Human Impact Loads On Roofs

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Summary: Currently, roofs are designed to carry loads prescribed in BS 6399. These are static loads, which are not significant in structural terms and do not represent the load of a person falling on to or stumbling on the roof. Consequently, many people fall through roofs, often to their deaths. As a result of this unacceptable situation, the Health and Safety Executive embarked on a programme to quantify human impact loads and found that they exceeded the prescribed design loads. Finally, the test results were used to develop a test for fragility of roof assemblies, which has been published as ACR[M]001:2000, to help manufacturers develop roofing products, which are safe.

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, which would have required 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.

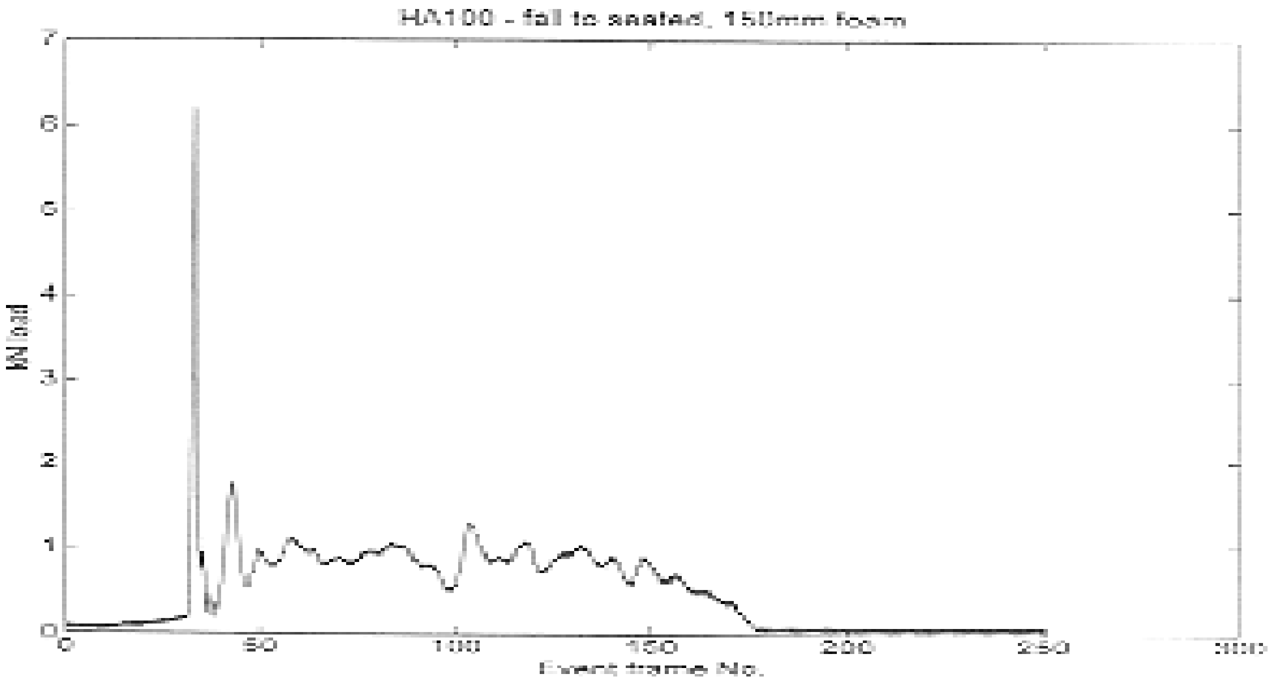

Figure 1: *Typical time-history for impact event*

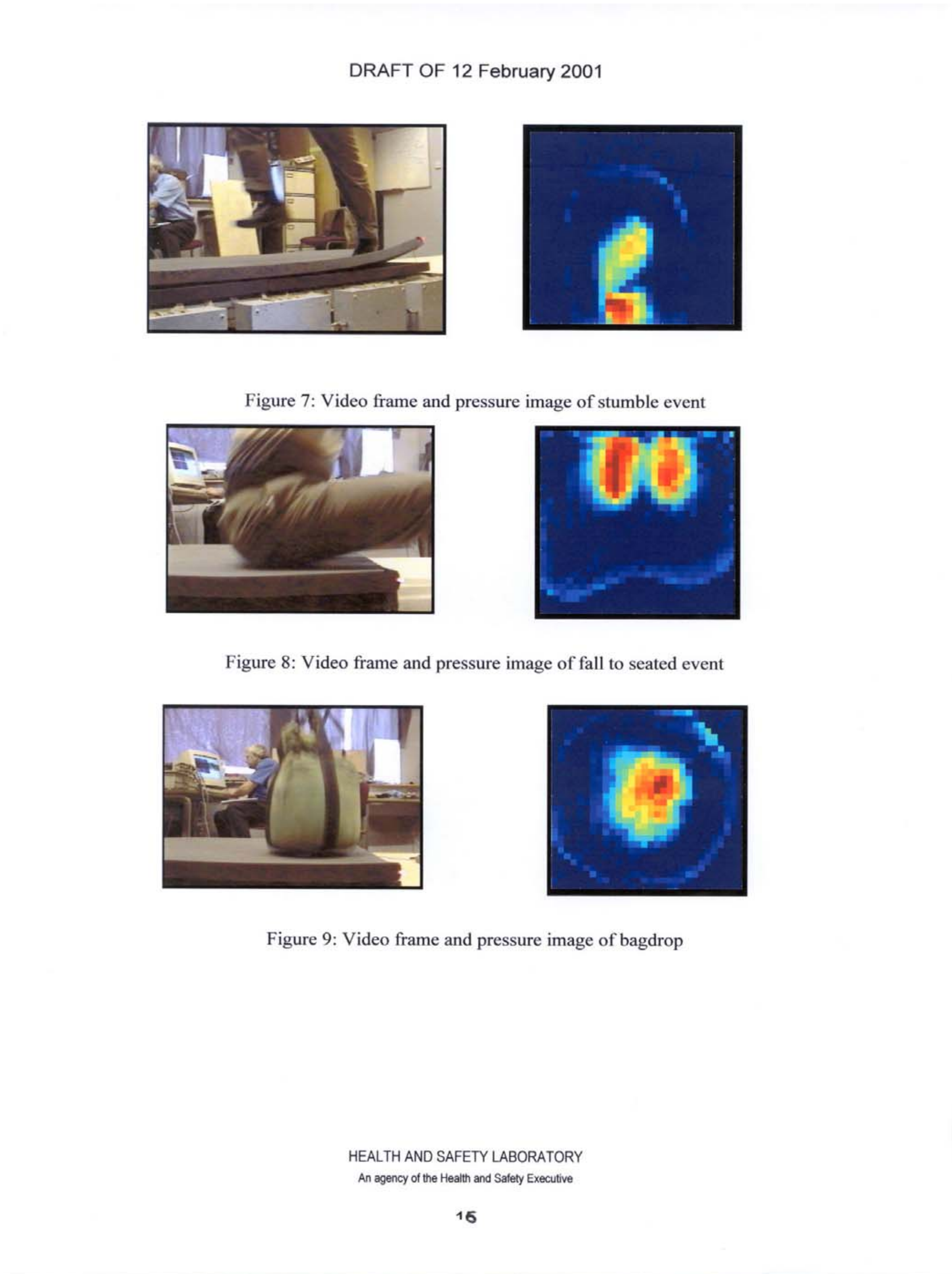

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Figure 7: Video frame and pressure image of stumble event

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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Figure 2: *Instantaneous pressure readings for first footfall during a stumble [at peak load]. This picture is 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*

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:

$$\mathbf{k}_V = [2gh_1]^{1/2} / [2gh_2]^{1/2} \quad \text{……………..(1)}$$

and where 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.

This indicated 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], $\mathbf{k}_W$…..$\mathbf{k}_S$, 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.

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