

Job creation possibilities by using round-end cut truss webs in the manufacture of timber trusses

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This paper discusses the concept of round-end cut webs for timber trusses. Punched steel gusset plates that are nailed by means of individual nails may be used for site assembly of trusses with round-end webs. Nailed gusset plate connections and full-scale truss test results are presented. Ways of improving the performance of nailed gusset plates are also suggested. The author points out that this method of truss assembly has advantages for the owner-builder and the small rural builder. In developing (Third World) countries, this method is particularly suitable because of its job creation possibilities.



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spent three years working for consulting engineers, returned to the University of Pretoria as a senior lecturer, and was later promoted to Professor of Structural Engineering. Ben van Rensburg and Walter Burdzik started timber engineering research at the University of Pretoria and have expanded the facilities to the extent that it is now one of the few recognised timber-testing facilities in South Africa. Walter has been intimately involved in the committees charged with writing the timber design codes and has undertaken numerous research projects as a result of this work.

INTRODUCTION

Timber roof trusses used in South Africa can be divided into two groups, those manufactured under factory conditions and those manufactured on site. The trusses made in factories are designed in accordance with the South African timber design code, SABS 0163 (1994), for the expected loading in accordance with the South African loading code, SABS 0160 (1992), and assembled under controlled conditions. The truss fabricators are inspected on a regular basis for ongoing quality either by the system supplier, the South African Bureau of Standards (SABS), or by a representative of the Institute for Timber Construction (ITC). A 'system supplier' is a company that supplies the nail plate connectors as well as the software used to analyse the roof structure. Moves are afoot to have every erected roof inspected by a suitably qualified person.

All site-made trusses should either be designed by a competent person or manufactured in accordance with the 'deemed-to-satisfy' clauses of Part L of SABS 0400. However, this is very seldom done, and in many cases they are knocked together by unskilled labourers without any knowledge of the importance of having the correct number and size of bolts and nails at the joints. These trusses have given problems in the past and will continue to do so in the future. Often the roof structure deflects until it rests on internal walls, which effectively shortens the span of the trusses.

PRE-FABRICATED TRUSSES

Pre-fabricated factory-assembled trusses have web members that are cut to the correct angles so that they butt up against one another. This ensures tight-fitting joints that can then be plated by the minimum-sized nail plate (see fig 1). All the truss members are in a single plane, ensuring ease of jointing and member design. Site-manufactured trusses have the web members overlapping each other, causing eccentricity in the joints, which is seldom, if ever, taken into account in the rare instances that a truss is designed. Generally, the moment, which is induced by this eccentricity (see fig 2), is ignored. The web members are trimmed after they have

been nailed or bolted. Often minimum end distances of connecting devices (nails and bolts) are ignored to improve the 'neatness' of the truss.

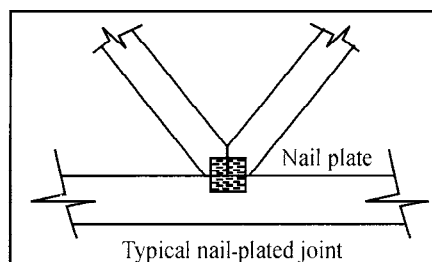


Figure 1 Typical connection detail of nail-plated joint

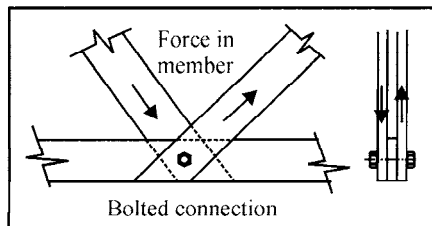


Figure 2 Typical joint in a bolted truss showing eccentricity of the connection

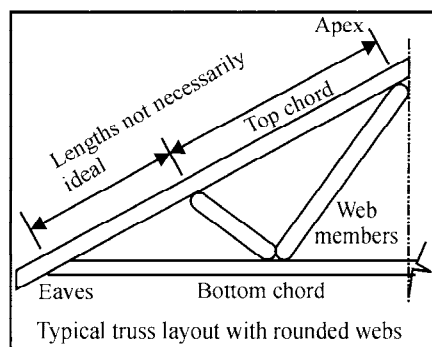


Figure 3 Layout of truss with rounded webs

The ideal solution for a site-made truss would be one that has the same level of safety as a pre-fabricated truss, but that can be assembled easily by semi-skilled labour. Some system suppliers offer a punched-nail plate (generally referred to as a 'grasshopper' plate) that can be nailed using a hammer. This solution is not very satisfactory as the plates are generally much bigger than the factory-installed plates and therefore uneconomical.

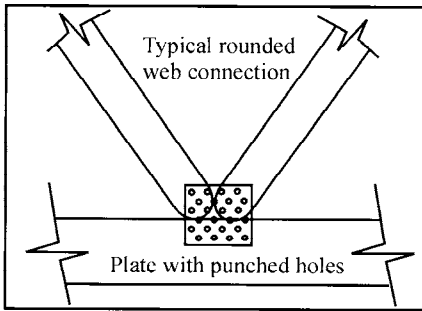


Figure 4 Detail of rounded web connection

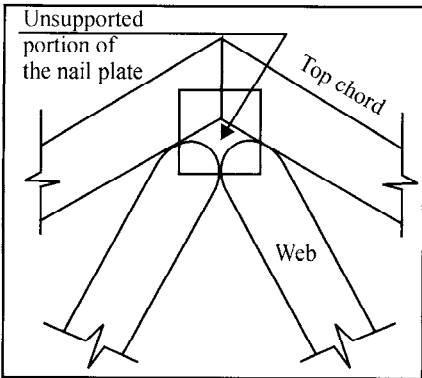


Figure 5 Sketch showing joint where nail plate will have a large portion which is unsupported

Furthermore, the web members must be cut to the correct angles so that proper butting will occur at the joints.

THE ROUNDED WEB SOLUTION

In order to simplify the problem of web members that must be cut to the correct angles, rounded webs were considered. These rounded webs can always be placed so that they butt up against one another and against the top and bottom chord. If one considers that the spans for which site-made trusses will be used are limited, it then makes sense to limit the range of web lengths (stock lengths) for these trusses. With a limited number of web lengths, it is no longer possible to consistently obtain the ideal placement of the webs in a truss (see fig 3). This is not seen as a major problem if one bears in mind that members in trusses generally have some additional load capacity. To connect the members, it was assumed that either punched-nail plates could be used in a factory environment, or that plates with punched holes to receive wire nails could be used for on-site manufacture of the trusses (see fig 4).

Concern was expressed that the rounded webs would not behave as well as the cut-to-fit webs as the contact area between the webs and the chords was greatly reduced and that large portions of the nail plates would be unsupported (see fig 5). There were fears that the unsupported plate could buckle. It was appreciated that the rounded webs may require more nails than the conventional web, but it was expected that the nail plate size would not increase dramatically.

TEST PROGRAMME

The test programme could be divided into two sections, namely the first part where the joints were tested in isolation and a second part where the joints were tested in a full-scale truss setup. The full-scale truss tests were restricted to a span of 6 m because of limited laboratory space and the fact that most low-cost houses have roof spans between 6 m and 6,6 m.

Nailed gusset plates with pre-punched holes

Factory-assembled trusses with proprietary punched-nail plate connectors do not address the needs of the small home-builder. Furthermore, the requirements of underdeveloped countries and communities will be better addressed by providing employment opportunities to small builders who can get involved in their communities by building low-cost houses.

Neither safety nor aesthetics should be sacrificed under any circumstances when providing the roof for low-cost housing. Trusses that can be sold in a kit form and that meet all the requirements of the design codes are a far better option than trusses whose design is left to the imagination of the builder.

The objective of the designer of the Omni-web® system, that is rounded web, was to provide the buyer with a kit that contains all the truss members as well as nails and steel plates. Builders require no electrical tools on the site to assemble an Omni-web® truss. The steel plates were to be of similar size to that of the punched-nail plates, so that the perception would be one of equal strength and cost.

Test programme of nailed gusset plates

Various nail configurations, plate thickness and nail lengths were tested. The plate thickness was limited to a maximum of 1,6 mm, as the cost of thicker material would then become too high. The nails that were used were galvanised wire nails with a flat wide head. These nails are commonly used to fix truss hangers and are called 'clout nails' in South Africa.

It was found that if nail containment between the nails on either side of the member could be achieved, the plate thickness was not that important. The nail containment is shown in figure 6 as opposed to nail clashing, also shown in figure 6. Nail clashing tended to cause the timber to split under loading. Containment of the timber in the region of the plate by the nails, allowed close spacing of the nails.

To avoid interference between the nails the plate holes had to be positioned in such a way that when the second plate was placed, the nails would automatically land up between existing nails, that is, nails from the first side. Staggering of the nails, marking of the outside face of the plate, as well as plate cutting ensured that

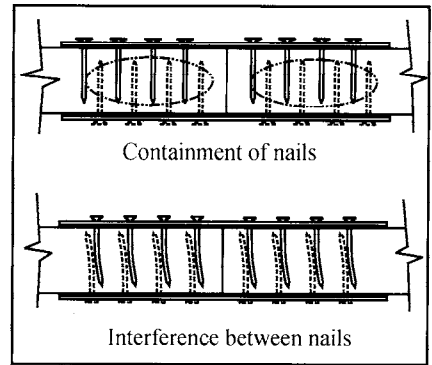


Figure 6 Containment of nails and interference between nails

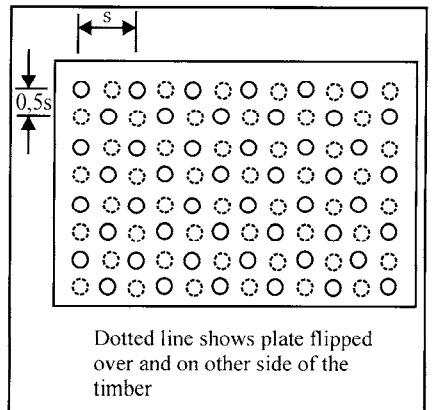


Figure 7 Layout of nail holes to ensure containment and not interference of nails

interference between the nails was avoided. As long as the marked face shows, it does not matter whether the plate is placed upside down or just flipped about the vertical axis. Figure 7 shows how this can be achieved.

Fifteen specimens for loading parallel to the grain and ten specimens for loading perpendicular to the grain were prepared for testing. The specimens had twelve pairs of 32 mm long nails into each piece. The diameter of the nail was 2,75 mm. Only the ultimate load was recorded, as experience had shown that the ultimate load criterion was critical. The criteria normally used in South Africa for determining the allowable load are

- ultimate load divided by three
- fifth percentile of ultimate load divided by 2,22
- load at a slip of 0,76 mm divided by 1,6

For loading parallel to the grain, the ultimate load was 1,783 kN/pair of nails with a fifth percentile of 1,526 kN/pair. For loading perpendicular to the grain, the ultimate load was 1,300 kN/pair with a fifth percentile of 1,118 kN/pair. The allowable force per pair parallel to the grain is equal to 0,594 kN, and perpendicular to the grain, 0,433 kN. The load per pair of nails is in the region of three to four times that of the nails in punched-nail plate connectors (nail plates).

The average number of nails in a 76 x 100 mm nail plate is 96 nails, with one nail occupying an equivalent area of

about 80 mm². If one wants the driven nails to have the same equivalent strength, the area that may be used for driven nails may then not exceed 4 x 80 mm² or 320 mm². It is then possible to calculate the maximum spacing of the nails for the driven nails. The maximum spacing is then equal to 25 mm, using the pattern in figure 6. The minimum spacing can be obtained from relevant design codes such as SABS 0163:1 (1994). To fit in with standard punched-nail plate sizes, the spacing was reduced to 22 mm. This ensured that sufficient nails would always be provided.

Theoretical strength of test nails

The load-carrying capacity of the nails was calculated using the Johansen, 1949, theory. It was assumed that the flat head of the clout nail would prevent rotation of the gusset plate side of the connection. The failure load, or rather the fifth percentile failure load of the nail, was calculated at 0,548 kN/nail. A higher value of 0,722 kN/nail can be obtained if one assumes that the flat head of the nail prevents rotation at the gusset plate side of the connection. The Johansen, 1949, equations do not differentiate between parallel to the grain and vertical to the grain. The fifth percentile value for a pair of nails, that is one nail on either side of the timber, can be taken as 1,1 kN. Compare this value to the test values of 1,118 kN/pair for loading perpendicular to the grain.

Full-scale truss tests

The estimated load on the standard 26° pitch trusses spaced at 800 mm was 0,56 kN/m² for tiles, 0,12 kN/m² for the ceiling and a live load of 0,5 kN/m². Total linear load was assumed to be 0,94 kN/m. Total load = 5,64 kN. Trusses were loaded by means of three interconnected similar-sized jacks that spread the load by means of spreader bars as in figure 8.

The deflections were measured on the bottom chord in the centre of the span and the load was measured on the one side. All the trusses failed at the heel or eaves joint nail plates.

The top and bottom chords had dimensions of 36 x 111 mm and were of a grade 5 SA pine with the bottom chord pre cut to the correct angle. The grade number refers to the allowable bending stress for the timber. (The grade stress is obtained by dividing the fifth percentile ultimate bending stress by a factor of 2,22.) The webs were of 36 x 73 mm grade 5 SA pine. Plates were placed so that the centre of the plate and the centre of the joint coincided. Plate type and positions were as shown in figure 9 and these were nailed in accordance with the values in table 1.

The rate of loading was so that failure could be achieved within two minutes. Deflection was measured on the bottom

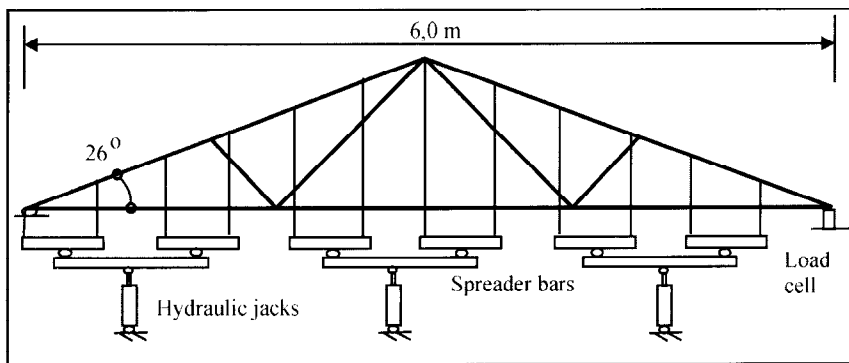
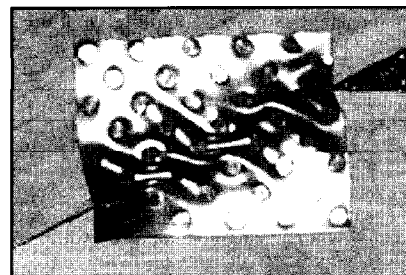


Figure 8 Truss geometry and loading of test specimens

Table 1 Size of plate and number of pairs of nails into each member. A pair of nails refers to one nail from either side of the timber

Plate	Size (mm)	Nail pairs into chord	Nail pairs into web
1	88 x 110	16 (t) 17 (b)	
2	44 x 110	7	7
3	88 x 110	15	6
4	88 x 110	12	4

(t) is the top chord, (b) the bottom chord



Photograph 1 Shear failure at the heel joint

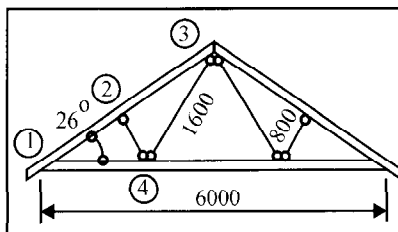


Figure 9 Layout of truss and punched-nail plates

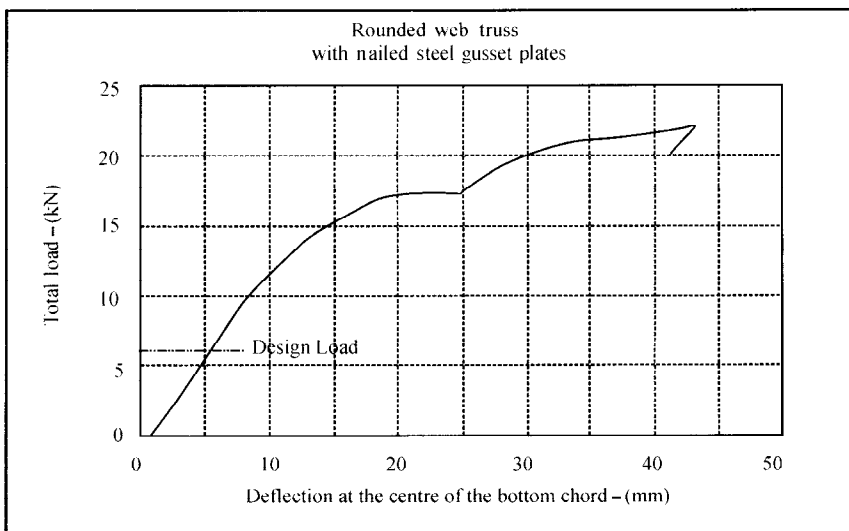


Figure 10 Load deflection curve for truss with rounded webs and nailed steel gusset plates

chord in the middle of the truss. Three trusses were loaded to failure, two having every nail placed, and one having the minimum number of nails. The two trusses that had all the nails failed at a load of 19,58 kN and 23,50 kN respectively. The minimum strength was in excess of 3,47 times the design load. The truss with the

minimum number of nails failed in buckling of the plate at the heel joint at a load lower than the design load. Initial failure in all the trusses was initiated at the heel joint through wrinkling of the plate due to shear (see photograph 1). At this point the nails were still fully embedded in the timber.

The load deflection curve for the truss with the greatest resistance is shown in figure 10. Note that the design load is still in the elastic region of the load-deflection curve and that the maximum deflection under serviceability loading is about span/1 200.

CONCLUSION

It has been the author's experience that the rounded web, Omni-web®, solution works very well for the short span trusses that one would expect in lower-income housing. The punched gusset plates would make it very easy for the owner-builders to construct their own trusses, in the knowledge that they would then have a roof that has been designed and is safe, as long as the plates are fully nailed.

Not only can the owner-builder use the rounded web solution but it could also be beneficial to the small builder in outlying areas of southern Africa. This can help with job creation, as the assembly of the trusses is labour intensive. A moderate level of skill is required, and as the strength of the connections is higher than required, the trusses should be quite forgiving with regard to slight misplacement of the plates.

Acknowledgements

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