SPRA
Single Ply Roofing Association

TECHNICAL GUIDANCE

WIND LOADING
PROTOCOL FOR CALCULATIONS

ENSURING THAT CLIENTS OBTAIN HIGH QUALITY POLYMER-BASED SINGLE PLY ROOFING, THROUGH A PARTNERSHIP OF QUALITY ASSURED MANUFACTURERS AND CONTRACTORS

S11b/19

SPRA would like to thank and acknowledge the work of many industry professionals in developing this new SPRA wind load calculation protocol, including:

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Further information may be obtained on the SPRA website www.spra.co.uk and from the current version of the SPRA Design Guide together with the suite of associated guidance documents on all aspects of single ply roofing.

SPRA TECHNICAL GUIDE S11B/19
WIND LOADING FOR SINGLE PLY ROOFING - PROTOCOL FOR CALCULATIONS

1.0 INTRODUCTION

The person undertaking the wind load calculation for a specific project should follow this calculation protocol in order to obtain correct and consistent results. By doing so they will ensure that the same result is achieved as others undertaking the same calculation, thereby ensuring that competing design solutions offer equivalent performance and margins of safety.

This document gives guidance to the person undertaking the calculation and assists the process of interpretation of results. It should be used in conjunction with the SPRA guide S11a/16 *'Wind loading - a checklist of the parameters required for calculation; a guide to reduced risk'* which contains a checklist and guidance notes to the person supplying the parameters required for calculation. This will ensure that all required parameters are given and that they are expressed in the correct units.

The correct calculation methodology for UK Building Regulations compliance is defined by the relevant standard *BS EN 1991-1-4:2005+A1:2010 when supplemented with the UK National Annex (NA) incorporating National Amendment A1 of January 2011*. This document does not reproduce the requirements of the Eurocode and the UK National Annex but provides supplementary guidance for the specific application of these standards for calculation of wind load acting on flat and pitched roofs. For property protection reasons, certain insurance companies covering e.g. industrial and commercial property, such as Factory Mutual, may require enhanced wind uplift performance of roofs to that indicated by EN 1991-1-4 alone. It is therefore important that, at an early stage, the roof designer attempts to identify who the insurer of the finished building will be and thereby determine their specific requirements.

2.0 CALCULATION SOFTWARE AND COMPETENCY

The software used to undertake a wind load calculation must be suitable for use in flat and pitched roof applications. It must comply with the requirements of *BS EN 1991-1-4:2005+A1:2010 and supplemented with the UK National Annex (NA) incorporating National Amendment A1 dated January 2011*. The person undertaking the calculation should have a thorough knowledge of the calculation procedure, be trained in the use of the appropriate software and be suitably indemnified against error.

3.0 ESSENTIAL INPUT DATA

3.1 LOCATION

Always ensure that the location of the building is recorded correctly. Should the software use an appropriate database, the correct grid reference or site location must be used as this will automatically select the terrain category. For users without appropriate software, take time to check that the terrain category selected is correct and applicable to one of the 3 types available. For example, if the building is located in a seaside town, only select *'Sea or coastal area exposed to the open sea'* if the building is located on the seafront. If the building is within the town boundary then *'Country'* terrain or *'Town'* terrain may be appropriate. In all cases ensure that the correct distance to the sea is input as part of the location to reflect this position. Note that the UK National Annex refers to 3 terrain categories in contrast to the 5 categories in Eurocode1. If the terrain type is not given assume *'Country'* terrain. BRE Digest 436 part 1 gives guidance on determining terrain categories.

Site altitude and the topographic relief of elevated terrain (orography) are also important for the accuracy of the calculation and will significantly affect the resulting wind load. Ensure the correct altitude is used.

Should a postcode be provided for the location, ensure that the position of the building requiring the calculation is accurately determined. Rural postcodes in particular can cover a significant area and therefore every effort should be made to ensure that the site altitude, distance to sea, distance to town and exposure factor are correctly defined.

The orography factor in software will usually default to 1.0. If the orography factor is provided by the Structural Engineer, this value should be used. Examples of locations where the orography factor will influence the wind load include where the project is located upwind or downwind of the slope of hills, ridges, cliffs or escarpments.

3.2 CALCULATION OF ROOF PERIMETER ZONES

Should the roof being assessed be joined to other roof areas, the complete building footprint should be considered for the calculation of the perimeter and corner zones and not just the roof being considered in isolation. If roofs are treated in isolation of the whole building this would generally produce a conservative (potentially overdesigned) result. See Appendix A for further guidance.

Adjacent structures

Separate roofs built off or adjacent to the roof being assessed should be considered as part of the calculation process. Shadow zones of adjacent higher buildings should be taken into consideration when determining the appropriate roof zones. For guidance with respect to connecting roofs and shadow zones see Appendix A.

The effect of separate adjacent buildings on perimeter zones and wind loads should be taken into consideration in accordance with the guidance provided by *PD 6688-1-4:2015, Published Document: 'Background information to the National Annex to BS EN 1991-1-4 2005+A1:2010 and additional guidance'*. Guidance is additionally provided within *BRE document Digest 436 (parts 1, 2 & 3) Revised 2015*.

3.3 ROOF TYPE

It is important to input the correct roof type e.g. flat (<5°), mono pitched (>5°), duo pitched (>5°), barrel vaulted etc. because this will affect the locations and magnitude of the appropriate roof zones. (Note that whilst *BS 6229 'Flat roofs with continuously supported coverings. Code of practice'* defines a flat roof as having a fall of less than 10 degrees, for the purpose of the *BS EN 1991-1-4:2005+A1:2010* calculations, the definition is taken as 5 degrees).

3.4 BUILDING HEIGHT & PARAPET WALLS

The calculated wind load on roofs increases with building height. The reference height should be taken as the highest roof point above ground level, and this dimension should include the parapet wall height should this be higher than the ridge at any point of the roof being evaluated. The effect of parapet walls on the external pressure coefficients for flat roofs (Cpe) should also be considered and in this respect, Table NA5 of *BS NA EN 1991-1-4 (2010): UK National Annex to Eurocode 1*. Actions on structures. *'General actions'* will provide further guidance.

Where the membrane is required to be secured to a parapet wall and the parapet wall height is up to 1100mm the calculated wind load of the adjacent roof corner zone may be assumed for this detail. For parapet walls higher than 1100mm consult the SPRA membrane manufacturer for guidance. When dealing with the boundary of an inset storey, this should be treated as a wall and not a parapet. The external pressure coefficients (C_{pe}) acting on the walls of inset storeys are detailed in *PD 6688 section 3.3.2*.

3.5 DECK TYPE

Identify if the roof deck is steel, concrete or timber panel (plywood, oriented strand board), ensure that the correct Cpi value is used for each deck type. See Appendix B.

4.0 SAFETY FACTORS

4.1 WIND LOAD CALCULATION SAFETY FACTOR Y_q

Partial safety factors must be applied to the wind suction loads, thereby increasing them in accordance with Tables *A1.1* and *A1.2 of EN 1990:2002*. For the wind suction load the partial safety factor is nominally 1.5. However, in normal use, the attachment of non-structural insulation and membrane may be designed for a lower consequence of failure than for the supporting building structure, in accordance with Table B1 of *EN 1990:2002+A1:2005 incorporating corrigenda December 2008 and April 2010 Consequence Class CC1*. As a result, the partial safety factor for design wind loads may be multiplied by 0.9 (Factor K_{FI} for Reliability Class RC1 from Table B3 of *BS EN 1990:2002+A1:2005*) giving a net increase of 1.35 applied to the design wind suction loads.

The wind load calculation safety factor Y_q value of 1.35 will be used for mainland United Kingdom for roof projects in accordance with the above EN 1990:2002 standard approach.

For high risk applications a higher consequence factor of 1 should be used which will reinstate the 1.5 Y_q partial safety factor. This will also apply where estimated values of locational or dimensional data are used. For locations including the UK offshore islands, Channel Islands, Isle of Man, Isle of Wight, Scilly Isles, Northern Ireland and the Republic of Ireland the 1.5 Y_q partial safety factor should apply.

4.2 MATERIAL SAFETY FACTOR Y_m

The partial safety factor Y_m is defined for specific tested products. See Section 5.0 Mechanically fastened applications and Section 6.0 Adhesive fastened applications.

4.3 TOTAL SAFETY FACTOR Y_{tot}

The overall system safety factor $Y_{tot} = Y_q \times Y_m$. So, for example where a steel profiled deck system is subjected to full scale dynamic testing to *BS EN 16002*, $Y_{tot} = 1.35 \times 1.5 = 2.03$ (203%). For design purposes this is rounded down to 2.0.

5.0 MECHANICALLY FASTENED APPLICATIONS

5.1 MEMBRANE FIXINGS

5.1.1 MATERIAL SAFETY FACTOR Y_m

The partial safety factor Y_m for the product is defined as 1.5 in *Annex 1 of EAD-030351-00-0402-209* for dynamic full-scale testing to *BS EN 16002*. Where a proposed construction has not been tested using a dynamic test, or for refurbishment applications, see Appendix C of this document for guidance on Y_m values.

5.2 FASTENER DESIGN VALUE

5.2.1 MEMBRANE FASTENERS

The admissible design value for the membrane fasteners should be provided by the membrane or fastener supplier respectively. This takes into consideration the following design value criterion:

1. The pull-out value of the fastener from the substrate.
2. The pull-over value of the fastener / plate sleeve.
3. The pull-through value of the plate / sleeve through the membrane.

For each of criterion 1 to 3, the admissible design value (W_{adm}) = Characteristic Value (W_{char}) / Partial safety factor (Y_m).

The minimum admissible design value (W_{adm}) for all pull-out, pull-over and pull-through values is the authoritative design value for the system. The partial safety factor Y_m varies for different tests and substrates. See Appendix C.

5.2.2 INSULATION FASTENERS

The admissible design value for the insulation fasteners should be provided by the membrane or fastener supplier respectively. This takes into consideration the following design value criterion:

1. The pull-out value of the fastener from the substrate.
2. The pull-over value of the fastener / plate sleeve.
3. The pull-through value of the plate / sleeve through the insulation layer.

For each of criterion 1 to 3, the admissible design value (W_{adm}) = Characteristic Value (W_{char}) / Partial safety factor (Y_m)

The minimum admissible design value (W_{adm}) for all the pull-out, pull-over and pull-through values is the authoritative design value for the system. The partial safety factor Y_m varies for different tests and substrates. See Appendix C.

To calculate the minimum number of insulation fasteners required per insulation board divide the wind load value of each roof zone by the appropriate design value (W_{adm}) and multiply this figure by the area of each insulation board in metres. Round up the resulting number of fasteners to the nearest whole number.

For applications where the membrane and insulation are both mechanically fastened, guidance on the minimum (and maximum) fastener requirement for PIR insulation per board size and per square metre of roof area is provided by the Insulation Manufacturers Association (IMA) document ID/1/2016. For all other insulation types see the current SPRA Design Guide, Thermal insulation.

5.2.3 CALCULATION OF THE INSULATION FASTENER PATTERN FOR HYBRID SYSTEMS

Hybrid systems are defined as installations where the insulation layer is mechanically fastened to the roof deck and the waterproofing layer is adhered to the insulation surface. The calculated wind load W_{tot} for each roof zone divided by the insulation fastener admissible design value (W_{adm}) will determine the minimum number of insulation fasteners per m^2. Multiplying this figure by the area of each insulation board will confirm the minimum number of fasteners required per board. The insulation fastener admissible design value (W_{adm}) should be determined by testing undertaken by the system supplier(s).

Where the insulation is PIR, guidance on the minimum fastener requirement per board size and per square metre of roof area is provided by the Insulation Manufacturers Association (IMA) document ID/1/2016. For all other insulation types, see the current SPRA Design Guide, Thermal insulation.

5.3 FIELD PULL-OUT TESTING

This should be carried out for all refurbishment projects and new build concrete deck applications. The protocol for testing and calculation of the resulting fastener design value is detailed by the SPRA document *Site pull-out protocol for flat roofs (S15-19)*. See also Appendix C of this document.

5.4 STEEL DECK

The deck profile and gauge should be known. For in-seam (lap) or bar fastening systems, fasten in a straight line at regular intervals at right angles to the direction of the deck crowns. For in-seam fastening, no more than one fastener is permitted per deck crown. Should additional fasteners be required then mid seam fastening rows should be added. For field fastening systems, fasteners should be installed in a uniformly distributed grid pattern for each roof zone to ensure that the wind load is spread uniformly over the membrane surface. For all systems, the maximum fastener centres will be defined by the SPRA membrane manufacturer.

5.5 CONCRETE DECK

For in-seam (lap) fastening or bar fixing systems, concrete fastener centres should be greater than 100mm. For field fastening systems, fasteners should be installed in a uniformly distributed grid pattern for each roof zone to ensure that the wind load is spread uniformly over the membrane surface. For all systems, the maximum fastener centres will be defined by the SPRA membrane manufacturer.

6.0 ADHERED APPLICATIONS

6.1 ADHERED SYSTEM REQUIREMENTS

It must be demonstrated that the calculated wind uplift loads on the system are less than the maximum design resistance of the system proposed, including the provision of a suitable factor of safety. In order to ensure compliance with the design requirements for wind uplift, appropriate test evidence should be available from the system provider in conjunction with the appropriate adhesive manufacturer. This should be based upon the test method as derived from *BS EN 16002* in conjunction with the load steps detailed by *EOTA TR 005*. At the time of this publication, *CEN TC254* is currently drafting a test standard applicable for adhered single ply membranes which is expected to be released mid 2021.

Any proposals for an adhered roof construction must be made in accordance with the technical requirements and appropriate design values of the manufacturers of the membrane, insulation, air & vapour control layer and adhesives. The design value of an adhered roof construction will be determined by the least bond strength between components in the construction. Consequently, the individual bond strengths between all components should be established. However, for a complete roofing system where the overall performance has been established by testing, it may not be necessary to consider the individual adhesive bond strengths between layers.

A partial material safety factor Y_m of 1.5 (50%) should be applied to the characteristic value derived from the dynamic wind testing of adhered systems. Therefore, as an example based on a typical characteristic value of 4.8kN/m^2 being achieved, the resulting admissible design value (W_{adm}) for the system is calculated at 3.2kN/m^2 (the admissible design value (W_{adm}) for the system = Characteristic Value (W_{char}) / Partial safety factor (Y_m)). This applies only where an appropriate partial safety factor Y_q has been used in the wind load calculation (a higher safety factor Yq of 1.5 may be required). Should the partial safety factor Y_q of 1.35 (35%) have been used in the wind load calculation the overall system safety factor (Y_{tot}) is therefore 1.35 x 1.5 = 2.03 or 2.0 (rounded down). See Section 4.0 for further detail on calculation of the overall system safety factor (Y_{tot}). Where the wind load exceeds the admissible design value (W_{adm}) for the system, additional measures will be required which could include the use of mechanical fasteners or ballast where appropriate.

6.2 METAL DECKS

Where the substrate consists of a profiled metal deck, the system bond area cannot be assumed to be 100%. The bond area in this instance is dependent on the steel profile deck type but would usually be of the order of 45% (excluding deck profile stiffeners). If the bond area is less than 45% additional design measures will be required depending on the calculated wind loads and the system manufacturer should be consulted.

6.3 REFURBISHMENT AND BONDED OVERLAYS

For bonded overlay applications to existing reinforced bitumen membrane or asphalt roofs the designer or specifier should ensure that the wind load calculated with an appropriate partial safety factor Y_q does not exceed 3.2N/m^2 and also confirm that the existing roof build-up is dry and sound. Alternatively, or for higher wind loads the new insulation or existing bonded layers should be mechanically fastened.

7.0 BALLASTED APPLICATIONS

7.1 WIND SPEED RESTRICTIONS

Maximum system wind speed should be confirmed in order to reduce the risk of green roof growth media and/or roof gravel becoming disturbed. *BS EN 1991-1-4* calculates peak velocity pressure and not wind speed. However, the gust wind speed can be determined from equation *4.10 of BS EN 1991-1-4* by using peak velocity pressure q_p rather than the basic velocity pressure q_b. Ensure that a partial safety factor of 1.5 is applied to the qp value before the gust wind speed is calculated.

7.2 STONE AND GRAVEL WARM BALLASTED AND INVERTED ROOFS

The minimum ballast weight requirement is project (and roof) specific and should be sought from the appropriate SPRA membrane manufacturer, particularly with respect to maximum threshold wind speeds as indicated in 7.1. Should calculation indicate gravel scour, the size of the stone ballast could be increased or it should be replaced by paving stones.

Note that if the stone ballast is larger than 32mm diameter it ceases to be 'deemed-to-satisfy' as regards compliance with external fire performance requirement given in the *European Commission Directive 2000/553/EC*.

7.3 BALLASTED ROOF INSTALLATION

Extensive green roof systems may have a dry weight of less than 80kg/m^2 and therefore may require supplementary mechanical or adhesive attachment for insulation and membrane layers subject to wind uplift requirements.

Should the ballast layer not be installed during the same working day as the insulation, the insulation and membrane layers must be independently secured by temporary ballast, mechanical fixings or by the application of adhesive.

Further guidance with respect to the minimum ballast requirement can also be obtained from FM Global Loss Prevention *Data Sheet 1-29 'Roof Deck Securement and Above Deck Components'* pages 21-22. *BRE Digest 311, 'Wind scour of gravel ballast on roofs'* also provides further guidance where calculations indicate potential for gravel scour.

It is worth noting that to comply with the external fire performance requirement given in the *European Commission Directive 2000/553/EC* the minimum thickness of concrete ballast (aggregate size 4mm - 32mm) required is 50mm and concrete paving slabs is 40mm.

APPENDIX A

CONNECTING ROOFS INCLUDING FLAT ROOFS WITH INSET STOREYS

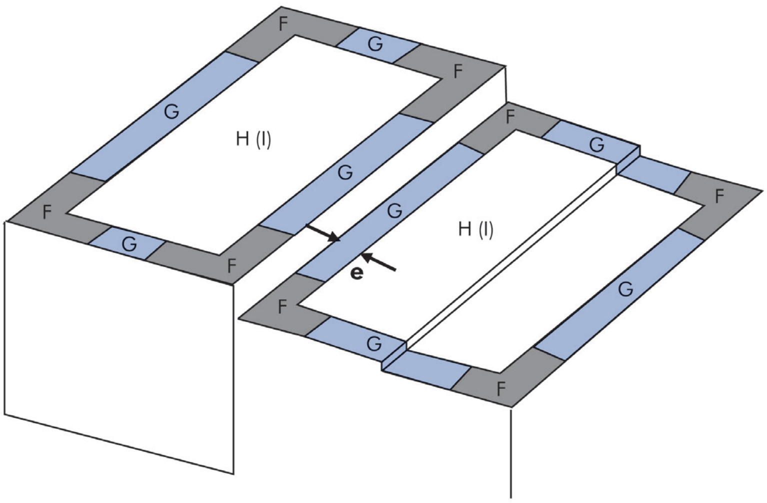
This appendix provides guidance with respect to dealing with differences in roof levels and with higher adjacent structures. Note that the extent of the zone areas shall be defined by the wind load calculation.

Zone areas are defined as follows:

F	Corner zone
G	Perimeter zone
H	Field zone
I	Inner field zone

A.1 LEVEL DIFFERENCES BETWEEN ADJACENT ROOF AREAS

This appendix provides guidance with respect to dealing with differences in roof levels and with higher adjacent structures.

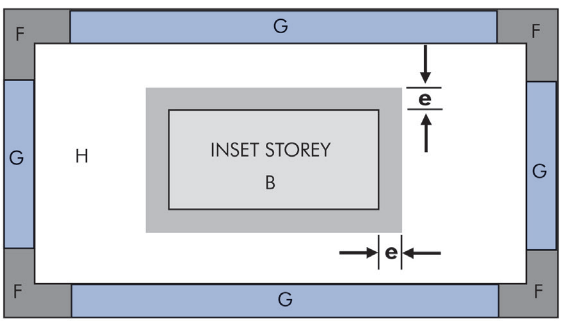


- Where the difference in roof height is ≤1m there is no adjacent perimeter area
- Where the difference in roof height is >1m there is an adjacent perimeter area on both roofs. In this instance follow the guidance in A.2 below

NOTE: Dimension '**e**' represents the width of the shadow zone due to the influence of the higher adjacent roof area. Follow the guidance in A.2 below.

A.2 FLAT ROOFS WITH INSET STOREYS

Inset storeys including plant room located on the roof area requiring calculation.



A further zone (shadow zone) around the base of the inset storey should be included. This shadow zone should extend by a distance of '**e**' from the base of the inset storey. The dimension '**e**' also represents the scaling length of the inset storey.

A conservative (potentially over designed) estimate of dimension '**e**' can be derived by calculating the smaller of **B** or 2 x **H** where b is the length of the inset storey and **H** is the height of the inset storey. Assume that the wind load acting on the shadow zone is equivalent to that on the lower roof perimeter zone G, except where it is located within the corner zone F of the lower roof.

For a more accurate determination of dimension '**e**' and for further details see *PD 6688-1-4:2015 Background information to the National Annex to BS EN 1991-1-4 and additional guidance, section 3.4 and Figure 6.*

APPENDIX B

INTERNAL PRESSURE COEFFICIENT CPI VALUES

DESCRIPTION	Cpi VALUE
Airtight roof deck	Cpi = 0
Air open roof deck, building with normal openings	Cpi = 0.2
Air open roof deck, building with dominant openings	Cpi = 0.72
Air open roof deck, building with one or two faces fully open	See below

DEFINITIONS

AIRTIGHT ROOF DECK CONSTRUCTION

Buildings with an airtight roof deck.
Example: Poured concrete or roof deck with fully bonded bituminous air and vapour control layer with perimeters sealed.

AIR OPEN ROOF DECK, BUILDING WITH NORMAL OPENINGS

Building envelope with normal doors and windows.
Example: Typical industrial building with steel deck.

NOTE: If the roof deck or air and vapour control layer is airtight then the Cpi can be taken as 0. If in any doubt however, assume a Cpi value of 0.2.

DOMINANT OPENINGS

Building envelope with dominant openings.
Example: Building with permanently open loading bays.

NOTE: If the roof deck or air and vapour control layer is airtight then the Cpi can be taken as 0. If in any doubt however, assume a Cpi value of 0.72.

BUILDINGS WITH ONE OR TWO FACES

Fully open buildings.
Example: Canopies or large overhangs.
Refer to information contained within BS EN 1991-1-4, table 7.6

NOTE: If the roof deck or air and vapour control layer is airtight then it does not matter whether the building has an exposed soffit because this will not affect the membrane wind loads.

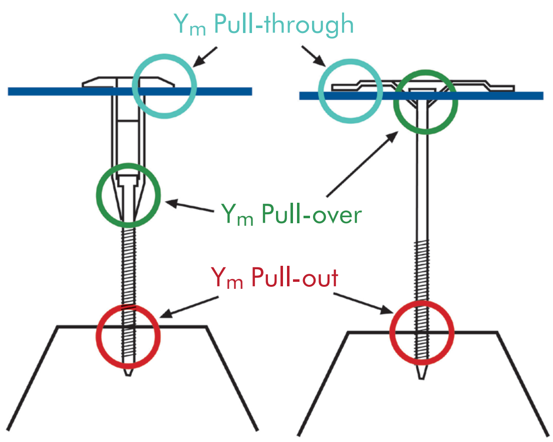
APPENDIX C

Material safety factor (Y_m) values for design criterion and calculation of admissible (design) load per fastener from site pull-out test data.

C.1. MATERIAL SAFETY FACTOR (Y_m) VALUES FOR DESIGN

Pull-out

Substrate	Y_m Static test EAD-03051-00-042 (see note)	Y_m Dynamic test EN 16002
Steel deck ≤0.7mm	2.00	1.50
Steel deck > 0.7mm	1.85	1.50
Concrete (see note 4)	3.00	1.50
Aerated concrete	3.50	1.50
Timber (see note 2)	2.00	1.50
Aluminium	2.50	1.50



Pull-through test (EN-16002) **Y_m = 1.5**
Pull-over test (EAD-030361-00-0402) **Y_m = 1.5**

NOTE:

1. The material safety factor (Y_m) values provided above for pull-out, pull-through & pull-over are minimum requirements and are provided for guidance purposes. System providers may increase these values where necessary. See Section 5.0 for further detail.
2. The minimum thickness of OSB3 and plywood required is 18mm. The minimum thickness of timber boarding is 25mm.
3. The authoritative design loads for the membrane and insulation fasteners are project and product specific and should be confirmed by the appropriate membrane manufacturer based upon specific testing undertaken.
4. Mechanical fasteners must not be installed into screed layers, but through to the base concrete deck. Follow the guidance from EAD 330232-00-0601 Mechanical Fasteners For Use in Concrete and BS 8539-2012 Code of practice for the selection and installation of post-installed anchors in concrete and masonry where appropriate.
5. The static test should be undertaken in accordance with EAD-03051-00-0402 Annex C.

C.2. CALCULATION OF ADMISSIBLE (DESIGN) LOAD PER FASTENER FROM SITE PULL-OUT TEST DATA

Extract of information from the SPRA document: Site *pull-out protocol for flat roofs (S15-19).*

X_m = Mean value of all pull-out tests
K = Factor according to BS EN-1990 Table D1. See reproduced table below.
s = Standard deviation
Y_m = Material safety factor. For the appropriate Y_m values see section C.1
X_n = Individual test value
n = Number of samples

NOTE:

6. For calculation of the admissible (design) load derived from site pull-out tests the standard deviation value of the results is required in order to ensure that variation between individual test results is taken into consideration. The methodology given in *BS EN 1990:2002 +A1:2005 incorporating corrigenda Document 2008 and April 2010: - Eurocode - Basis of structural design* should be followed. See below.

Standard deviation s

$$s = \sqrt{\frac{\Sigma (X_n - X_m)^2}{n - 1}}$$

K values

n	5	6	8	10	20
K	2.33	2.18	2.00	1.92	1.76

Where F_{adm} = characteristic admissible (design) load per fastener
$F_{adm} = X_m - K*s / Y_m$

For design purposes and in accordance with the SPRA document Site pull-out protocol for flat roofs, the lowest value of either W_{adm} derived from full scale or small-scale testing or Fadm determined from the site pull-out test as described above should be used. Remember that the minimum admissible design value (W_{adm}) for all pull-out, pull-over and pull-through values is the authoritative design value for the system. See section 5.2 for further guidance.

WORKED EXAMPLE

Assume steel deck, thickness 0.7mm

(T1 = pull-out test 1, T2 = pull-out test 2 etc.)

Test number	T1	T2	T3	T4	T5	T6
Test results (kN/m^2)	1.24	1.22	1.23	1.20	1.25	1.21

n = 6
X_m = 1.23 kN/m2
K = 2.18
Y_m = 2.0
s = 0.02

$F_{adm} = X_m - K*s / Y_m$
F_{adm} = 1.23 - (2.18 * 0.02) / 2.0
F_{adm} = 0.593kN or 593N per fastener.

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