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Tests on Full-Scale Cold Formed Steel Roofing Systems

Essais en vraie grandeur de systèmes de toiture en acier formé à froid

Versuche an kaltverformten Stahldachbelagssystemen

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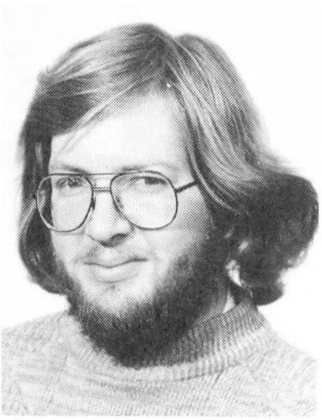

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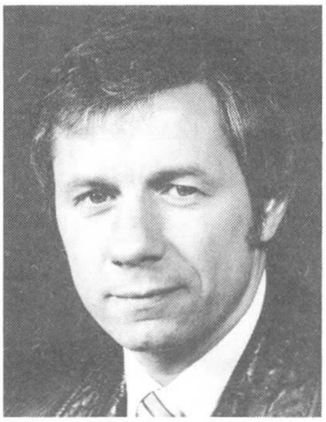

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SUMMARY

An experimental investigation was undertaken on three representative British cold formed steel roofing systems to assess the effect of drifting snow. Details of this investigation are presented here. Comparisons are made between variably distributed loading and equivalent uniformly distributed loading. Differences in response are identified and the implication for design discussed.

RÉSUMÉ

Une étude expérimentale a été effectuée sur trois systèmes de toiture d'acier formés à froid, typiques de ceux fabriqués au Royaume-Uni, afin d'évaluer les effets d'un amoncellement de neige. Des détails de ce programme sont présentés ainsi que des comparaisons entre les charges réparties variables, simulant un amoncellement de neige, et les charges équivalentes uniformément réparties. Une discussion s'ensuit, concernant l'écart entre les résultats obtenus et leurs conséquences pour la conception de telles structures.

ZUSAMMENFASSUNG

Vollmassstäbliche Versuche wurden an drei typischen kaltverformten Stahldachbelagssystemen, wie sie in Grossbritannien hergestellt werden, durchgeführt, um die Auswirkungen von Schneeablagerungen zu beurteilen. Das Versuchsprogramm wird ausführlich beschrieben. Beliebig verteilte Lasten sind mit gleichmässig verteilten Belastungen verglichen worden. Unterschiede zwischen den Ergebnissen werden festgestellt und ihre Bedeutung in Bezug auf die Konstruktion diskutiert.

1. INTRODUCTION

During the winter of 1981/1982 heavy falls of snow accompanied by strong winds resulted in damage to a number of light-gauge steel roofs within the United Kingdom(U.K). A review of these failures indicated that in many cases the snow load on some parts of the roof, particularly those areas close to parapets, was considerably higher and of a different distribution than is currently specified in the British Standard code of practice for loading[1]. This review also indicated that although the failures were principally due to excessive snow load, the stability of light-gauge steel roofs was questionable under the loading distributions observed.

Consequently the Building Research Establishment(BRE) in collaboration with the Cold Rolled Sections Association(CRSA) started a programme of research to investigate the performance of light-gauge steel roofing systems. Although there are many different systems available the double span sleeve system with any one of the zed, zeta and sigma purlins is commonly used within the U.K. Trapezoidal profiled sheeting and a 10° roof pitch are also commonly used with these systems. The test roofs incorporated all these features.

A general layout of the roofs tested is shown in Figure 1. For each of three roof systems tested the purlins and sheeting were selected using the manufacturer's safe load tables. The size of the purlin and sheeting chosen for each system and their corresponding working and design loads are given in Table 1.

SECTION TYPE	SIZE (D*B*T)	WORKING LOAD(kN/m^2)	DESIGN LOAD(kN/m^2)
SIGMA	140*70*1.6	1.40	2.38
ZETA	125*60*1.6	1.02	1.73
ZED	140*50*1.6	1.16	1.97
SHEETING	A1000[2]	3.28	5.58

TABLE 1 Dimensions and loading for each roof

This paper briefly describes the tests carried out on part of these three typical cold formed steel roofing systems. A more detailed description is contained in reference [3]. The test programme included loading each roof with uniformly and variably distributed loads. The performance of each roof under the different load distributions is compared and recommendations for their design subject to variably distributed loading, proposed.

2. LOADING AND INSTRUMENTATION

Dead weight applied at forty-eight independent points was used to load each roof. With this scheme it is possible to simulate uniformly and variably distributed loads, varying in either the longitudinal or the transverse directions. The load was applied in available combinations of weights(5.5kg, 9.5kg, 19kg and 45.5kg) to each hanger and transferred to the sheeting by a 380*380*25mm thick plywood spreader board.

The translations and rotations of each purlin were measured at mid-span; the former in both parallel and perpendicular directions to the roof slope. Transducers capable of measuring displacements upto 100mm with an accuracy of 0.01mm were used to record the translations. To prevent the transducers being damaged, they were positioned away from the purlin and the movements of the purlin transferred to them via a steel bar rigidly connected to the purlin. Contact between the transducers and steel bar over the full range of displacements was maintained by fitting an aluminium bar bent at right angles to each transducer. Details of this arrangement are shown in Figure 2. Accelerometers, rigidly mounted on the web of each purlin, were used to detect rotation. These instruments can measure angles upto 90deg with an accuracy of 0.01deg. For some tests the movements of the purlin supporting cleats were monitored using dial gauges.

The readings from each transducer and accelerometer were recorded by a data logging system and stored on magnetic tape. The logger was also programmed to display the readings of particular interest so the performance of the roof could be monitored as the test proceeded.

3. TEST PROGRAMME

Traditionally manufacturer's safe load tables are used to select cold formed steel roofing systems and in most cases these are based on either test data or the simplified design rules given in BS 449 Addendum No.1[4]. Both these methods assume the load is uniformly distributed over the roof. In practice, however, snow can build-up behind parapets and in valleys, loading roofs with variably distributed loads. It is therefore pertinent to investigate the performance of traditionally designed systems when subject to these loading conditions. Using BRE Digest 290[5] as a guide the following practical loading distributions were identified:

a) Uniformly distributed load(u.d.l) over the complete structure.

b) Transverse variably distributed load(v.d.l) over the complete structure.

c) Uniformly distributed load(u.d.l) over the end-bay only.

d) Longitudinal variably distributed load(v.d.l) over the end-bay only.

Load case (b) simulates the build-up of snow either behind a parapet at the eaves or in the valley between multi-bay pitched roofs, while (d) simulates the build-up of snow behind a gable end parapet. The uniformly distributed loads (a) and (c) are included as a standard against which the performance of the roof subject to loads (b) and (d) can be compared.

The test programme consisted of working load tests, design load tests, long-term tests and a test to failure. Only the following two phases are discussed here;

the remainder are detailed in reference [3].

phase 1:- working load tests

At this stage it was considered essential to keep the loads within the working load of the roof so that any comparison between distributions would not include the non-linearities resulting from yielding or buckling of the structure.

The four loading cases identified above were applied to each roof and in each case the load was incremented until working load (as defined by the manufacturer's safe load tables) was attained. After each load increment the displacements and rotations of each purlin were recorded.

phase 2:- design load tests

The purpose of these tests was to determine the strength of each roofing system under different loading distributions and identify the most critical loading distribution.

For the zed and zeta systems loading cases (a),(c) and (d) were applied to the roof and in each case the load was incremented until design load was attained.

4. DISCUSSION OF RESULTS

4.1 Working load tests

4.1.1 Comparison of u.d.l with transverse v.d.l.

Figure 3 shows typical load-displacement characteristics for the sigma, zed and zeta roofing systems respectively subject to load cases (a) and (b). Also shown in Figure 3 is the purlin identification nomenclature. The response is seen to vary in an approximately linear fashion upto working load indicating that for both load cases the behaviour of each roof was completely elastic. As expected for each roof the displacements of purlins a-d and i-l for load case (a) are similar while for load case (b) those of purlin a-d are approximately one quarter those of purlin i-l. Furthermore for both load cases the maximum displacements occur in purlin g-h and are of similar magnitude. From this observation it is tentatively suggested that a reasonable estimation of the maximum displacement at working load for a transverse variably distributed load can be obtained by considering the roof to be loaded with an equivalent uniformly distributed load.

4.1.2 Comparison of u.d.l. with longitudinal v.d.l.

Figure 4 shows the load displacement characteristics for the sigma, zed and zeta roofing systems respectively for load cases (c) and (d). Once again all the displacements are seen to vary in a linear manner upto working load; moreover, the magnitude and distribution of these displacements are similar for both load cases. Again this suggests that a reasonable estimate for both the size and distribution of displacement for load case (d) can be obtained be replacing the longitudinal v.d.l. with the same total load distributed uniformly. In making this recommendation, it is appreciated that the transducers were not positioned at the point of maximum displacement for load case (d). However, the difference between the true maximum and the measured maximum is small and will not invalidate this recommendation.

4.2 Design load tests

4.2.1 Comparison of u.d.l with transverse v.d.l.

The load-displacement characteristics from working load to design load (1.7*working load) for each roof are shown in Figure 3. Just after working load has been applied curling of the compression flange at an internal support occurred for both the zed and zeta roof systems. On increasing the load both structures exhibited pseudo-plastic behaviour but continued to carry the load in a stable manner.

4.2.2 Comparison of u.d.l. with longitudinal v.d.l.

Figure 4 shows the load displacement characteristics for each roof up to design load. After working load these displacements continue to demonstrate linear behaviour indicating that the behaviour of each roof is completely elastic up to full design load. Again there is little difference between the displacements for either load case. These observations reinforce the supposition that there is little difference between the performance of each roof subject to load case (c) and (d). Furthermore, under these load conditions no local buckling or distress of any roof was observed. Thus it is concluded that the strength of each roof should be derived from the performance of each roof under either load case (a) or (b). However, load cases (c) and (d) give the largest deflections at working load , so if the deflections at serviceability are important they should be determined using these load cases.

4.3 Comparison with continuous beam theory

Figures 3 and 4 also show the theoretical displacements of the centre purlin These were calculated using continuous beam theory with the following three assumptions:

(a) The load on the centre purlin can be determined from the method described in reference [6].
(b) The sleeved connection are continuous and have the same flexural rigidity as the purlin.
(c) Each purlin bends about an axis parallel to the roof slope.

From the figures it is evident that the theory gives different degrees of accuracy for the different roofing systems; overestimating the displacements of the sigma system, accurately predicting those of the zed system and underestimating those of the zeta system. This probably results from assumption (b). Assuming continuous connections both increases the load and reduces the deflections of the centre purlin, while assuming the sleeve to have the same flexural rigidity as the purlin, results in an overestimation of deflection. Without detailed knowledge of the behaviour of sleeved connections it is difficult to quantify the effect of these assumptions. However, it is speculated that the difference between experiment and theory for the sigma system is due mainly to the underestimation of the connection's flexural rigidity. This view is supported by observing that the sleeve for this system penetrates further into the span than the sleeves for the other systems thus having a more pronounced effect on the displacements at mid-span. The performance of these connections is currently being investigated at the Building Research Establishment.

5. CONCLUSIONS AND RECOMMENDATIONS

Loading tests have been carried out on three full-scale cold-formed steel roofing systems. Each roof was clad with trapezoidal profile sheet and had a 10° pitch. The test programme included the application of both uniformly and variably distributed loads up to working load and design load. The v.d.l's were representative of drifting snow on roofs. The conclusions and recommendations are summarised as follows:

(a) For the determination of the maximum displacement normal to the roof a variably distributed load can be replaced by an equivalent uniformly distributed load.

(b) A longitudinal v.d.l should be used to determine the displacements at serviceability while a transverse v.d.l should be used to determine strength.

(c) The performance of sleeved connections need to be established if a more accurate theoretical model is to be made.

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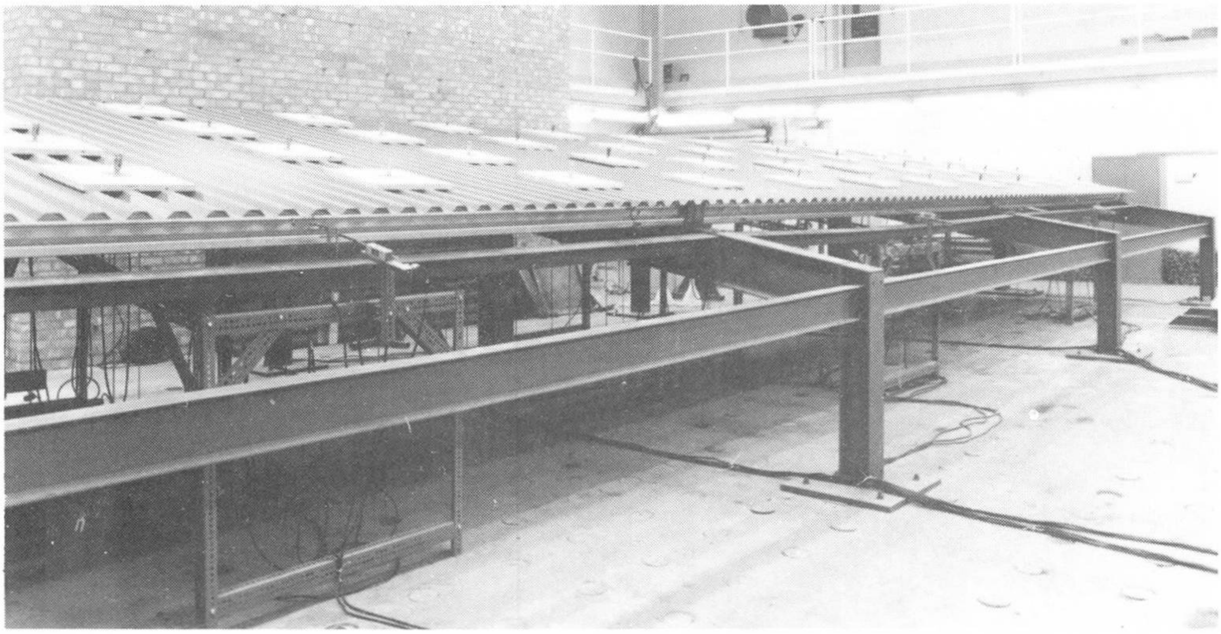

Fig. 1 General view of test roof

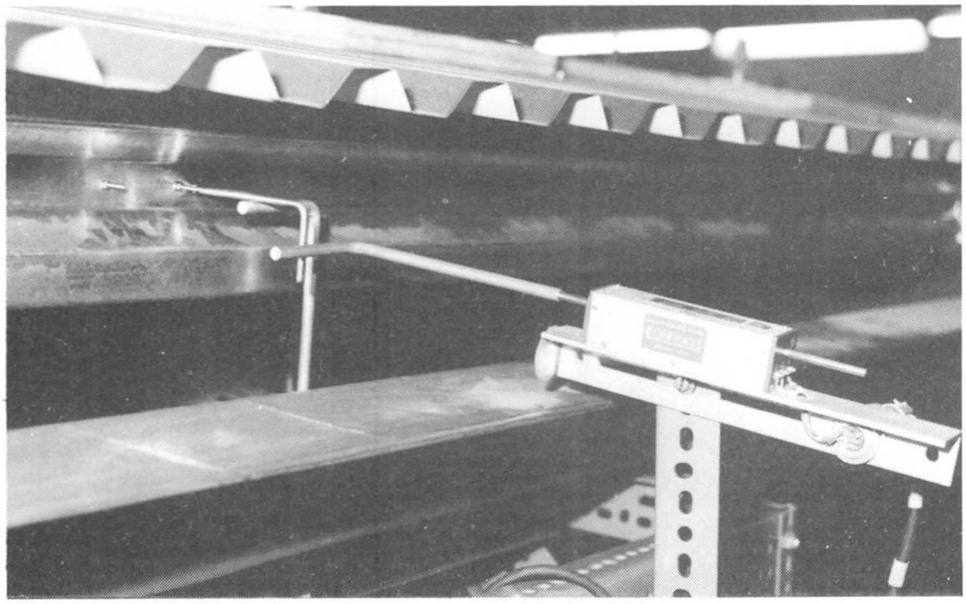

Fig. 2 Measurements of purlin displacements

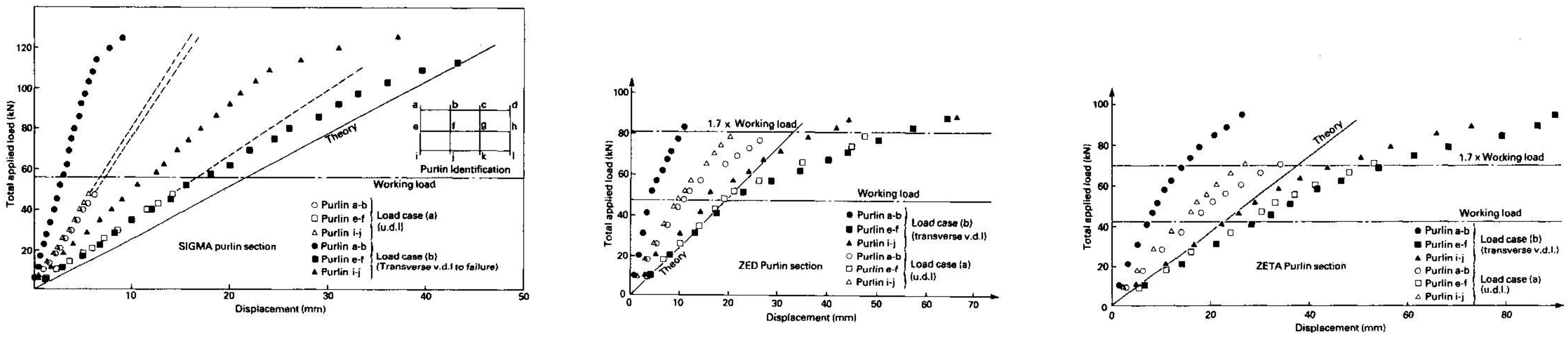

Fig. 3 Load displacements for u.d.l and transverse v.d.l

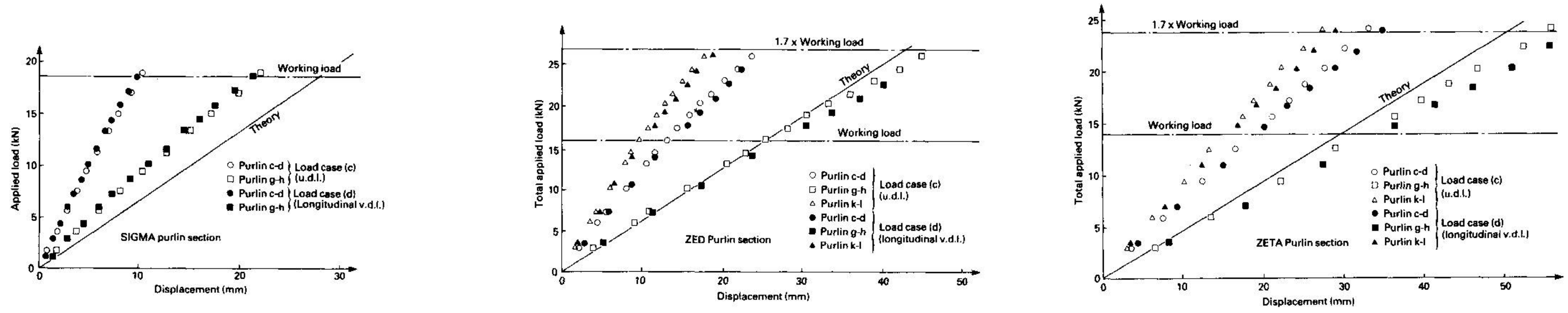

Fig. 4 Load displacements for u.d.l and longitudinal v.d.l