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Autor(en): **Bryan, E.R.**

Objekttyp: **Article**

Zeitschrift: **IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht**

Band (Jahr): **7 (1964)**

PDF erstellt am: **26.09.2024**

Persistenter Link: https://doi.org/10.5169/seals-7843

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The Stiffening Effect of Sheeting in Buildings

L'effet raidisseur de la couverture de tôle des bâtiments

Die aussteifende Wirkung der Dachhaut

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1. Introduction

Little attention has been given to the behaviour of sheeted pitched roof portal frames. PERCY [1] carried out the earliest known tests. GODFREY and BRYAN [2] found that the actual bending moments in a sheeted frame were closer to the moment distribution values allowing no spread of the eaves than to the full theoretical values. They also found evidence of some tee-beam action between the sheeting and rafters.

The present paper is a general survey of further work which has been done at the University of Manchester in conjunction with W. M. EL-DAKHAKHNI. Detailed aspects of the work will be published elsewhere.

2. Tee-Beam Effect

In order to find the moment contribution of the sheeting in a tee-beam, the experimental arrangement shown in Figs. 1a and 1b was set up. The central strains and deflection of the beam were measured as load was applied

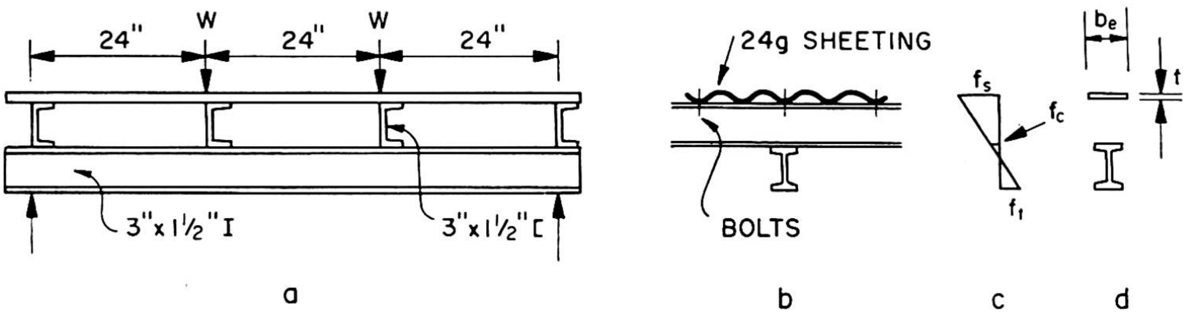

Fig. 1.

to the $^1/_3$rd points of the beam. From the measurements, the force in the sheeting could be deduced. This force may be regarded as the linear elastic stress, f_s (Fig. 1c), acting over the equivalent width of sheeting, b_e, (Fig. 1d) multiplied by the thickness, t. The value of b_e was found to be practically independent of the level of stress and was more dependent on the number of fastening bolts than on the width of sheeting. The maximum value found, $b_e = 1.17$ in., would probably not be exceeded in practice, even though thicker sheeting were used, in view of the close bolt and purlin spacings used in the test. Putting $b_e = 1.17$ in., the percentage moment contribution of the sheeting in conjunction with any rafter section and purlin depth may be easily calculated. Although the contribution of the sheeting in the experimental tee-beam was up to 25%, the contribution is reduced to 3% for a 8 in. deep rafter with 4 in. deep purlins; for bigger beams it is still less.

For practical purposes, therefore, the tee-beam effect of sheeting may be ignored.

3. Membrane Effect

By far the most important stiffening effect of roof sheeting is its resistance to shear. The end gables of a pitched roof shed are extremely stiff in their own planes, so that, when an intermediate frame tends to spread under load, the displacement forces are carried back to the end gables by means of diagonal tension fields in the roof sheeting.

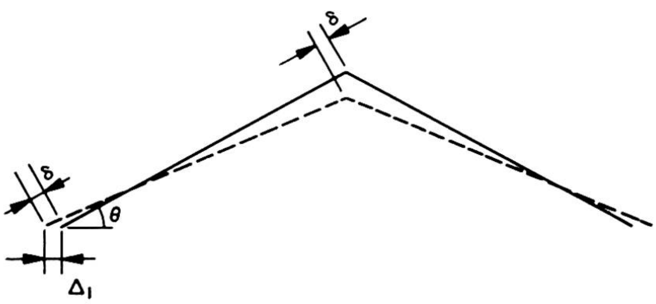

Fig. 2.

From Fig. 2, the shear displacement, δ, in the plane of the sheeting is given by

$$\delta = \Delta_1 \cos\theta, \tag{1}$$

where Δ_1 is the actual eaves displacement and θ is the rafter angle.

Referring to the simple shed shown in Fig. 3a, assume the intermediate frame spreads some amount Δ_1 at each eave under load, and the roof sheet provides some horizontal force P preventing further spread.

Let Δ = theoretical eaves displacement of bare frame,
k = theoretical eaves displacement of bare frame due to two opposite horizontal unit eaves loads.

For the frame,

$$\Delta_1 = \Delta - k\,P. \tag{2}$$

For the sheeting, shear displacement $\delta = c \times$ shear force, where c = shear displacement of panel under unit load.

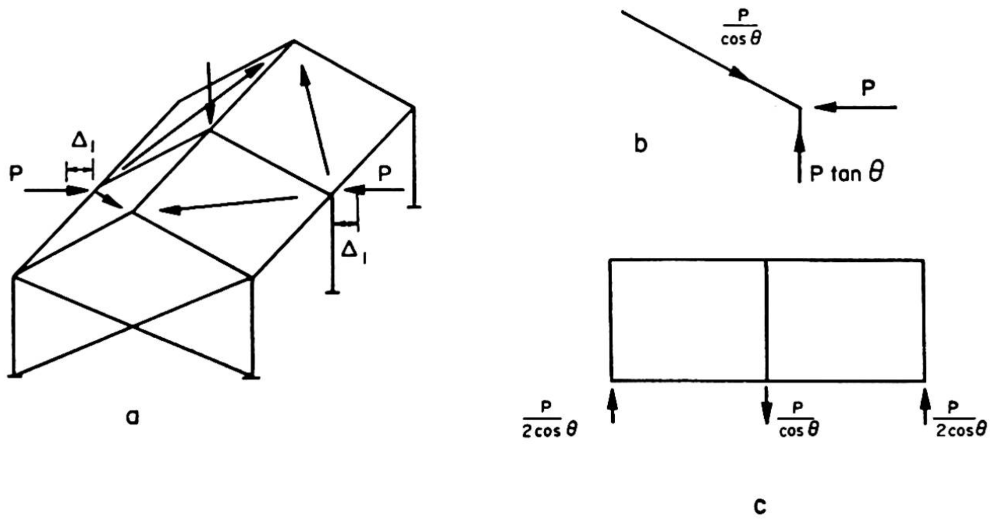

Fig. 3.

From equation (1) and Figs. 3b and 3c, $\Delta_1 \cos\theta = c\dfrac{P}{2\cos\theta}$,

so that, putting $c_1 = \dfrac{c}{\cos^2\theta}$, $$\Delta_1 = c_1 \frac{P}{2}. \qquad (3)$$

Equating equations (2) and (3), $$P = \frac{\Delta}{k + \frac{c_1}{2}}. \qquad (4)$$

Thus, the intermediate frame should be designed for the combined effect of the roof load and the eaves restraining force P.

By similar means, it is possible to find the eaves restraining force at each frame in a long shed for the cases of (1) all frames loaded (e.g. snow load) or (2) one frame loaded (e.g. runway load). It is also possible to treat multi-bay and unsymmetrically loaded frames in the same way, though the working is naturally more tedious.

4. Modified Moment-Distribution

In a bare frame, using moment distribution analysis,

Final moments = Non-spread moments + Spread moments. (5)

The forces preventing spread of the eaves are called the "artifical joint restraints" (A. J. R.), and the spread moments are due to eaves forces, equal and opposite to the A. J. R. In a sheeted frame, the spread moments to be considered are those due to an eaves force equal to the difference between the A. J. R. and the force actually provided by the roof sheeting.

For the shed in Fig. 3a, $$\text{A.J.R.} = \frac{\Delta}{k}. \qquad (6)$$

From equation (4), $$\text{A.J.R.} - P = \frac{\Delta}{k}\,\frac{\frac{1}{2}r}{1+\frac{1}{2}r}, \qquad (7)$$

where $$r = c_1/k \tag{8}$$

i. e. r is the stiffness of the sheeting relative to the stiffness of the frame.

Thus, Final moments =

$$\text{Non-spread moments } + \frac{\frac{1}{2}r}{1+\frac{1}{2}r} \times \text{(Spread moments of bare frame).} \tag{9}$$

For a long shed with similar frames, and all frames loaded, the central frame is the design criterion. The central eaves restraining force may be calculated in terms of Δ/k and r, so that, for the central frame:

$$\text{Final moments} =$$
$$\text{Non-spread moments } + m \text{ (Spread moments of bare frame),} \tag{10}$$

where m may be calculated in terms of r.

A design chart has been drawn up for sheds with different numbers of intermediate frames, n, showing the variation of m at the central frame with n. This has been done for various values of r.

Similarly, taking advantage of the fact that the intermediate frames near the end gables receive more support than those further away, design charts have been drawn up for sheds with different numbers of intermediate frames, showing the variation of m with the position of the intermediate frame. Again, this has been done for various values of r.

When only one frame is loaded, the design charts may still be used, but the value of m obtained must be divided by a factor which is approximately equal to $\frac{1}{2}(n+1)$ provided r is small. The sheeting is specially effective in this case.

5. Shear Stiffness of Sheeting

It should be noted that the stiffening effect of sheeting may only be utilized for loads applied after the sheeting has been fixed. At the moment, the main difficulty in applying the stiffening effect of sheeting to the design of frames, is the determination of c, the shear displacement of a panel under unit load. A great deal of theoretical and experimental work has been done on panels of plain sheeting with flexible edge members, and is proceeding for corrugated sheeting. For the present, it is recommended that practical tests [3] be carried out on a panel of the sheeting to be used, complete with purlins, fasteners, etc., in order to determine c.

6. Experimental Work

All the theoretical work described has been verified experimentally by model tests, tests on a 150 ft. span portal frame shed, and by semi-full scale tests in the laboratory.

Fig. 4 shows the arrangement for the latter tests. The shed was 16 ft. span, 48 ft. long, with frames at 8 ft. spacing. The frames were of 3 in. × 3 in. I section with either pinned or encastre bases; the end gables were tied. The corrugated sheeting was of 26 gauge mild steel fixed with self tapping screws. Load was applied to the apex. The behaviour of the bare frames agreed exactly with theory.

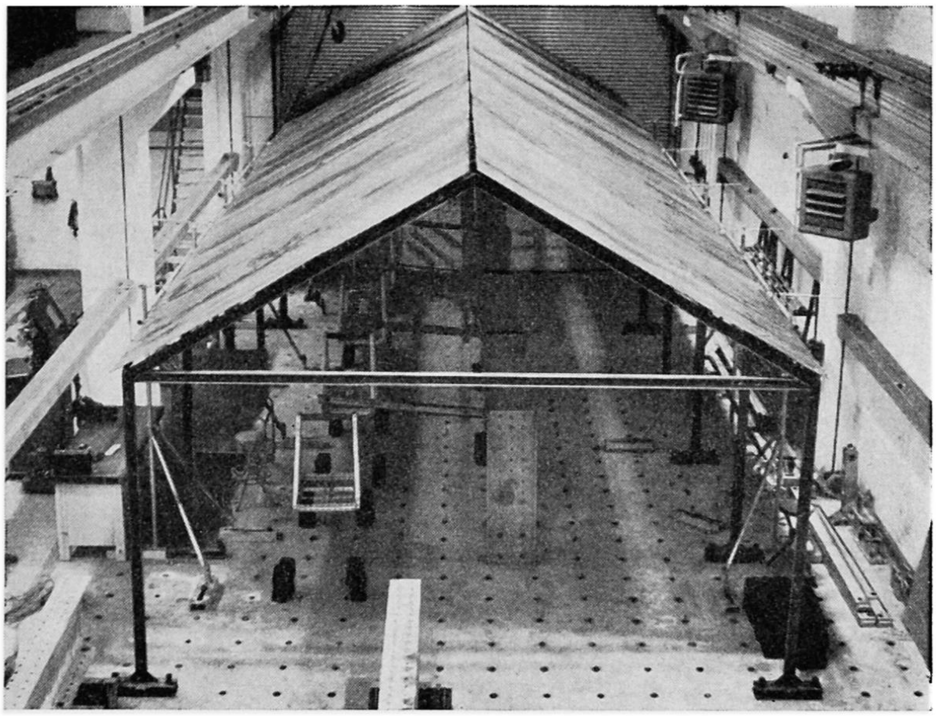

Fig. 4.

In the sheeted shed, when all frames were loaded, the maximum bending moment measured in the central frame was only 70% of the bare frame value for the case of pinned bases, and 80% for the case of encastre bases. These values agreed closely with the bending moments predicted by the proposed theory.

Opportunity was also taken to load the pinned base shed to collapse by means of jacks. The actual collapse load of a bare frame (an end gable with the tie removed) was 2.85 tons and agreed exactly with the value predicted by simple plastic theory. The collapse load on each frame at collapse of the shed was 4.05 tons and agreed exactly with the value given by the proposed theory assuming linear behaviour of the sheeting up to collapse.

The stiffening effect of sheeting is therefore just as important in the plastic range as in the elastic range.

References

1. D. H. LITTLE and A. A. SMITH: "Some Steel Structural Frames Designed on Plastic Theory." (Appendix II by J. H. PERCY). Proc. Instn. Civ. Engrs. Pt. III, Dec. 1955, p. 830.
2. D. A. GODFREY and E. R. BRYAN: "The Calculated and Observed Effects of Dead Loads and Dynamic Crane Loads on the Framework of a Workshops Building." Proc. Instn. Civ. Engrs., June 1959, p. 197.
3. A. H. NILSON: "Shear Diaphragms of Light Gauge Steel." Jour. Am. Soc. Civ. Engrs., Struct. Div., November 1960, p. 111.

Summary

Sheeting in a pitched roof portal shed acts like the web of a deep plate girder, spanning from gable to gable, tending to prevent intermediate frames from spreading. This important effect has been studied theoretically and verified experimentally. Unless it is taken into account, calculated frame stresses are fictitious.

Résumé

La couverture de tôle d'un halle joue le rôle de l'âme d'une poutre très haute allant d'un pignon à l'autre et tendant à empêcher tout déplacement latéral des portiques intermédiaires. On a étudié la théorie de cet important effet puis on a procédé à une vérification expérimentale. Tout calcul des sollicitations d'une charpente est purement imaginaire si l'on ne tient pas compte de ce facteur.

Zusammenfassung

Die Dachhaut einer Hallenkonstruktion wirkt als Steg eines von Giebelwand zu Giebelwand gespannten hohen Trägers und hindert die Portalrahmen am seitlichen Ausweichen. Dieser bedeutende Effekt wird theoretisch untersucht und hernach experimentell bestätigt. Wird er vernachlässigt, so erweisen sich die rechnerischen Spannungen in den Rahmen als unbrauchbar.