ADVISORY COMMITTEE FOR ROOFWORK

Materials Standard

ACR[M]001:2005
Test For Non-Fragility of Profiled Sheeted Roofing Assemblies
[third edition]

FASET FRA FCMA HSE MCRMA NARM NFRC RIDBA SPRA

PREFACE

The original standard, which this revised standard replaces, arose out of concerns expressed by the HSE and the roofing industry about the lack of guidance on what is a fragile roof assembly. Its basis is a series of tests, carried out by the HSE, which quantified human impact loads on surfaces. The report of these tests has been included in this revision Most roofing Trade Associations sent delegates to the working group, which formalised this standard.

The working group met several times during 2003 and this revision of the original standard document is the result of their deliberations. We still believe that the test specified in this document is a severe one and will provide:

a) The means for verifying claims and decisions about fragility; and
b) Greater assurance of safety in roofwork, by giving designers a means of specifying the correct product;

This document has been revised under my tenure as chairman. The need for revision arose out of the experience of using the document and to clarify some ambiguities. I would like to reiterate the previous chairman's statement that it has been a privilege to chair this working group of able and professional people. In addition, I would wish to commend their honesty. Without exception, their intention was to make working on roofs a safer job, which this standard has achieved already. **P Franklin** [Chairman]

CONSTITUTION OF THE TASK GROUP

The following Associations were represented on the task group – National Association of Rooflight Manufacturers [NARM], Metal Cladding and Roofing Manufacturers Association [MCRMA], Fibre-Cement Manufacturers Association [FCMA], The National Federation of Roofing Contractors [NFRC], Rural and Industrial Design and Building Association (RIDBA), Flat Roofing Alliance, Fall Arrest & Safety Equipment Training [FASET] and the Health and Safety Executive [HSE], by the following people:

P Franklin	FRA	Chairman
A Hutchinson	FCMA	
A Lowther	RIDBA	
A Maitra	HSE	
B Green	FASET	
C Johnson	FRA	
K Greally	FRA	
M E Holden	HSE	
M Long	NFRC	
I McKane	NARM	
C Pearce	NARM	
P Jarratt	NFRC	
P Roberts	MCRMA	
R Bennett	MCRMA	
W Chan	BSI	
W Hawker	NARM	
V Cranmer	Co-opted	
Ms L Cowen	HSE	Secretary

CONTENTS

FOREWORD

In an effort to reduce the numbers of people falling through roofs, there is an increasing demand for roofing products to be non-fragile. Unfortunately, clear accurate standard means by which manufacturers could show that they are meeting this requirement has not, to-date, existed. Specialist Inspectors Report [SIR] No 30, published by the HSE, offered some advice and this document builds upon this advice, to remove any ambiguities and define a method for testing for non-fragility, which gives consistent results when repeated or reproduced by different assessors.

Roofing products in use are subjected to a wide variety of conditions, eg, weather, internal atmospheres, varying degrees of structural loads, misuse etc, possibly for 50 years or more. Therefore, this document can only be considered as giving information on a product's performance under test at the time of the test. It should be borne in mind that a product's properties may change during its service life.

Guidance on longer-term non-fragility for roofing assemblies should be obtained from recognised Trade Association publications and industry standards. For example, guidance on achieving up to twenty-five years non-fragility for GRP in-plane rooflights is contained in Guidance Note 2004/1, from the National Association of Rooflight Manufacturers.

While this document provides a method specifically for testing profiled sheeted roof assemblies, the basic method of applying the instantaneous load is applicable to any surface upon which infrequent passage by persons is likely.

Important revisions to third edition
This third edition of the document contains the following major technical changes:

Section	Revision
Scope	Wording revised
Principles behind test	Paragraph extended to include text about rigidity of the test rig.
0.1	Definition of Competent person extended and duties added.
0.2	Deleted
2.1	Added: requirement for supervision by competent person. Text about adaptability of test rig added
2.3.5	Added: 1. Competent person to determine worst case impact positions; 2. Requirements for tests extended.
2.3.6	Competent person duties introduced.
2.3.8, 2.3.9, and 2.3.10	New sections added.
3.4.1	Requirement for height of second drop test clarified
4.1 f)	Competent person duties extended.
4.3	New section 4.3 added
6	Retitled & revised completely.
Annexes	Annex 4: Drawings minor revisions
	Annex 5: added-complaint procedure

INTRODUCTION

The performance of a product is defined as its behaviour related to foreseeable use. For roofs, this means protecting the inside of a building from the weather. Therefore, they do not have to provide the same level of performance that is required for floors. But, for the purpose of designing the structure, which supports them, roofs are assigned loads to be supported depending on whether access onto them is or is not required. These loads are static loads.

However, these static loads do not account for the fact that people who walk across roofs may stumble and fall onto them, applying an instantaneous load which may be much greater than the static loads prescribed for the roofs. Under these types of impact, roofs have failed, allowing the person to fall through and suffer serious injury or death. The situation became intolerable and a solution had to be found.

To provide this solution, the Health and Safety Executive undertook research, which allowed the magnitude and distribution of the instantaneous force to be quantified. This data lead to the development of a test which represented a human impact incident on a surface reasonably accurately.

The test, which is specified in this document, checks whether a surface can support, without catastrophic failure, the loads that will be applied by a person falling onto it and is applicable to any surface, wherever it is. It does not specify any other requirements, allowing a manufacturer maximum freedom on choice of materials. In addition, the method of classification will allow specifiers to select roofing products on the basis of their particular needs.

SCOPE

The tests described in this document are applicable to any large element roof assembly and any accessories, which may be fitted on it, eg, rooflights and smoke vents, and are intended to provide information about whether the particular element can support the instantaneous loads imposed by a person stumbling or falling onto it.

PRINCIPLES BEHIND THE TEST

Human impact loads can occur anywhere on a roof. Therefore, any test which purports to check fragility of a roof should check its resistance to impact everywhere, by a suitable means. This test satisfies this requirement by checking a roofing product's ability to first arrest and then retain a load falling through gravity and impacting at locations, which, in the opinion of people with many years experience in the roofing industry, are most susceptible to fracture under impact loads. The test rig is relatively rigid, designed to simulate the most rigid localised areas of a roof. The rigidity of the test rig should never be reduced (for example by using more flexible purlins or omitting stiffening struts), even where an actual roof may be more flexible in certain areas. Where an actual roof may be more rigid (for example if concrete purlins are being used) then the rigidity of the test rig should be increased accordingly.

0 DEFINITIONS

For the purposes of this document the following definitions apply:

0.1 Competent person or persons

Person [or persons] who can demonstrate that they have sufficient professional or technical training, knowledge, actual experience and authority to enable them to:

a) Carry out their assigned duties at the level of responsibility allocated to them;
b) Understand any potential hazards related to the work (or equipment) under consideration;
c) Detect any technical defects or omissions in that work (or equipment), recognise any implications for health and safety caused by those defects or omissions; and
d) Be able to specify a remedial action to mitigate those implications.

In this context, for assessing non-fragility, a competent person is one who can demonstrate that he/they has/have:

a) Thorough knowledge of roofing and of the mechanical and physical properties and behaviour of the particular product and assembly when subjected to this test; and
b) Extensive knowledge and experience of installation of the product, its usage limitations, behaviour and mode of failure in service.

Note: The competent person's responsibilities include ensuring that the worst-case scenario has been covered when:

a) Defining roof assembly to be tested (2.3.1)
b) Defining test position(s) (2.3.5)
c) Determining any conditioning of the samples (2.3.2)
d) Deciding the number of tests necessary to ensure results are statistically significant (2.3.4 and 2.3.7)
e) Determining the number of profiles to be tested (2.3.8)
f) Evaluating the damage to the assembly (2.4.4)
g) Together with signing of the test report (4.1(f))

0.2 Inspection
Visual exercise, which is not carried out at close-quarters.

0.3 Examination
Thorough inspection carried out at close-quarters, which may, at the discretion of a competent person, be more than just visual.

1 QUALITY CONTROL TESTS

1.1 Applicability of test
1.1.1 The quality control tests are non-destructive tests used to confirm the consistency of the materials used in roofing products, by testing samples from production batches. Consistency of production shall be demonstrated by consistency of weight and of cross-sectional properties.

1.1.2 These tests are not necessary when it can be shown that the materials forming the roof structure comply with the requirements of a relevant current European, British or ISO standard.

1.2 Selecting the samples
Five test samples should be taken at random from a production batch without being specially prepared.

1.3 Consistency test procedures
The consistency test shall test the consistency of the weight of a number of material samples and their cross-sectional properties.

1.3.1 *Weight of the samples*
The test samples shall be weighed and consistency of weight shall be taken as an indicator of consistency of production.

Each of the five test samples shall be weighed and the weight recorded. The average, W_{av}, of the weight of the five samples shall be calculated and recorded. To satisfy the requirements of this standard the weight of each sample shall be within 10% of the average.

1.3.2 *Cross-sectional properties*
For each sample deflections under load shall be measured. Consistency of deflection shall be taken to demonstrate cross-sectional consistency.

Each of the samples shall be subjected to a test, as detailed below:
1.3.2.1 The test sample shall be simply supported 150 mm from its ends on a rigid support and shall be level to within ± 1°. The test load shall be applied over an area 250 mm x 250 mm.

1.3.2.2 A pre-load of 20 kg shall be applied at the centre of the test sample and held there for two minutes. The load shall be removed and the sample in this state shall be the datum for all subsequent measurements of deflection.

1.3.2.3 A test load of 100kg shall be applied, in 10kg increments. At each incremental load point the deflection under load shall be measured and recorded. The load shall be removed and on completion of this operation, the deflection of the sample shall be re-measured.

1.3.2.4 On completion of testing the following average values from Five tests shall be calculated:
a) The deflection under maximum load;
b) The residual deflection after removal of the load;
c) The deflection modulus, E, defined as follows (see Figure A2/1, in Annex 2):
   i) for non-linear load deflection behaviour: the gradient of the straight line connecting the origin of the load deflection curve to the 20kg point;
   ii) for the linear load deflection behaviour: the gradient of the line

1.3.2.5 For a material to satisfy the requirements for cross-sectional consistently of this standard, no individual test deflection modulus shall be more than 10% different from the average values calculated in (a), (b) and (c) above.

1.3.3 Only samples which satisfy the requirements of 1.1.2 or both the requirements for consistency, described in and 1.3.1 and 1.3.2, shall qualify for a non-fragile classification under this standard.

2 TESTING TO DETERMINE NON-FRAGILITY

2.1 Principle of the test
A specified weight shall be released in a controlled fall under gravity towards the test sample at critical points, to check if the test sample has an adequate resistance to withstand the impact from the weight.

A competent person [see 0.1] must supervise the entire test.

2.2 The Test Rig
The test rig, which is to be used for "flat" large element roof assemblies (such as profiled metal sheets and in-plane rooflights) shall be as shown in Annex 4. When testing particular aspects of a roof assembly, where the rig is not appropriate, such as for hip arrangements, or for curved roofs, or for accessories, such as out-of-plane rooflights, the rig must be adapted so that it realistically simulates the particular construction to be tested, to the satisfaction of the competent person.

2.3 The Test
2.3.1 The roof assembly to be tested shall be the worst case as prescribed by the relevant industry guidance or competent person or persons [see 0.1] and shall be fixed onto the test rig prescribed in 2.2.

2.3.2 The samples shall be conditioned to ensure that they are tested in a condition which could reasonably exist in service and which would be the worst case for impact strength – see Note 1. The competent person shall prescribe the conditioning.
Note 1: conditioning may require the samples to be soaked in water to achieve saturation, or testing at elevated or low temperatures, as prescribed by the competent person.

2.3.3 The impact is obtained by the vertical fall under gravity of a cylindrical sand-bag. A typical test apparatus is shown in Annex 2, Figure A2/2. The sand bag is suspended by a quick release mechanism to the point C1, which ensures that the underside of the sandbag is a minimum of 1200 mm above the highest surface of the test sample.

2.3.4 The sand bag shall comprise a cylindrical canvas bag of diameter 300 mm – see Note 2. The sand shall be dry, have an apparent density of approximately 1500 kg\m^{-3} and shall pass through a sieve of aperture size 2 mm. Just

before carrying out the test, the sandbag shall be weighed and **it shall weigh at least 45 kg**.
Note 2: The sandbag is shown in figure A1/1 in Annex 1.

2.3.5 From its initial position, a minimum of 1200mm above the highest surface of the sample under test, the sand bag shall be allowed to fall freely under gravity on to the surface of the test sample. It shall impact the test sample at the position determined as the worst case by the competent person (see 0.1). The competent person shall use existing data (typically industry guidance) to establish which test position(s) is the worst case, or in the absence of such data shall carry out a sufficiently rigorous test programme to establish this position(s). As a minimum, the test sample shall be impacted at [see also figure A2/3 in Annex 2]:

a) Within 150mm of the centre of the test sample;
b) Within 300mm of the support point, at least 150mm away from the support; and
c) Within 150mm of the edge of the sheet, adjacent to the underlap with the other sheet.

When testing profiled sheet, impacts shall be carried out on both trough and crown of the profile, unless the competent person has determined which of these is the worst case, in which case that shall be used

Sheets shall be tested in the same span configuration as they are to be used: single, double and triple span arrangements will require testing separately. Tests on triple span sheets can be assumed to be representative of sheets spanning more than 3 purlin spaces. Every location in every span of double and triple span sheets must be tested .

2.3.6 The test described above shall be carried out on at least three samples. The result declared shall be the lowest classification of any individual sample. Where the test result is borderline, or there is significant variation between test results of individual samples, the competent person (see 0.1) shall ensure sufficient further tests are carried out to ensure the test results are statistically significant, and the declared result will be consistently achieved.

2.3.7 It is not a requirement to test each sample in each of the three positions specified. The number of positions, which must be tested may be reduced. However such rationalisation of testing shall be supported by evidence, supplied by the competent person or persons (see 0.1), that the test positions used include the worst case.

2.3.8 Where a manufacturer or supplier provides the same product in a number of profiles, the number of profiles to be tested shall depend on the instruction of the competent person (see 0.1). Different profiles should normally be tested independently; results from one cannot usually be assumed to apply to another. Where sufficient data is available to demonstrate that variation between profiles will not affect results (typically in the form of industry guidance) then the competent person may be able to use such data to avoid the need to test all profiles.
Note: Specific guidance on the application of this test to GRP profiled rooflight sheeting is given in NARM Guidance Note 2004/1, which can be obtained from NARM.

2.3.9 Where different manufacturers make the same profile to the same nominal specification but with possible variations in process, raw materials, etc (eg profiles from different rooflight manufacturers) then results from one cannot be assumed to apply to another, and performance of each product must be demonstrated individually.

2.3.10 The manufacturer(s) of any components used in the assembly shall ensure that the samples tested are representative of all production. If any alterations are made to product design or manufacturing method which may affect the test results, any existing classification should be disregarded and the test should be repeated.

3 CLASSIFICATION OF ROOF CONSTRUCTION

3.1 Carry out the drop-test described in 2.3. If the impactor passes through the test assembly and hits the ground, the test assembly shall be classified as **fragile**.

3.2 To be classified as non-fragile, under the test described in 2.3, the assembly under test shall arrest the fall of the impactor and retain it on the test assembly for a period of at least 5 minutes. The requirement to retain the impactor for 5 minutes may be reduced on the instruction of the competent person – see Note 3.
Note 3: if in the opinion of the competent person there is no likelihood of the test impactor causing further elongation or tearing that would allow it to pass through the test sample, the test may be terminated.

3.3 Assemblies subjected to a single drop test

If after the first impact the impactor is retained on the test assembly, satisfying conditions set out in 3.2, and no other drop tests are carried out on the assembly, the assembly shall be classified as a **Class C non-fragile assembly.**

3.4 Assemblies subjected to multiple drop-tests

3.4.1 The impactor may be removed and the test assembly may be subjected to a second drop test at the same locations as the first drop (from 1200mm measured from the sample after the first drop).

3.4.2 If the impactor passes through the test assembly and hits the ground, the assembly shall be classified as a **Class C non-fragile assembly**.

3.4.3 If the impactor is retained on the test assembly, satisfying the conditions set out in 3.2, the assembly shall be classified as a **Class B non-fragile assembly**.

3.4.4 On conclusion of the second drop test, the load shall be removed and the assembly examined by the competent person and if, in his opinion, the roof sheet and the assembly shows no signs of significant damage that will affect the long term strength and weatherability of the assembly – see Note 4, the assembly may be classified as a **Class A non-fragile assembly**.
Note 4: Any tearing at the fixings, fractures in the sheet or the assembly support structure, delamination of the sheet or damage to the surface protection which could accelerate the degradation process should be seen as sufficient to withhold a Class A rating.

3.5 A flowchart for the tests is given in Annex 3.

4 TEST REPORTS

4.1 The test report shall contain the following information:

a) A detailed description of the assembly tested

b) A detailed description of the observations from the close examinations required in 3.4.4;
c) The results of the consistency tests if carried out;
d) Confirmation that the test for fragility was carried out in accordance with this test method, and date of the test
e) The classification which the material satisfies;
f) The name, address and dated signature of the competent person(s), including a statement confirming evidence of compliance with the requirements of **0.1**.

4.2 Photographs and videos may be supplied as evidence to support (a), (b) and (c).

4.3 This test report shall be made available to any person who asks for confirmation that the claim for ACR classification of the assembly is correct.

5 MARKING AND LABELLING

5.1 Each sheet or component shall be marked clearly and visibly using a durable method which does not affect the long-term performance of the material. The labelling shall contain the following:
a) Name of the manufacturer;
b) Product reference or specification**.**

6 COMPLAINTS PROCEDURE: A code of practice

6.1 Where it is suspected that a manufacturer or supplier is using an ACR[M]001 classification incorrectly, this should be reported to the relevant Trade Association.

6.2 In the first place, the Trade Association receiving such a report should investigate this claim. If it is found that the classification is being used incorrectly, the member should be instructed to withdraw it. In addition, the manufacturer should inform any person who has bought the product of the change in classification.

6.3 Where there is a dispute about the correctness of a classification, the Trade Association should refer the matter to the Advisory Committee on Roofing [ACR], through their delegate on the Committee.

6.4 Upon receipt of a referral, The ACR shall follow the procedure set out in Annex 5.

ANNEX 1
SANDBAG FOR THE DROP TEST

A1.1 The sand bag for use in the drop test for fragility – see 2.3.4 – shall be as in figure A1/1:

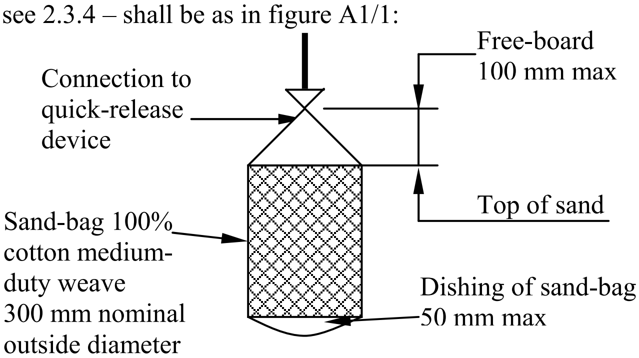


Figure A1/1 – Sand-bag for drop-test

A1.2 The bag shall be filled with the dry sand, in layers not exceeding 150 mm deep. Each layer shall be compacted by ramming with a 32 mm diameter x 1.0m long reinforcing bar. The ramming action shall be achieved by raising the reinforcing bar to a height of at least 50 mm above the sand and letting it fall through gravity at least ten times. The compacting action shall be spread over as much of the surface of the sand as possible.

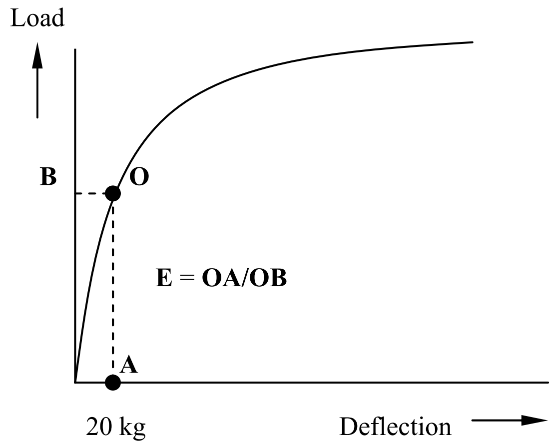
A1.3 On completion of the compaction of the sand, the bag shall be drawn tight as close as possible to the top surface of the sand. The free space above the sand shall not exceed 100 mm. The bag shall be tied to ensure that sand cannot escape**.**

A1.4 The connection to the quick release device shall be arranged to ensure that the bag hangs within 1.5° of the vertical**.**

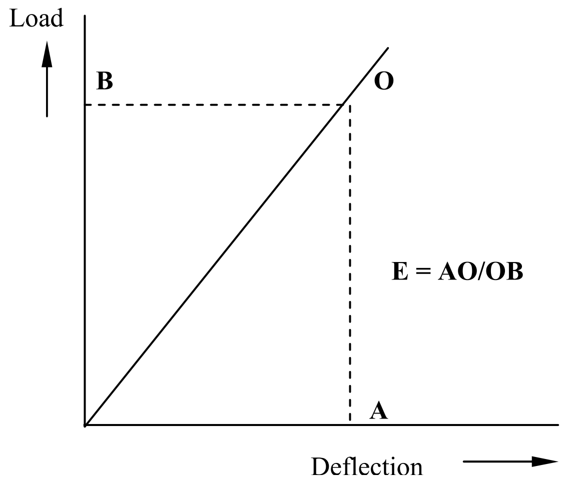
ANNEX 2

FIGURES REFERRED TO IN THE TEXT

A2.1 The figures referred to in the text at 1.3.2.4, 2.3.3 and 2.3.5 are shown in Figure A2/1, A2/2 and A2/3 respectively.



E for non-linear load-deflection behaviour



E for linear load-deflection behaviour

FIGURE A2/1 – **Methods of calculating E from load deflection curves** [1.3.2.4]

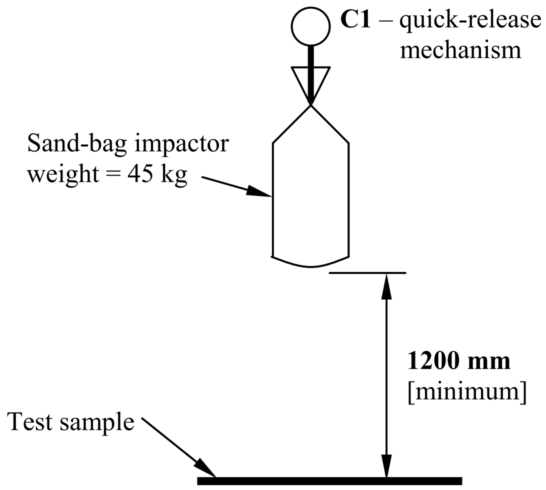
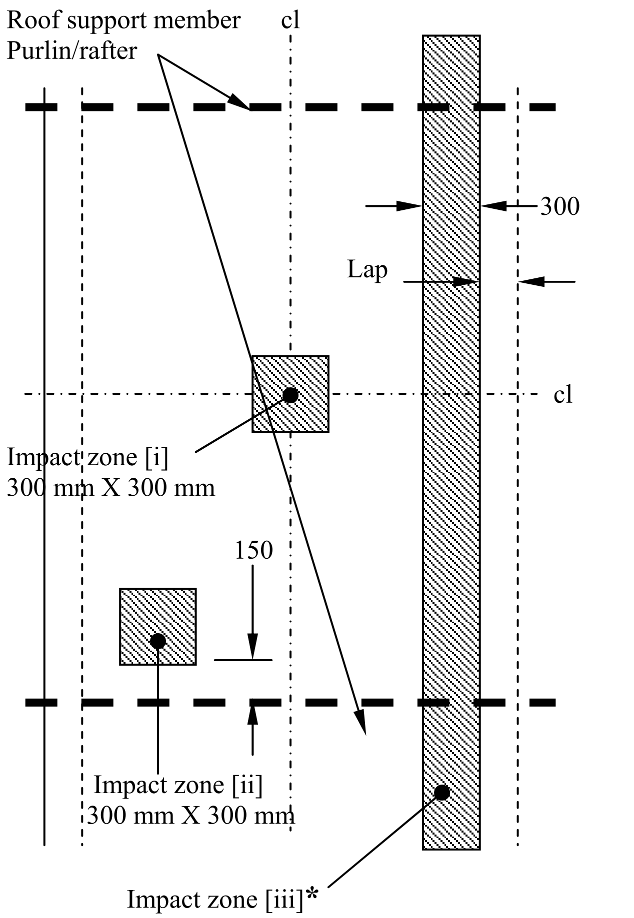


FIGURE A2/2 – Arrangement for drop-test [2.3.3]



Note 1: * exact position in zone [iii] to be specified by the competent person.
Note 2: All dimensions are in millimetres.

FIGURE A2/3 – Impact zones for drop-test in accordance with 2.3.5

ANNEX 3 FLOW-CHART FOR FRAGILITY TEST

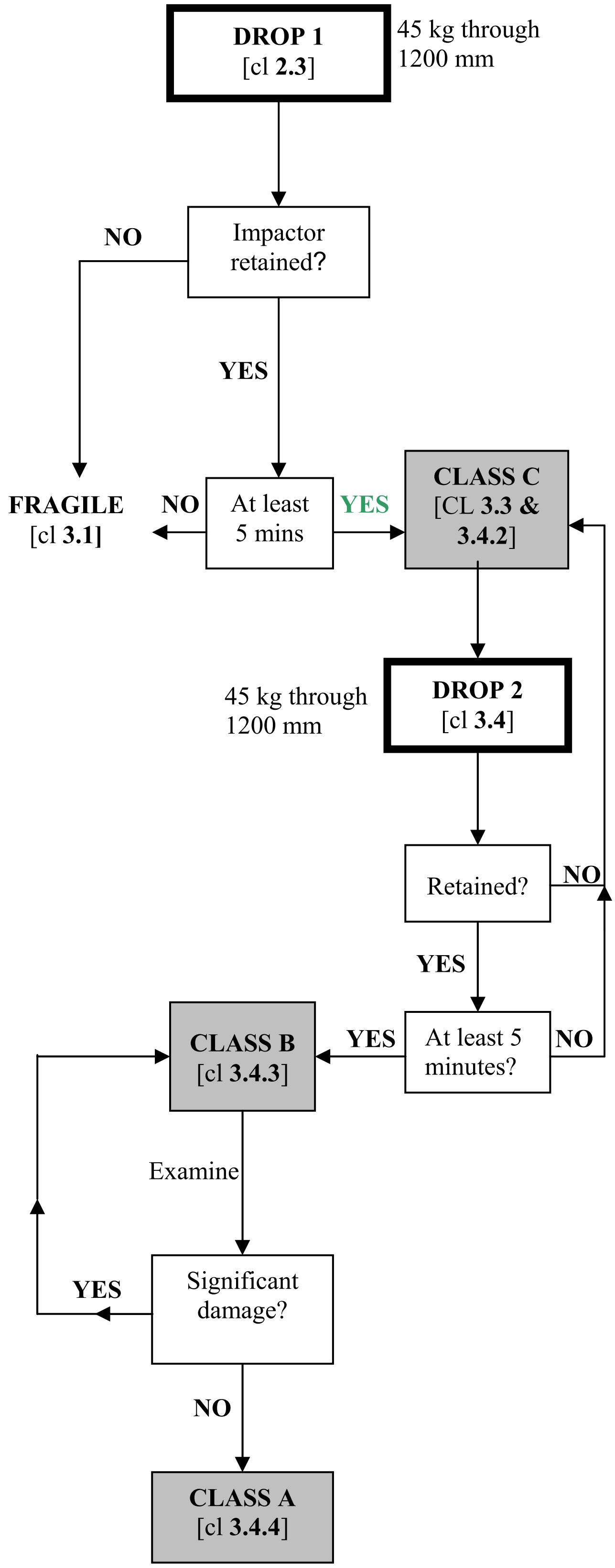
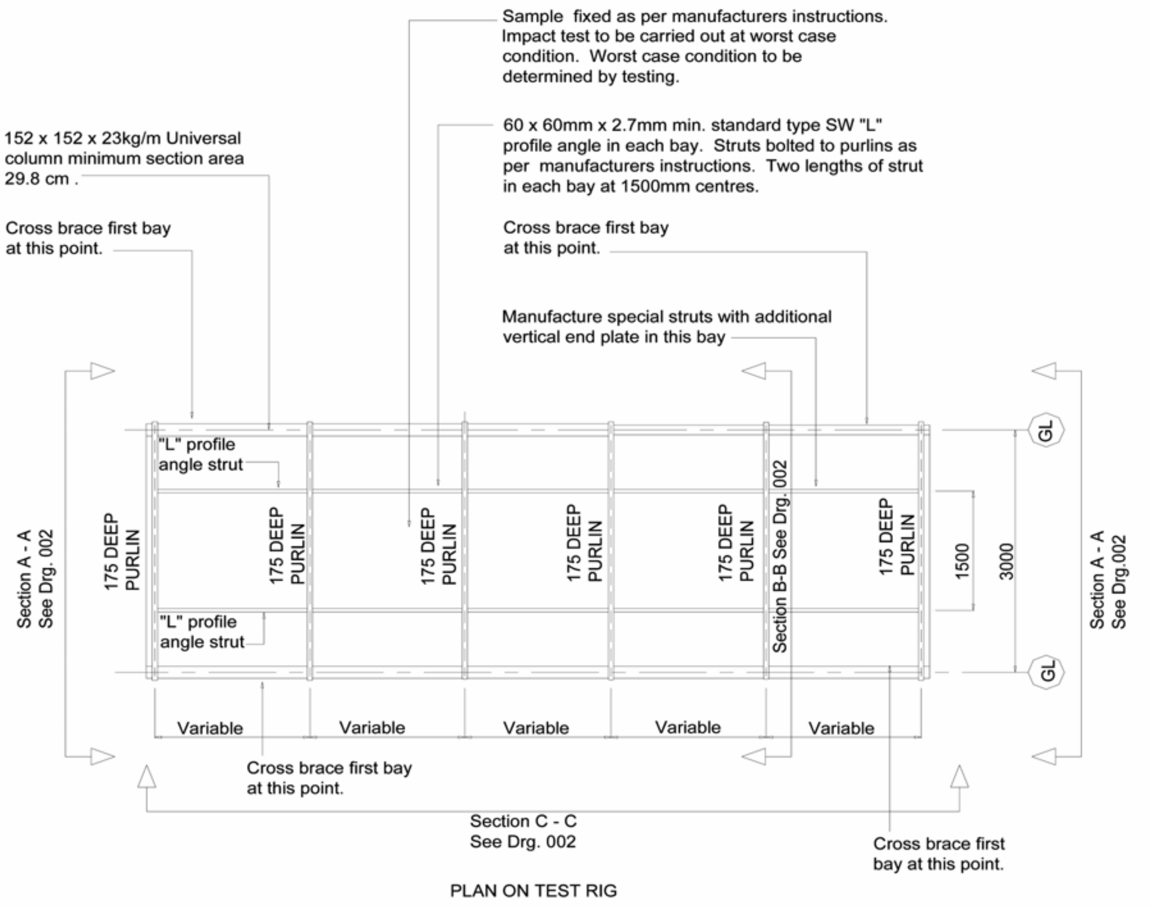


Figure A3/1: Flow-chart for classification

ANNEX 4 DRAWINGS OF TEST RIG

A4.1 PLAN ON TEST RIG [DO NOT SCALE]



Notes

The test rig must be supported on a solid concrete base.

The rig may be bolted or welded construction. Diagonal cross bracing may be added to the support structure as necessary to ensure stability.

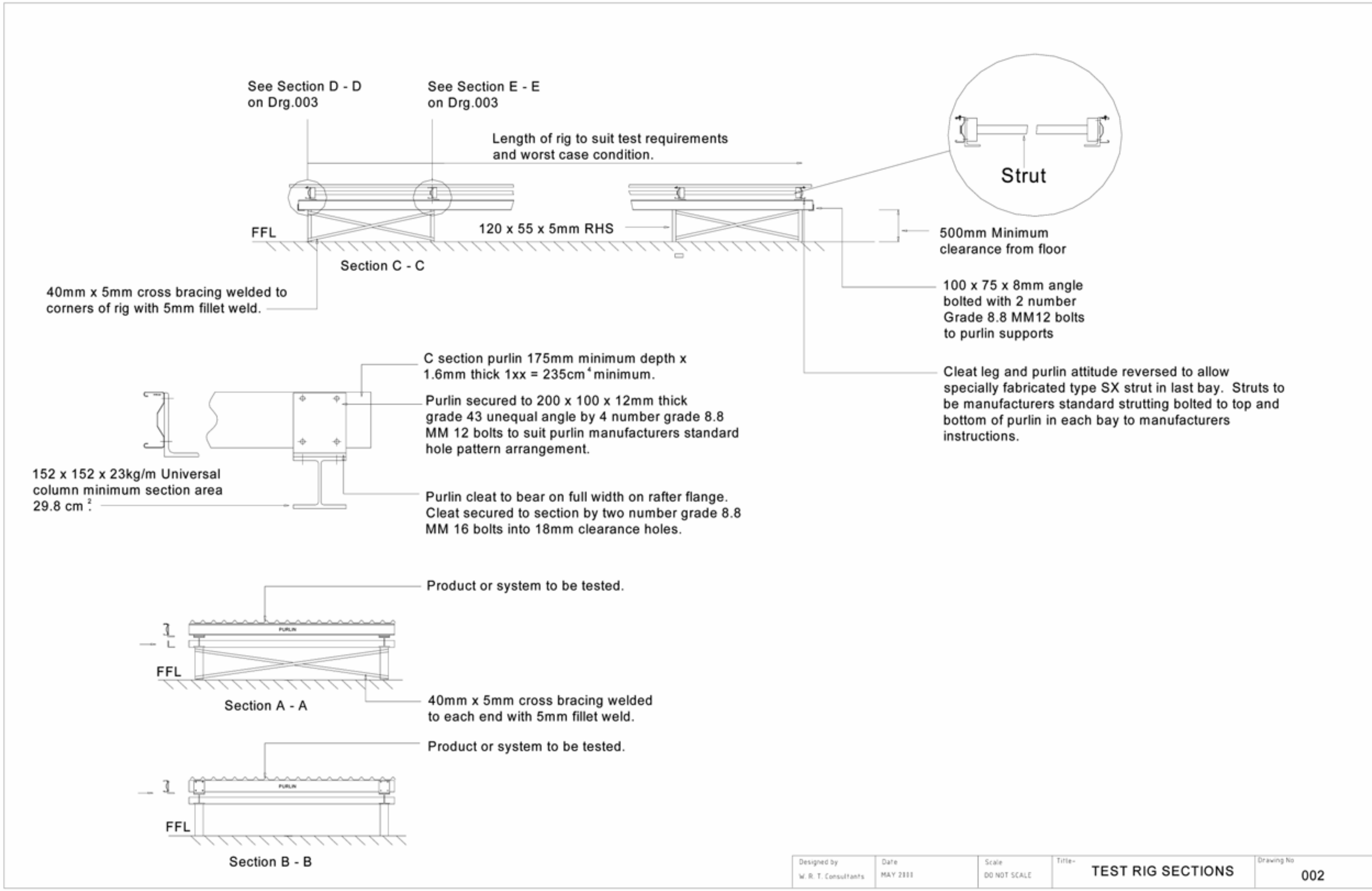
The underside flange of the purlin must be a minimum of 500mm from FFL to enable inspection of the test sample.

Details of the test procedure, loading bag and quick release mechanism are recorded in the notes for guidance. (Annex 1 and 2)

R.H.S. legs are to be sited at 1800 +/- 200mm centres.

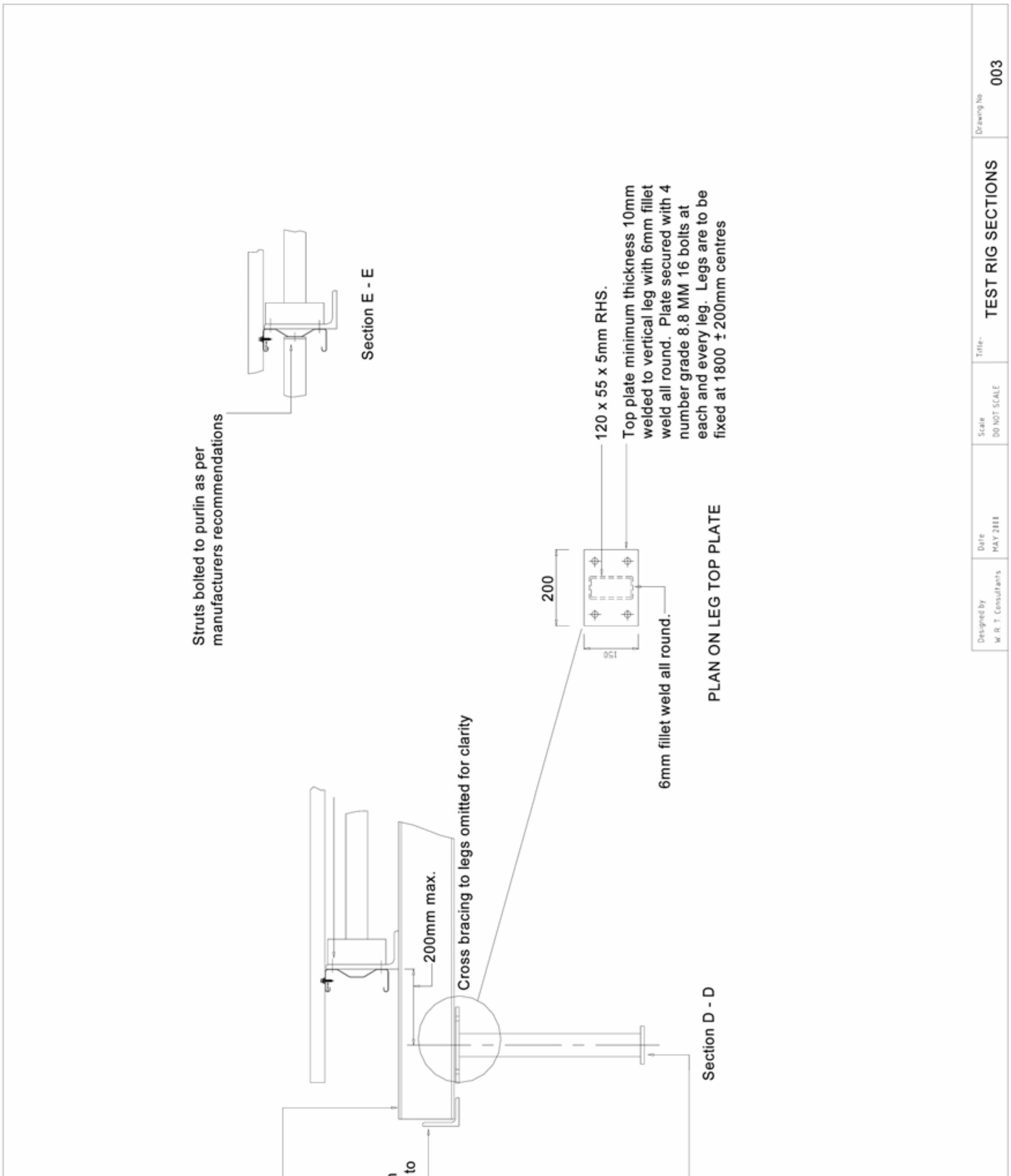
Designed by	Date	Scale	Title-	Drawing No
W. R. T. Consultants	MAY 2008	DO NOT SCALE	PLAN OF TEST RIG	001

ANNEX 4 DRAWINGS OF TEST RIG
A4.2 ELEVATIONS SECTIONS AND TYPICAL DETAILS

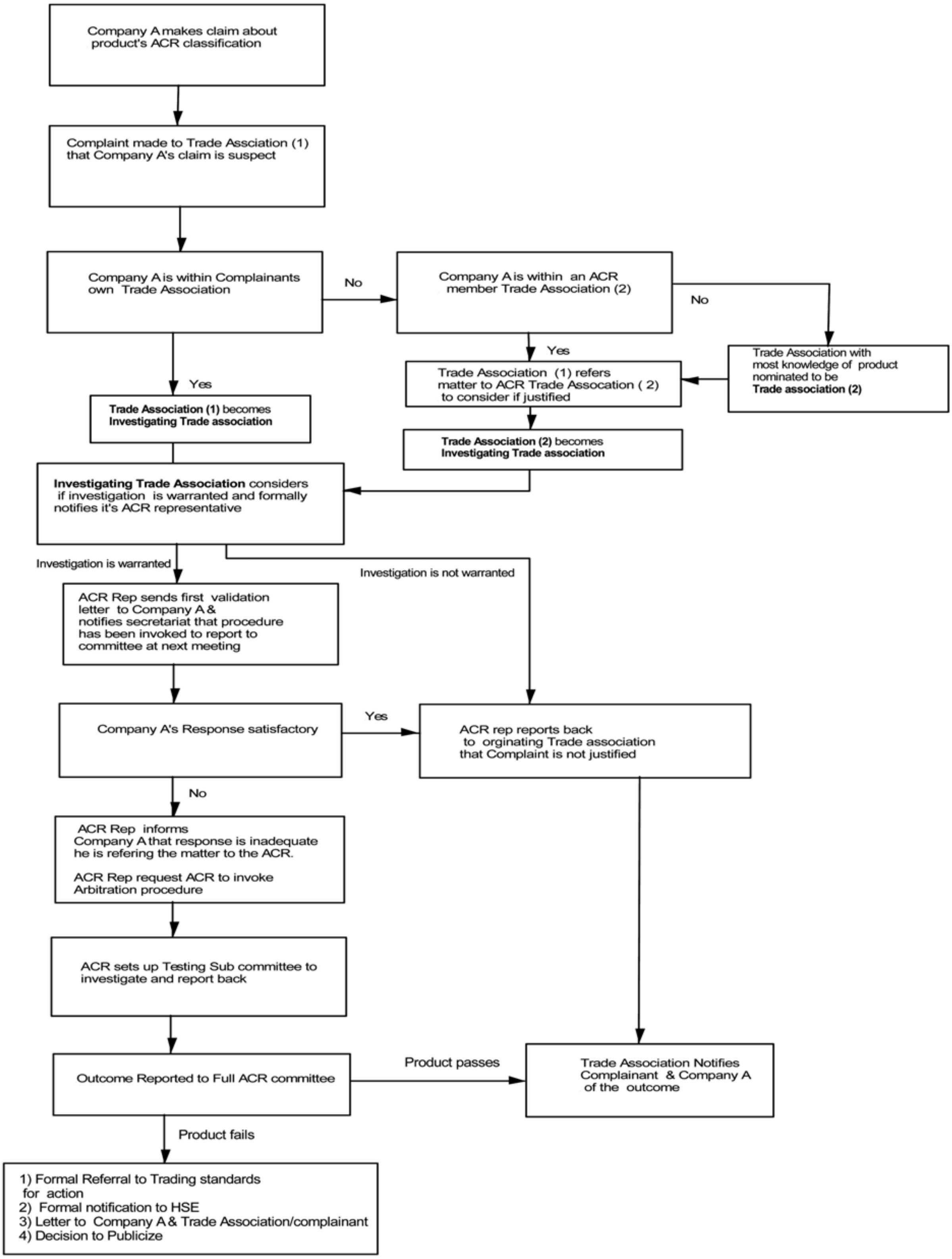


ANNEX 4 DRAWINGS OF TEST RIG

A4.3 ELEVATIONS SECTIONS AND TYPICAL DETAILS



ANNEX 5 COMPLAINTS PROCEDURE FLOWCHART



ANNEX 6 REPORT ON TESTS CARRIED OUT TO DETERMINE HUMAN IMPACT LOADS ON ROOFS

THE PROBLEM

1. BS 6399 - part 3[1] prescribe live loads for roofs, which they recommend should be used for their design. These are static loads and it is presumed that their use provides a reliable structure.

2. For most structural components, the combination of recommended live loads with component self-weights ensures that the resulting design loads are high enough to make loads from human impact events, eg, stumbles and falls, insignificant. With roofs, this is not the case. Consequently, many people working on roofs have fallen through them, often to their deaths. This should not be acceptable to civil and structural engineers; workers on roofs deserve the same level of protection as other workers.

3. The problem is exacerbated when engineers (and architects) design building components to penetrate the roof, eg, vents, chimneys etc, which usually require maintenance and regular access across the roof.

4. Construction health and safety law had recognised this problem many years ago and made it illegal for persons to work on or near fragile materials. Unfortunately, the engineering professions did not and have not risen to the challenge; they continue to specify fragile roofs.

5. This led to the Health and Safety Executive [HSE] publishing the Specialist Inspector Report (SIR) 30[2], with the intention of encouraging the development of a definitive test for non-fragility, which would ensure that a roof assembly would not fail under the load of a person. Because these hopes were not realised, the HSE acted to provide a means of assuring non-fragility.

DEVELOPING THE TEST

Governing Principles

6. In keeping with the principles of UK health and safety law, the Test would have to be reasonably practicable; that is, it would have to satisfy two requirements, it should:

a) Provide a safe margin against failure under human impacts; and
b) **Not** be so onerous as to reclassify materials known to be non-fragile.

Existing Information

7. An examination of existing information indicated that there were ready-made solutions available. A test based on the theoretical consideration of energy[1], as used in some parts of Europe, could have provided a solution. However, it would have penalised the roofing industry, because it would have required the production of heavier-duty roof sheets, requiring heavier structures to support them. Consequently, this approach was abandoned. However, to ignore the theoretical approach and base the test on an empirical approach would require the acquisition of data.

Note1: A 100kg man with his centre-of-gravity acting at 1.0m above the surface falls onto the surface with an energy of 1000 J at impact. By applying a factor of safety of 2.5, you arrive at design impact energy of 2500 J, which defines the test: a 100 kg sandbag allowed to fall through 2.5m.

Acquiring the necessary data

8. This was a major problem. In order to provide a safe margin against failure, it would be necessary, initially, to obtain an accurate assessment of the forces. Three options were available. We could:

a) Base the test on theoretical considerations of energy;
b) Use already published data, which used anthropomorphic dummies; or
c) Develop our own data.

9. There was some doubt about using the approach advocated in **9** (a), because it was almost impossible to calculate how much energy the human body could absorb. Using published forces, based on the use of anthropomorphic dummies [**9** b)] were also considered but discarded, because dummies do not model a body's unique capability to absorb energy accurately. Consequently, both methods could give an overestimate of the forces and their use would probably have violated governing principle **6** b).

10. Therefore, it was agreed that the only way to quantify human impact forces accurately, to allow the provision of a credible safe margin [governing principle **6** a)], was to use people to generate the forces.

Test should represent the actual event

11. Another problem was replicating an impact event in a test. For any test method to be representative of the human impact event, it would have to satisfy three conditions:

a) It would have to apply the same total force to the surface; with
b) The same time-history, at least for the first impact; and if possible
c) Generate the same local effects.

12. Therefore, the impact surface would have to measure the total load as well as the instantaneous load over the period of the impact. A special impact table would have to be constructed.

The Impact Table

13. A point for consideration was the stiffness of the impact table, because its flexibility would, in accordance with impact theory, modulate the forces being measured. After due consideration, it was agreed that the best course of action would be to use a stiff impact table, as this would give the highest forces and a better indication of forces at stiff points, eg, impact close to a rafter.

14. Consequently, the impact table comprised a stiff steel platform covered with approximately 1000 load cells, supported at each corner on a load cell. The surface load cells would record the local load at 50 Hz, while the load-cells under the corners would record the total impact force over the same time; allowing the requirements of **11** a) and **11** b) to be met and the comparison required by **11** c).

THE TESTS

15. Volunteers fell on to the impact table in various ways: stumbling while walking across it, falling from standing to sitting, etc. The forces applied to the table for each event were recorded: providing the forces applied by humans when they fall on to a surface, as well as a time-history of the event. The data was provided in two ways: a time-history plot and a pressure visualisation, which showed the build up of pressure over the whole impact event. Outputs from typical impact events are shown in Figures 1and 2, at the end of this report.

ASSIGNING FACTORS OF SAFETY

16. Having acquired the necessary data, the next significant point was the assignation of a factor of safety (FoS) to the impact force. Any FoS would have to provide an adequate margin against failure in the extreme case and, by default, a larger margin against failure for the non-extreme cases. For the purpose of this exercise, the FoS was arrived at simply, by applying multipliers for perceived sources of error in the test method, which were:

a) The 85 kg weight of the test specimen was less than the 95th percentile man, who weighs 94 kg. Assuming a linear relationship between weight and impact force, this required an adjustment factor for weight, $\mathbf{k}_W$, of **1.1**.

b) Errors in measuring the load, which, due to the careful calibration of the equipment, was considered to be very low. Nevertheless, an adjustment factor for measuring error, $\mathbf{k}_E$, of **1.1** was applied.

c) Fabrication tolerances in the material to be tested, which was taken as being covered by assuming that the material was 10% less thick than it should be. On the assumption that one failure mode would be due to bending, the ultimate bending strength of the thinner material would be $1.0^2 / 0.9^2$ less than a specimen fabricated to the correct thickness. This indicated the application of a factor for fabrication tolerance, $\mathbf{k}_F$, of **1.25**.

d) Differences in impact velocity, due to different heights of fall – people vary in height. This was accounted for by assuming that the impact velocities varied by the ratio $\mathbf{k}_V$, where:

$$\mathbf{k}_V = [2gh_1]^{1/2} / [2gh_2]^{1/2} \ldots\ldots\ldots\ldots\ldots(1)$$

h_1 = 1.0m the height to the posterior of the volunteer; and
h_2 = 1.15m, the height to the posterior of a taller man.

Indicating an impact velocity correction factor, $\mathbf{k}_V$, of **1.1**.

e) Finally, there had to be a minimum margin against failure. This was the most difficult part of the exercise, as this minimum margin had to be applied to the extreme case. For the answer, HSE accident statistics were examined and these showed that the majority of people [approximately 85%] who fell through roofs had, reportedly, stumbled on the roof. The other 10-15% had fallen, either forwards or backwards. And, as the tests had shown that the maximum force occurred when a person falls from standing to sitting, this was chosen as the extreme event to attract the minimum FoS. In line with some existing standards, a factor of safety, $\mathbf{k}_S$, of **1.15** was assigned to this force.

17. This gave the overall minimum factor to be applied to the measured "extreme" force, which was **1.9**, being the product of the factors[2], $\mathbf{k}_W \ldots \mathbf{k}_S$, listed above in **16** a) to **16** e). This was rationalised to **2.0**, and eventually defined the test for assuring non-fragility as: the dropping, under gravity, of a bag of diameter 300 mm containing 45 kg of dry sand through 1.2 m onto the surface, determined by trial-and-error.
Note 2: By the method of SRSS the minimum factor becomes 2.7

18. This test has been adopted by the Advisory Committee on Roofing, and has been published as ACR [M] 001:2000 – Test For Fragility of Roofing Assemblies[3].

REFERENCES

[1] **British Standards Institution.** BS 6399:Part3 - Code of practice for imposed roof loads;
[2] **Health and Safety Executive.** Specialist Inspector Report No 30 – Test for fragility;
[3] **Advisory Committee For Roofing.** Materials Standard ACR[M]001:2000 – Test for Fragility of Roofing Assemblies.

FIGURES REFERRED TO IN THE TEXT

The figures included below are referred to in the text at paragraph 15

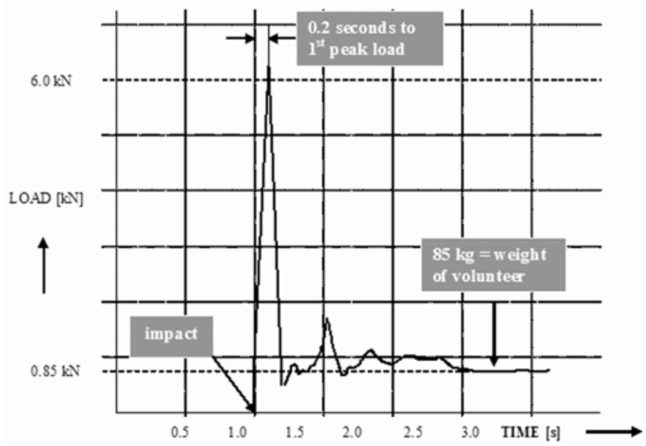


Figure 1 – Impact Time-history: standing to seated

DRAFT OF 12 February 2001

Figure 7: Video frame and pressure image of stumble event

Figure 8: Video frame and pressure image of fall to seated event

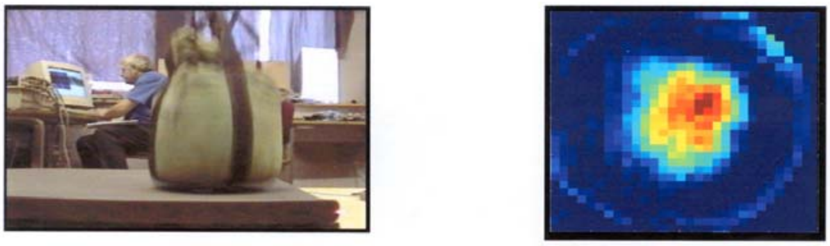


Figure 9: Video frame and pressure image of bagdrop

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15

Figure 2 - Instantaneous pressure readings for first impact [at peak load]. These pictures are built up every 1/50th of a second from the first impact In the figures, the colours indicate intensity of pressure: red is the highest intensity and blue is zero [Image abstracted from the contract research report]

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PARTICIPATING ORGANISATIONS

This document may be obtained from any of the organisations at the addresses printed below or from the ACR website at www.roofworkadvice.info

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Fax 020 7397 8121
e-mail enquires@faset.org.uk
Contact Mr S Kennefick

Flat Roofing Alliance
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Tel: 01444 440027
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Contact: Mr P Franklin

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The Advisory Committee for Roofwork [ACR] is a body dedicated to making working on roofs safer. Its membership is made up of nominees from the major roofworking Federations and Associations and the Health & Safety Executive, who provide the experience of many years of involvement in working on roofs in the advice given in their documents.
