr>
<tr>
<td>Altitude, site exposure, topography</td>
<td>+25 m (82 ft.), sheltered, urban</td>
</tr>
<tr>
<td>Roof area</td>
<td>2,000 m² (21,500 sf)</td>
</tr>
<tr>
<td>Roof slope</td>
<td>Flat</td>
</tr>
<tr>
<td>Roof type</td>
<td>Single-ply membrane, adhered</td>
</tr>
<tr>
<td>Roof sub structure</td>
<td>Mineral wool thermal insulation, screw fixed through vapor control layer into steel deck</td>
</tr>
<tr>
<td>Basic wind speed (hourly mean)</td>
<td>22 m/s (49 mph)</td>
</tr>
<tr>
<td>Recorded peak speed (hourly mean)</td>
<td>18 m/s (42 mph)</td>
</tr>
<tr>
<td>Design wind suction pressure in damage zone</td>
<td>-1.8 kN/m² ↑ (38 psf)</td>
</tr>
<tr>
<td>Extent of detachment</td>
<td>200 m² (2,150 sf) of single-ply membrane roofing and roof edges</td>
</tr>
<tr>
<td>Estimated financial loss</td>
<td>£1 million</td>
</tr>
</tbody>
</table>

*Table 4 – Basic data for Case Study B.*
Case Study C: Roof Edge Overhang

Getting to a site as soon as practical after wind damage is first reported can be beneficial in gathering the essential evidence and identifying causation. This was the case for a large school building in Newcastle upon Tyne, in northeast England. On Tuesday, January 3, 2012, a length of roof overhang became detached from the southwest corner of the Sports hall and fell to the ground. The school was subsequently closed and the 1,800 students sent home without any reported injuries. Two days after the report, I was able to inspect the wind damage and to observe further elements becoming detached during the prolonged stormy period (See Table 5.)

The site is on the top of a hill overlooking the Tyne valley and severely exposed to the prevailing winds blowing from the southwest. The single-ply membrane roof deck extends out 1,200 mm (4 ft.) around the perimeters of the buildings (Figure 7) and was supported by galvanized steel cantilever brackets that were fastened back to hot-rolled steel eaves beams (Figure 8).

Wearing a full-body harness connected to the fall restraint system, the author could see from above that the fasteners retaining the cantilever bracket did not have washers and passed through slotted holes in a thin plate, which had distorted and split. In the external corners, there were no additional diagonal support brackets. The plywood deck had an inadequate number of screw fixings into the bracket top flanges.

In addition, there were other defects with the roof, including inadequate fixings to the external sigma-shaped fascias, with no provision for thermal movement and no crossfall on the overhangs, including long-term ponding and water overtopping the roof edges.

One of the challenges for putting right the inadequate roof edge construction was that extensive roofs built at different levels on the hillside had a total length of almost 2,000 m (6,500 ft.) with more than 3,000 cantilever brackets, all of which had been constructed to the same inadequate details. As part of a value-engineering exercise, the roofing contractor had changed the supplier of the steel brackets to save costs, from a recognized roof edge system manufacturer to a local sheet-metal fabricator.

The second challenge was to reach agreement on who should pay for the necessary remedial works. The roofing contractor had gone out of business, and responsibility passed to the project architect, the structural engineer, and the general contractor. Following two years of protracted arguments, agreement was reached for costs to be shared between the parties.

The school issued a commission to prepare the detail specification and drawings for the replacement of all of the roof overhangs. The new brackets were designed, tested, manufactured, and installed, with satisfactory completion reached in September 2014.

LESSONS LEARNED FROM WIND DAMAGE INVESTIGATIONS

Safety Comes First

Our first responsibility is to the safety of ourselves and of those around us, including members of the public. Roof consultants inspecting wind-damaged roofs should be experienced at working at heights and in wearing appropriate personal protective equipment. Particular care is required when working close to unprotected roof edges, often requiring the provision of a mobile platform or fixed scaffolding.

Immediately after a storm in which elements of a roof have come loose, a cordon would usually be set up at ground level to keep people away from high-risk areas where further pieces could fall and cause

<table>
<thead>
<tr>
<th>Location</th>
<th>Newcastle upon Tyne, England</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building use</td>
<td>School</td>
</tr>
<tr>
<td>Altitude, site exposure, topography</td>
<td>+55 m (180 ft.), severe, urban</td>
</tr>
<tr>
<td>Roof area</td>
<td>5,700 m² (61,300 sf)</td>
</tr>
<tr>
<td>Roof slope</td>
<td>Flat roofs</td>
</tr>
<tr>
<td>Roof type</td>
<td>Single-ply membrane roof overhang</td>
</tr>
<tr>
<td>Roof substructure</td>
<td>Plywood deck fixed to steel cantilever brackets</td>
</tr>
<tr>
<td>Basic wind speed (hourly mean)</td>
<td>25 m/s (56 mph)</td>
</tr>
<tr>
<td>Recorded peak speed (hourly mean)</td>
<td>14.9 m/s (34 mph)</td>
</tr>
<tr>
<td>Design wind suction pressure in damage zone</td>
<td>-3.6 kN/m² ↑ (75 psf)</td>
</tr>
<tr>
<td>Extent of detachment</td>
<td>10 m (33 ft.) of roof edge overhang</td>
</tr>
<tr>
<td>Estimated financial loss</td>
<td>£2 million</td>
</tr>
</tbody>
</table>

Table 5 – Basic data for Case Study C.
injury. This is particularly important in urban areas and around assembly buildings where people gather, such as schools and hospitals. Usually these precautionary measures have been undertaken in advance of the arrival of the roof consultant.

**Adopt a Scientific Approach**

It is important to inspect the wind damage as soon after the incident as possible, before the areas are modified, such as by the removal of loose elements or local emergency repairs. This often requires travel at short notice, and the consultant should be prepared.

The pattern of damage on first sight is usually confusing, with multiple failures and impact damage caused by flying debris. The challenge is to identify the first link in the roof assembly that failed. A methodical approach should be adopted following the good practice set out in the “Guide to Surveys and Inspections of Buildings” published in the UK by the Institution of Structural Engineers. Practical difficulties on site often mean that it is not always possible to gain access to all roof areas on the same day, and an adaptable approach is required to gather as much information in what is often only a short period of time at roof level.

Careful records of observations and sketches with site measurements are important, examining both the zone of detachment and any loose debris. Color photographs that are dated should include general views of the wind-damaged building, the surrounding topography as seen from roof level, and close-ups of the roof assembly—both damaged and undamaged. Where there is some movement in the roof, video recording can be of assistance. Collected samples of damaged elements and fasteners that can be removed should be properly labeled. They can be of great assistance for close examination and reference at the time of report writing, and later for presenting in meetings to assist in explaining likely modes of failure.

**Eyewitness Information is Useful**

Reliable eyewitness evidence can be invaluable in determining the probable sequence of events. This should include informal discussions with security staff, maintenance workers, neighbors, and roof repair contractors, keeping a note of the names of the eyewitnesses. Closed-circuit security video records may also be of assistance.

**Examine Weather Data**

The meteorological data from the nearest recording station should include the hourly wind speeds and directions for the period leading up to and including the time of the reported damage. The wind speeds should include the hourly mean, as well as the maximum ten-minute and three-second gust wind speeds. Occasionally, the air tem-
perature and rainfall data are also of assistance in assessing the strength of the components; for example, some artificial slates absorb water and lose flexural strength.

**Commission Testing**

Basic static screw and nail pullout strengths can be determined using screw jack equipment, either on-site or on a lab bench. A first estimate of the degree of movement can be measured by pulling a flexible sheet by hand and measuring the applied load with a spring balance. Other test methods include the Factory Mutual wind uplift field test and laboratory tests of full-scale roof assemblies using compressed air bags to apply an upward loading that allows for changes in the shape of the roof cladding.

**Prepare Calculations**

To check the structural adequacy of the original design, calculations should be prepared to estimate the applied wind loads on the different “links in the chain,” transferring the upward wind loads down into the supporting structure and assessing their factors of safety.

Within a multilayer roof system, the wind pressure acting on each layer is not the same. The layer with the greatest upward pressure (or the critical layer) is the first air-impermeable barrier from the underside of the roof. The critical layer could be a concrete roof deck, a vapor-control layer laid over perforated metal decking, or a waterproofing layer above an unsealed metal deck and fibrous insulation. This should be considered by the roof consultant in assessing the applied wind loading on the roof system.

**Undertake Desk Study**

Any project drawings or specifications should be examined, together with copies of original manufacturers’ literature relating to the claimed performance of the roofing system. This, in turn, requires access to a reference library with historical product literature. Ordnance survey maps are particularly useful in the UK for identifying the topography and exposure of the land around the site, which may give rise to unusual wind features. Enquiries into similar damage reports elsewhere both nationally and internationally may provide useful background information.

**Prepare Report**

The report should bring together the information collected and present the facts and discussion in a logical order with concise conclusions and clear recommendations. The use of photographs and line drawings is particularly helpful to the lay reader in illustrating where the failures probably occurred. Recognizing the commercially sensitive nature of some wind damage investigations, there is a need for matters to be dealt with strictly on a confidential basis.

When instructed, the options for repairing or replacing the wind-damaged roofs should be identified, with the advantages and disadvantages of each summarized. From experience, there are occasions when the roof consultant cannot be certain of the precise reasons why the roof failed. On such occasions, there is a need for further examination, testing, and analysis to improve the understanding of the performance of the roof when subjected to strong winds.

**CONCLUSIONS**

A methodical approach should be adopted in gathering and recording the evidence of wind damage, in undertaking the desk study, and then in producing the factual report. It is recognized that these time-consuming tasks often need to be completed promptly to enable repairs to be started and the building brought back into use.

There is a need to learn from experience and to avoid repeating mistakes. This recurred in Ireland in February 2014, when the roof of another aquatic center in County Wexford blew off, suffering the same mode of failure as the aquatic center in Dublin a decade earlier. The lessons from previous investigations weren’t shared within the roofing community.

It is hoped that by sharing feedback from wind damage reports in an independent and constructive way, we can improve our common understanding of failure mechanisms, enabling us to design and build more reliable building envelopes that are better able to withstand the extremes of changing weather patterns in whatever country in which we practice.

**REFERENCES**


