P-5: Date first received 1 February 2002; Date accepted for publication 3 May 2002

Low-Cost High-Quality Roof Construction with Round Timber

Edward Lusambo
Department of Agricultural Engineering, School of Engineering, University of Zambia
PO Box 32379, Lusaka, Zambia
edward.lusambo@eng.unza.zm

Abstract

Pole timbers provide an inexpensive source of structural timber in many developing countries and are widely used for traditional buildings. The use of round timber has considerable potential in comparison to the use of sawn timber because of its higher structural strength and its low material cost. There are, however, problems associated with working with non-uniform sections and also with jointing. The traditional methods of jointing using sisal rope or strips of bark in rural areas do not permit the full strength of the poles to be utilised. Improved low cost methods of connecting poles could lead to stronger structures and more economical use of materials. This paper reviews aspects relating to the use of round timber and describes the design and fabrication of some low-cost, yet high-quality structural systems suitable for roof structures of modern buildings.

Keywords: *Round timber, Roof structures, Connections, Jointing methods*

Introduction

In rural parts of many developing countries, poles are the most commonly and most widely used building material for construction of roofs of dwellings and agricultural buildings. Rural populations use round timber primarily because it is readily available within their localities and quite often because it is cheaper than sawn timber. Even in cities and at tourist and pleasure resorts, roundwood, which may be a by-product of forest thinning, can be used for construction of innovative and attractive wooden structures.

Timber for sawing is grown in plantations where the trees are planted in close proximity to each other so that, in their early stages, they grow up in a slim upright manner with little development of lateral branches (Jayanetti, 1990). Thinning is usually carried out when the trees are about 10 m high in order to concentrate on a fewer number of trees per hectare forming the final crop. At this stage the tree is about 150 mm in diameter at its base, tapering to about 70 mm at a height of 7 m. These thinnings or small-diameter poles are not big enough for commercial sawing but can be used efficiently in their round form as low-cost structural material. At present the use of small-diameter round timber for structural construction can be considered to be inefficient and wasteful in relation to its physical properties and its potential as a structural material. Jointing is the main technical problem barring large-scale engineering use of small-diameter poles. Craft methods of jointing such as the use of sisal ropes or bark fibres do not make full use of the strength of the poles. Improved techniques should aim at producing simple and easily understood connections which require only simple tools and moderate skills. Such connections should be able to cope with the natural taper and variation in pole diameter, be applicable to a variety of frame forms and, use ancillary materials which are readily available. This paper reviews aspects relating to the use of round timber and describes the design and fabrication of some low-cost, yet high-quality structural systems using round timber that are suitable for roof structures of modern buildings.

Availability of Round Timber in Zambia

Utilisation of indigenous forests in Zambia is patchily distributed. In the southwest, Zambian teak and mukwa are heavily logged and used for construction, flooring, railway sleepers, mine props, furniture, and some exported. A little quality timber is also produced in the north. The rather limited and scattered useful trees, and archaic production methods forced Zambia to import much timber for construction purposes. During the second world war when imports were disrupted, extensive development of commercial plantations was undertaken to satisfy the demand for fencing poles, telegraph poles, electricity distribution poles and also for structural, general purpose and mine timbers.

A tropical softwood, *Pinus kesiya*, is currently the major commercial timber species in Zambia (Sekeli and Samaraki, 1983). After many trials, the commercial planting of this species started in 1962 near the City of Ndola. By 1982, a cumulative net area planted with Pinus kesiya had amounted to 26,000 hectares with an average annual planting rate of about 1500 hectares. This was about 70 percent of the total industrial plantation estate. Another softwood species currently under commercial production is Pinus oocarpa. However, Pinus kesiya will remain the main commercial timber species in industrial plantations for a long time to come (Sekeli and Samaraki, 1983). Regarding survival, growth rate and seed production, Pinus kesiya has proved its vigour in local conditions (Mikkola, 1982). Another important species grown for commercial timber in Zambia is the Eucalyptus grandis species (Samaraki and Sekeli, 1984). Eucalyptus cloesiana is the second major eucalyptus species after E. grandis. Eucalyptus is a hardwood which is indigenous to Australia but has been widely planted elsewhere, either as ornamentals, or for timber, firewood, charcoal or essential oils. The main silvicultural practices which affect wood properties include choice of planting stock, initial tree spacing or stocking density, thinning, pruning and rotation length (Walker, 1993). Thinning is a major source of poles for construction in Zambia. Tables 1 and 2 show some of the end uses of Zambian grown P. kesiya and E. grandis, respectively.

Table 1: End Uses of Zambian Grown P. Kesiya

Age (years)	Felling regime	End use
11	1st thinning	Fence posts, charcoal, pulpwood
15	2nd thinning	Building construction and furniture timber, pulpwood
19	3rd thinning	General building timbers, joinery, furniture, pulpwood, wood based panels, charcoal, resin products
25	Clear felling	As indicated under 3rd thinning

(From ZAFFICO, 2001)

Table 2:End Uses of Zambian Grown E. Grandis

Age (years)	Felling regime	End use
5	1st thinning	Fence posts, dropper, logging poles, charcoal
8	2nd thinning	Smelter, refinery, telephone, transmission and builing poles, round mine support timbers, sawn timber, purlins, pallets, charcoal, pulpwood
12	Clear felling	Construction timbers, joinery, furniture, pallets, shuttering cladding peeler logs, pulpwood, charcoal, oils

(From ZAFFICO, 2001)

Potential of Round Timber

In rural buildings, wood is often used in its natural form, i.e. as round poles. In areas where enough trees are grown on the farm or in local forests, poles can be obtained at very low cost (Bengtsson and Whittaker, 1986; Herbert, 1985). The use of round timber eliminates the cost and wastage of sawing and the associated energy consumption. Trees are allowed to grow to maturity for many years before they are felled and sawn. Larger trees must be selected for sawing into planned rectangular sections. A sawmill will pay more for a large butt log than for an equal volume of smaller wood, because sawn timber can be cut more economically from large logs and a better grade of timber is obtained (Walker, 1993). On the other hand, round timber may be harvested earlier or as a by-product of the normal maintenance of forests. While it is expected that costs may vary from country to country and also from region to region within a country, some generalisations can still be made on the cost of a round timber structure in comparison to the cost of a sawn timber structure. Paw et al. (1990) indicated that the cost of a first thinning tree is in the region of £5 to £10 per cubic meter of wood when standing and £20/m³ of wood when felled and extracted. On the other hand, when a tree is grown to saw log size, it is worth £40/m³ of wood when standing and £100 to £150/m³ of wood when sawn. Therefore, sawn timber is at least five times the cost of extracted round timber. Spence and Cook (1983) indicated that the cost of stumpage, cartage to the mill, sawing at the mill, 50 percent loss in sawing and cartage to city amounted to 100 Australian Dollars per sawn timber. The equivalent cost for a round timber was only 45 Dollars. Darby (1987) indicated that a sawn timber is approximately 3 times the cost of an unsawn round timber of equivalent strength. Lusambo (1997) found from tests on 6 m span Fink trusses that the cost of timber required for a sawn timber truss was at least 3 times the cost of the timber required for a round timber truss of equivalent strength.

As timber grows, natural defects occur. These defects include cracks, fissures, rind gall and burring. All these defects result in a considerable loss of strength of the timber. Grain defects occur in the form of twisted grain, cross grain or spiral grain, all of which can induce subsequent problems of distortion in use. The strength of poles is less affected by the presence of spiral grain and knots than sawn timber due to the continuity of the grain (Herbert, 1985). The sawing of logs into planks is extravagant since sawing and planning can sacrifice some 40% of the timber and also diminish the inherent strength which the original tree trunk derives from the complex fibrous structure of concentric growth rings. Tables 3 and 4 compare structural strength properties of round and sawn British Scots pine and American ponderosa pine, respectively. The higher strength of round timber is evident.

Table 3: Basic Permissible Stresses for Scots Pine Timber

Type of member	Bending parallel To grain (N/mm²)	Tension parallel to grain (N/mm²)	Compression parallel to grain (N/mm²)
Round Timber, debarked only	15.7	12.6	9.7
Round Timber, machine rounded	13.4	10.7	8.9
Sawn (G.S) to BS 5268	5.3	3.2	6.8

(From Darby, 1987)

Table 4: Design Stresses for Preservative-Treated Round Poles and Sawn Posts of Ponderosa Pine in Wet Condition

Type of member	Bending (N/mm²)	Axial Compression (N/mm²)	Horizontal shear (N/mm²)	Compression perpendicular to grain (N/mm²)
Poles	8.97	4.48	0.62	2.21
Select Structural (SS) Sawn Posts	6.89	5.00	0.45	1.72

(From ASAE, 1997)

Problems Associated with the Use of Round Timber

There are obvious disadvantages, however, in using round timber for building construction. The round, non-uniform tapered section makes it difficult to work with. It can be shown that the circular sections of round timber are not ideal for use in bending since the material near the neutral axis is wasted. Further, the cut ends of poles are susceptible to damage from shrinkage due to drying. Poles also tend to split along their length as they dry due to the larger amount of sapwood relative to heartwood. As poles shrink circumferencially during the drying process, they will show radial shrinkage cracks sooner or later. The stresses induced during the drying period due to differential drying causes splitting along the length of the poles. This fact, however, has been accepted as the maturing of poles and must be considered during jointing because methods of connection using bolts, dowels or nails may increase the size of the splits and substantially weaken the structure (Huybers, 1988).

Developments in Jointing Techniques

(i) *Joints using metal plates*

This technique uses thin sheet metal of up to 1 mm thick, cut to the required size and shape and wrapped around the joints and firmly nailed on to the timber as shown in Figure 1. The technique was developed by JPM Parry Associates' Workshops (Parry and Gordon, 1987). To ensure uniform dimensions, the trusses are made with the help of templates laid on the ground and held in place by wooden or steel pegs. The poles are placed as accurately as possible on the template, then cut to size and joined together. The technique is simple and requires only sheet metal and nails. The most suitable application of this method is in the prefabrication of pole timber trusses. The plates act as gussets that transmit joint loads among the connected members

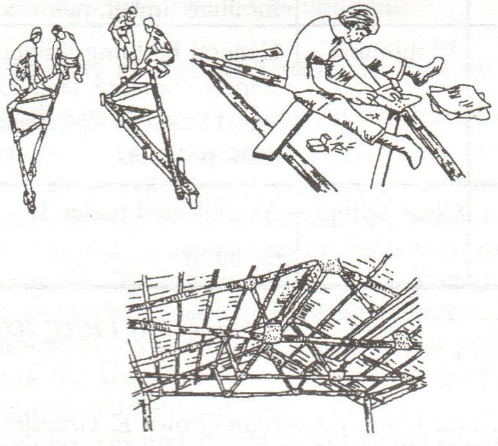


Figure 1: Truss joints using sheet metal plates and nails.

(ii) ***BRE method of connecting poles using a nailed steel flitch plate***

This method was developed by the Building Research Establishment (BRE) in UK (Herbert, 1985). It uses nailed flitch plate (NFP) connections which consist of mild steel sheets inserted into longitudinal saw cuts in the timber poles and connected to them by nails driven through the timber and the steel at right angles to the plates as shown in Figure 2. Trials conducted by the BRE have shown that 3.26 mm diameter round wire steel nails can be driven through mild steel sheets 1 mm thick without pre-drilling. Thicker sheets require drilling or the use of hard steel nails. Exposure trials were conducted in Kenya, using 6.0 m span Fink roof trusses made from locally grown radiata pine. After one year, it was found that the moisture content of the timber had decreased to 12-15% and the joints had opened slightly but there was little splitting at the ends of the poles or at the nail fixings. The trusses were able to carry the design loads without undue stress and all nails seemed to be holding well. Loading tests to failure were also conducted on two types of trusses, the Fink and king-post types, in order to determine their behaviour under load, mode of failure and the order of the ultimate load. The poles were made from timbers with diameters varying from 100mm to 150mm. The ultimate loads were found to be 78.5kN for the king-post truss and 68.7kN for the Fink truss. The failure was gradual and occurred in the flitch plates due to bearing stress. Figure 3 shows the use of nailed flitch plates in portal frames.

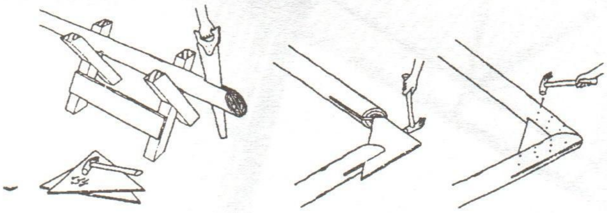


Figure 2: BRE method of connecting poles using a nailed flitch plate.

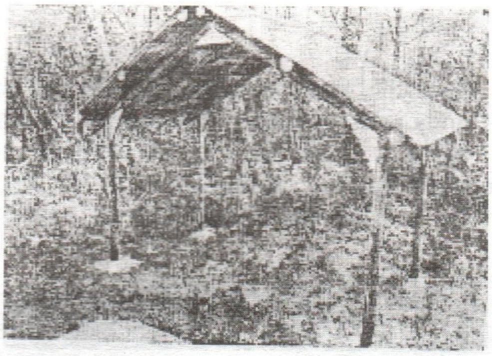


Figure 3: Use of nailed flitch plate BRE method in portal frames.

(iii) *Use of steel plate with wire lacing*

This method, called steel binding, uses steel plates, steel tubular dowels and wire lacing. It was developed at the University of Delft, in The Netherlands (Huybers, 1988). Figure 4 shows a typical end construction for round timber. Special connectors are required to complete a joint as shown in Figure 5. A wire-laced connection is made up of a 6 mm thick steel plate inserted in a clearance slot at the end of the member. Two 16 mm diameter steel tubular dowels are then inserted in pre-drilled holes in the timber and the plates. To hold the dowel in place and to bind the outside of the timber, wire lacings are made through the tubular dowels and around the timber. These lacings are made using a wiring tool that tensions, twists and then cuts the lacing. The ultimate strength of the joint is 64 kN, the characteristic yield strength at 4 mm deflection is 45.5kN, while the design strength, adjusted for safety and long term conditions is 21.4 kN. The design strength is some 35% greater than that of a joint using 16 mm diameter bolts.

A configuration that does not use wire lacings was described by Lukindo et al.(1998a) who tested different configurations of sizes of plates and bolts. This joint is shown in Figure 6. The joint was further strengthened by using ridged plates (Lukindo et al.,1998b).

It has also been concluded that the lacing makes a definite contribution to the strength of the joint. Darby (1987) described a prototype of a double layer square grid space frame roof construction at the Farm Buildings Development Centre (FBDC), Reading, UK which uses steel plates, steel tubular dowels and wire lacing. The inside of the roof at the FBDC is shown in Figure 7.

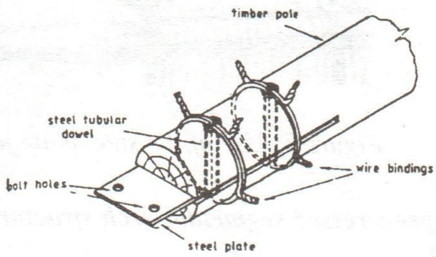


Figure 4: Steel Plate joint with wire lacing

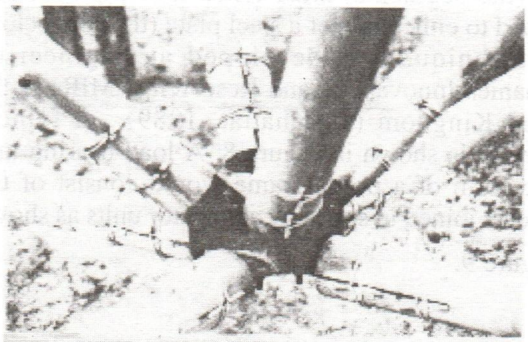


Figure 5: The 8-way space frame connector

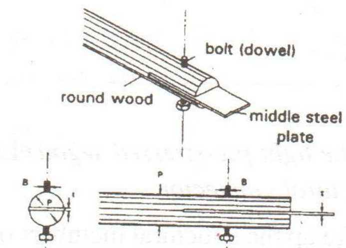


Figure 6: Bolted flitch plate connection

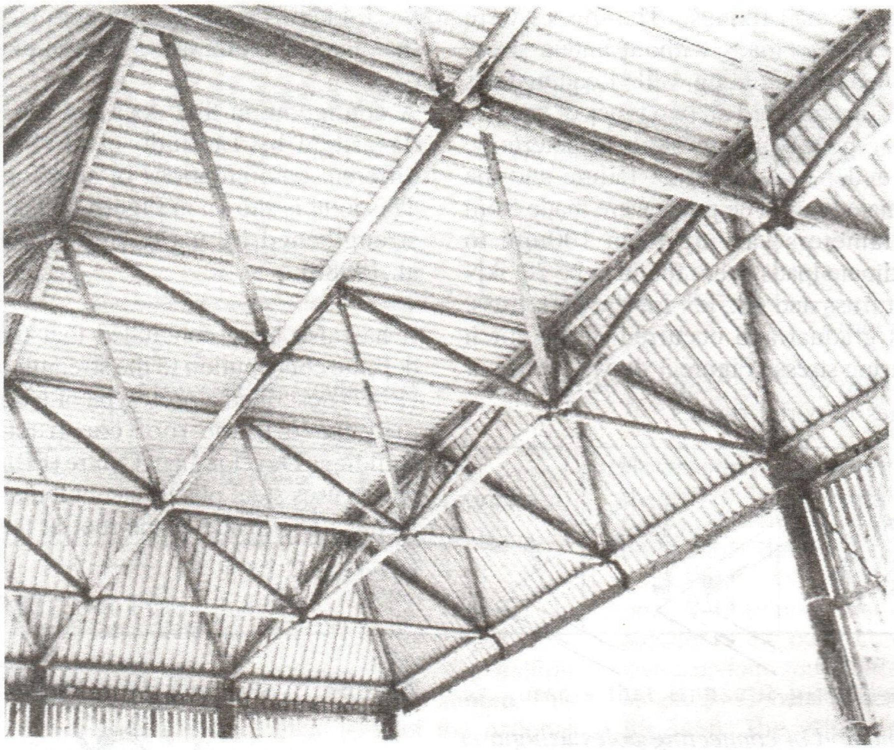


Figure 7: Use of the steel plate joint with wire lacing in a space roof structure

(iv) *Light pre-stressed segmental arch structural system*

The Light Pre-stressed Segmental Arch (LPSA) structural system consists of timber logs with tapered ends (the segments) slide-fitted into pipe sockets attached to either side of a steel plate (the connector). The technique was developed at Engineering Mechanics Innovations and Research (EMIR) in the United Kingdom (Al-Khattat, 1989). A typical connector is shown in Figure 8. A load-bearing unit in the form of a portal frame would consist of the segments joined in series by connector units as shown in Figure 9.

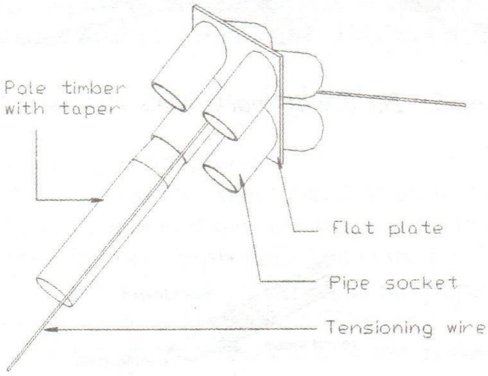


Figure 8: The light pre-stressed segmental arch (LPSA) structural connector

The logs make up the structural members or segments and since a segment can be made up of more than one log – and typically consists of three or four – the connecting plates can have several sockets on each side. Once the whole structure comprising several LPSA units is assembled, wires are passed through each unit and anchored. Tensioning the strand produces balancing compression in the segment members, and the whole load bearing unit is held stiffly together.

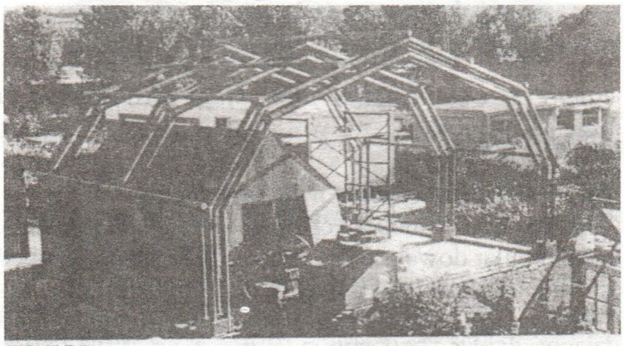


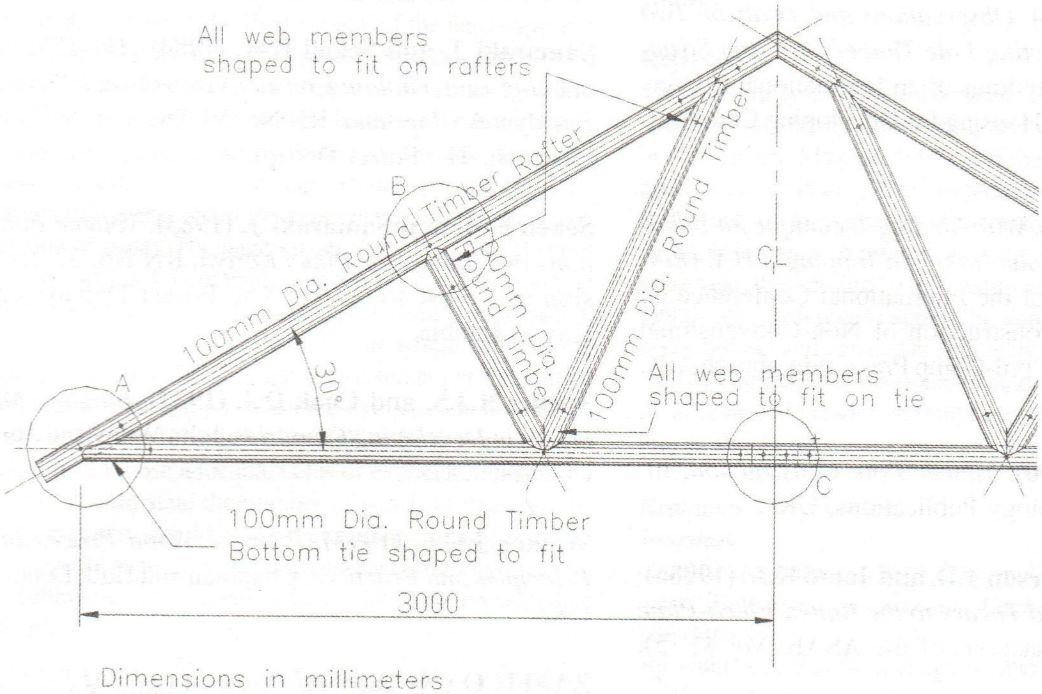
Figure 9: The light pre-stressed segmental arch (LPSA) structural system

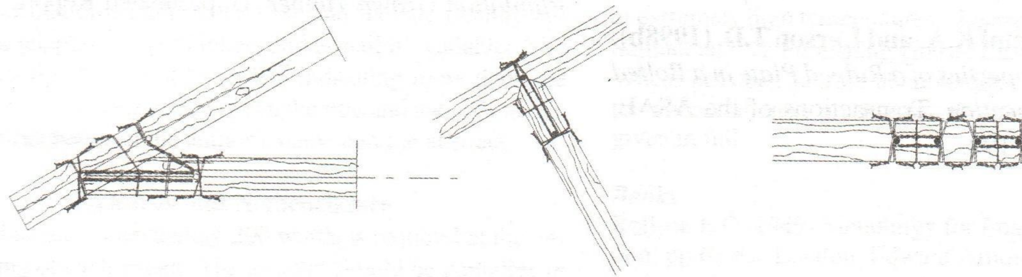
(v) *Tensioned wire binding with steel dowels*

This technique, developed by Lusambo (1997), uses wire lacings wound round the poles and steel dowels. The technique is suitable for fabrication of trusses where members are connected in the same plane. Figure 10 shows the construction of a roof truss. The truss joints are fabricated by first cutting the members to the required lengths and then shaping the ends of members where they butt into others so that they are joined snugly. Shaping is achieved by marking the shape required to be removed, drilling a series of holes along the marking and then chipping off the shape using a chisel. The members are then put together and the position of the 16 mm diameter holes marked off. The holes are drilled and mild steel dowels are inserted in the holes to protrude by about 20 mm on either side of the timber pieces. The dowels provide points of anchorage for the wire. The timber members are clamped in position, above ground, so that they do not move relative to each other during fabrication. Wires are wound around the dowels and the timber in pairs. Twisting the pairs of wires against each other tensions them and helps to hold the timbers firmly at the joints.

Concluding remarks

Timber poles are an indigenous low-cost structural material readily available in Zambia. Traditional jointing methods, however, do not utilise the strength of the poles efficiently and the structures lack durability. It has been shown by several researchers that round timber structures have adequate strength for use in creative and innovative designs of structures. However, as opposed to sawn timber, at present, no guidelines exist in national building codes on the design and construction of round timber structures. This should change because round timber is, in fact, a relatively strong structural material in comparison to sawn timber, and methods of construction using round timber can be simple, cheap, and of high-quality as demonstrated by the jointing methods described in this paper. □





Detail at A

Detail at B

Detail at C

Figure 10: Tensioned wire and steel dowels truss

References

American Society of Agricultural Engineers (ASAE) Standards,(1997) St. Joseph, USA.

Al-Khattat I.M. (1989), *The LPSA: Cheap High Quality Building with Timber Logs, Farm Building and Engineering, Vol. 6 No. 2*, Farm and rural Building Centre, UK. Pp 42-43.

Bengtsson L.P. and Whittaker J.H. (Editors) (1986), *Farm Structures in Tropical Climates – A Textbook for Structural Engineering and Design*, Food and Agricultural Organisation, Rome, Italy.

Darby H.J. (1987), *Building with Home-Grown Round Timber, Farm Building and Engineering, Vol.3 No.3*, Farm and Rural Building Centre, United Kingdom. Pp. 18-21.

Herbert M. (1985), *Observations and Trials on Two Methods of Connecting Pole Timbers to Farm Structure Frames*, Proceedings of an International Conference on Low-Cost Housing for Developing Countries. Pp. 645-654.

Huybers P. (1988), *Wire Binding Technique for building Structures of Roundwood, in Topping B.H.V. (Editor)*, Proceedings of the International Conference on the Design and Construction of Non-Convensional Structures, Vol. I, Civil-Comp Press, Edingburgh, UK. Pp 107 –115.

Jayanetti L. (1990), *Timber Pole Construction*, Intermediate Technology Publications, UK.

Lukindo A.R., Larson T.D. and Janni K.A. (1998a), *Extending the Yield Theory to the Bolted Flitch-Plate Connection*, Transactions of the ASAE, Vol 41 (5). Pp 1483-1488.

Lukindo A.R., Janni K.A. and Larson T.D. (1998b), *Reinforcement Properties of a Ridged Plate in a Bolted Flitch-Plate Connection*, Transactions of the ASAE, Vol 41 (1) pp 187-192.

Lusambo E. (1997), *Use of Round Timber in the Construction of Roof Trusses for Agricultural Buildings*, Ph.D. Thesis, University of Newcastle upon Tyne, Newcastle upon Tyne, UK.

Mikkola L. (1982), *Some Results from the Oldest Pinus Kesiya Provenance and Progeny Trials in Zambia, RN No.31*, Division of Forest Research, The Forest Department, Kitwe, Zambia.

Parry J. and Gordon A. (1987), *Shanty Upgrading: Technical Handbook for Upgrading Squatter and Shanty Settlements*, JMP Parry Associates' Workshops, Cradley Heath, UK.

Paw C., Rattray J.C. and Robertson A.M. (1990), *Building with Roundwood 1*, Farm Building Progress Vol 99. 7-11.

Samaraki J. and Sekeli P.M. (1984), *The Effect of Spacing and Thinning on the Growth and Yield of Eucalyptus Cloesiana*, RN No. 34, Division of Forest Research, The Forest Department, Kitwe, Zambia.

Sekeli P.M. and Samaraki J. (1983), *Volume Functions and Tables for Pinus Kesiya*, RN No. 32, Division of Forest Research, The Forest Department, Kitwe, Zambia.

Spence R.J.S. and Cook D.J. (1983), *Building Materials in Developing Countries*, John Wiley and Sons, Chichester, UK.

Walker J.C.F. (1993), *Primary Wood Processing: Principles and Practices*, Chapman and Hall, London, UK.

ZAFFICO (2001), *Wood Properties of ZAFFICO Plantation Grown Timber*, Unpublished Report