Effective utilization of nailed laminated timber construction in buildings

Dr. S.K. Malhotra, P.Eng.
Associate Professor of Civil Engineering
Nova Scotia Technical College
Halifax, Nova Scotia, Canada
and
Dr. S.J. Mazur, P.Eng.
Professor of Structural Engineering, Emeritus
Nova Scotia Technical College
Halifax, Nova Scotia, Canada

Summary

Various projects dealing with nailed laminated timber construction in buildings are discussed in this paper. The highlights of research and development studies, both analytical and experimental, related to these projects are outlined. The main thrust of these studies is to evolve fabrication techniques and develop scientific design methods so as to utilze small dimension lumber effectively and efficiently for a variety of buildings. Types of nailed laminated timber structures mentioned in the paper are: segmental latticed trusses, rigid frame construction, industrial buildings, garages for construction equipment and built-up beams, columns and beam-columns.

The fabrication procedures for nailed laminated timber construction discussed in the paper require unskilled labour using simple carpenter's tools, thus making this type of construction very well suited to socio-economic conditions of developing countries.

Résumé

De différents projects concernant des constructions en bois de charpente laminé et clové, dans les bâtiments sont examinés dans cet article. Nous trouvons ici présentés les points les plus importants de le recherche et des études de développement sur ces projects conduites sur le plan analytique et experimental. Le but principal de ces études est de perfectionner les techniques de fabrication et de développer des méthodes de dessin scientifique afin d'utiliser de façon appropriée efficace du bois de charpente de petites dimensions pour de differents bâtiments. Les genres de structures en bois laminé et clové mentionnés dans cet article sont les suivants: fermes treillissées et segmentées, constructions en charpentes rigides, hangars à equipment de construction, poutres composées, colonnes composées et colonnes- poutres composées.

Les procédés de fabrication pour la construction en bois de charpente laminé et clové traités dans cet article exigent une main-d'oeuvre non-specialisée, utilisant de simples outils de charpentier, et par conséquent rend ce genre de construction trés convenable aux condition socio-économiquées des pays en voie de développement.

Introduction

Nails in various sizes, forms and shapes have been used for many decades and are continued to be used quite extensively as means of joining members in timber construction. Nails joints have definite advantage over other modes of jointing, as nailed connections, in general, require no or very little preparation of the members at the joints.

In nailed laminated timber construction, large sections and components are built up by fastening small dimension lumber by nails. A classical structure of this type should have either none or at the most very few other fasteners. Laminated construction, in general, offers the following advantages:

1. Structures can be fabricated from small dimension lumber that is too small in cross section to be structurally useful otherwise. This makes a larger percentage of the available lumber useful for significant structural applications.
2. Small dimension lumber can be laminated to form large size structural members to sustain heavy loads. This type of construction can offset the lack of sufficeint quantity or nonavailability of large dimension lumber and can, thus, be of special benefit in areas where timber is available mainly in small cross sections and short lengths.
3. Low-grade material can be placed in locations of relatively low stresses and the better quality can be used at the points of higher stresses, thereby utilizing material more efficiently.
4. It renders more flexibility to shape structures in many and varied forms.

Current codes, specifications and handbooks on timber design [1 to 5] either lack or provide a very limited information and guidance on design of nailed laminated construction, particularly for structures built up with 1-inch thick lumber. In the recent past, some research has been carried out on the fundamental behavior of nailed connections, but very limited work has been done on the applications to nailed laminated timber construction [6 to 10]. In recent years, many research and development studies have been conducted at Nova Scotia Technical College to seek answers to a number of unknowns related to performance of such construction. This paper outlines the highlights of those projects associated with buildings. The main objective of most of the investigations was to develop fabrication techniques and design procedures for a variety of nailed laminated timber structures using 1-inch thick lumber. In addition, vast amounts of information and data were generated on strength of nailed connections and fundamental properties of eastern spruce lumber.

Nailed laminated timber construction

In nailed laminated structures, primarily trusses, two different techniques of construction can be distinguished: one based on the use of 2-inch nominal size stock and the other based on 1-inch nominal size stock. They differ in method of construction and perhaps also in performance efficiency. In the development projects reported in this paper, construction technique using 1-inch thick lumber was applied to trusses. This technique was further developed through research and its applications were extended to various types of structures. An exception should be noted that the investigations on built-up beams, columns and beam-columns included not only 1-inch size lumber, but many other sizes of lumber and different sizes and types of connectors.

General design considerations

1. The fabrication procedure is to nail consecutive layers of laminae layer upon layer with the size of nail increasing from 1-1/2 to 3 inches; then the whole assembly is turned over and nailed with 3-inch nails. Details of a 60 ft. span truss built with this technique are given in Figs. 1 and 2.
2. The experimental studies were carried out with common wire nails of Canadian manufacture. Use of other types of nails require further study and may result in improvement in design.
3. In the present investigations, no scarfing or other method of longitudinal extension was used, only plane butt joints were provided. This requires careful attention to the location of splices and strict compliance with the following rules: (i) In any cross section of a built-up component, only one 1-inch by 4-inch piece may be spliced. (ii) Splicing in adjoining laminae must not be less than 4 ft. apart. This means that no piece of lumber may be shorter than 8 ft. This rule applies absolutely in tension members and tension chords of girders and should be attempted in other types of members. (iii) Splices in any layer should be staggered by at least 2 feet.

Special design considerations

To account in the design for the slip between laminae due to non-rigid connections, following recommendations are made. These recommendations are only tentative and require further confirmation by more testing. In computing effective section properties such as areas of cross section, moments of inertia and second moduli for bending, shear or torsion, reduce the areas of laminae (without changing the location of their centers of gravity) according to their relative positions to the plane of loading, using the coefficients below:

First lam. nearest to plane of loading or web --- 1.0
Second lam. nearest to plane of loading or web -- 0.8
Third lam. nearest to plane of loading or web --- 0.6
Fourth or higher order lamination nearest to plane of loading or web ---------------------------------- 0.4
Horizontal lamination -------------------------- 0.5

For webs of 2 layers at 45° inclination, reduce thickness by 25 percent and for webs of 3 layers, use horizontal thickness reduced by 50 percent. For plywood webs, apply principles of plywood design.

Research and development studies

Analytical and experimental investigations were conducted on a variety of nailed laminated timber structures. Tests were performed on full-size and scaled models of segmental latticed trusses and built-up beams, columns and beam- columns and on scaled models of other structures. All experiments were conducted on structures fabricated with construction grade eastern spruce lumber available in the Maritime Provinces of Canada. The results of investigations were applied to develop design procedures for the structures discussed below. Though the data and other information were developed specifically for structures made of eastern spruce, the design concepts and philosophy can be extended to other species of lumber to suit local conditions and design requirements.

Industrial buildings with segmental latticed roof trusses

Designs were developed for warehouse type buildings of 40, 50 and 60 ft. spans and for industrial buildings of 100 ft. width. Segmental latticed trusses were used for the roof system in the buildings. Figures 1 and 2 give construction details and typical design drawings for the roof trusses of 60 ft. span.

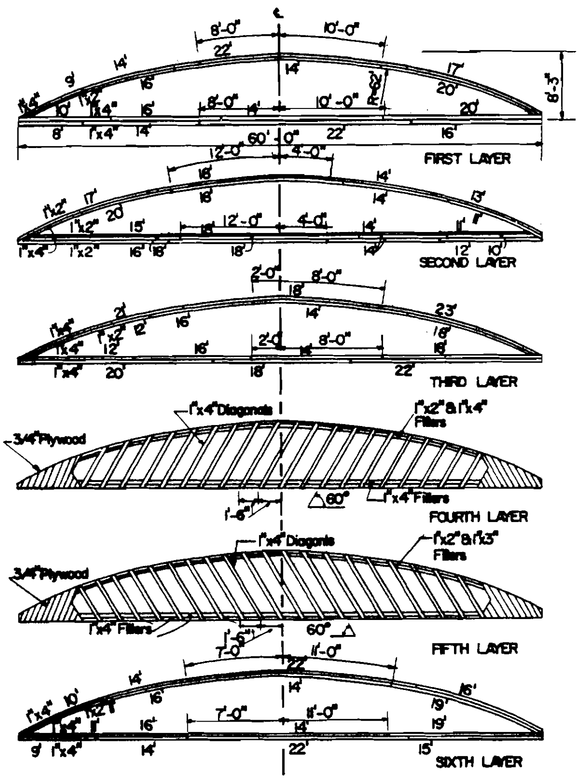

Figure 1. Layout of layers 1 to 6 in segmental latticed roof trusses.

Figure 3 shows a roof system made of segmental latticed trusses, ready for an ultimate load test. The roof system consisted of three trusses of 60 ft. span and 8 ft. rise, spaced 12 ft. center to center. The roof deck is composed of 2-inch by 6-inch purlins placed 16 inches center to center braced by spacer blocks over the trusses and at locations half-way between the trusses. Investigations were also conducted to evaluate economic proportions of the trusses for various spans [11, 12]. For details on development design drawings, consult [13 to 15] and for information on analytical and experimental investigations on segmental latticed trusses, see [16 to 21].

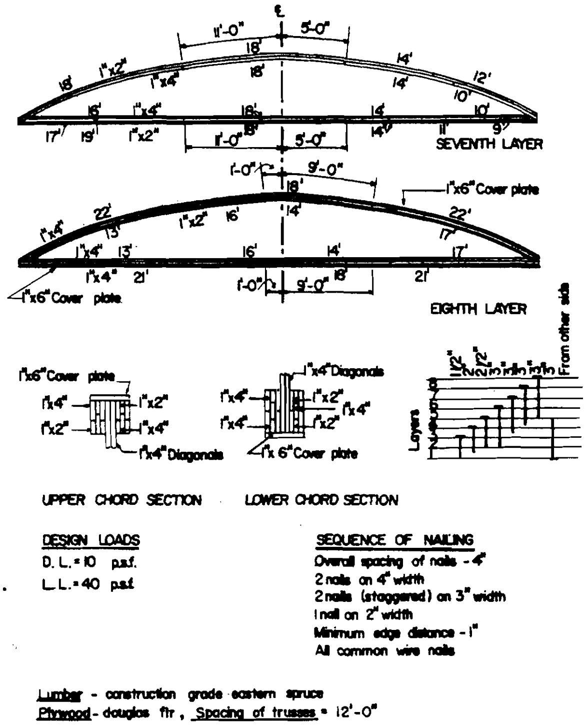

Figure 2. Layout of layers 7 and 8 and other details of segmental latticed roof trusses.

Figure 3. Set-up for test on roof trusses of 60 ft. span.

Designs were also prepared for two-hinged, semi-circular arches with vertically and horizontally arch ribs for spans 20 to 80 feet [22]. These types of arches can be used quite effectively for small span and high rise structures such as farm buildings, green houses and workshops.

Garages for construction equipment, with segmental latticed trusses

Designs were developed for standard type of a garage to house large construction equipment such as buildings, graders and scrapers and to provide a clear maintenance area of 50 ft. width [13, 23]. These designs have been used for actual construction by the Nova Scotia Department of Highways. A display model of this type of garage is shown in Fig. 4. Any length of the building can be obtained by repetition of standard bays of 16, 18 or 20 feet. It ought to be noted that this type of construction is more economical for 4 or more bays.

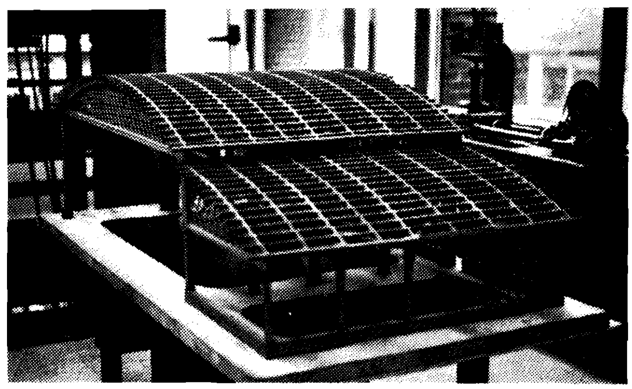

Figure 4. Model of garage for construction equipment

Rigid frame construction

Designs were developed for structures of spans 20 to 150 ft. with possibility of further extensions to 200 ft. or more [24, 25]. Examples are community buildings such as theatres, community centers, schools, gymnasiums and skating rinks.

Built-up beams, columns and beam-columns

Design was produced for tapered nailed laminated built-up I-beams [26]. Theoretical and experimental investigations were also performed on built-up beams [25, 27]. The broad objective of this research was to develop efficient beam layouts and rational procedures for the analysis and design of built-up beams. The investigations on built-up columns and beam-columns were quite extensive [28 to 34]. Theory was developed for predicting the ultimate strength of mechanically connected built-up columns including layered, spaced, braced and box columns. Many series of columns built up with various sizes of lumber and using different sizes and types of connectors (nails, bolts, split rings), were tested to verify the theory. Based on the research, a rational procedure for the design of mechanically connected built-up timber columns has been develoed [30, 32]. A computerized approach to the analysis and design of such columns has also been presented [31].

As an illustration, Fig. 5 is presented here to show a comparison between theoretical and experimental results of the study on box columns. The columns were constructed with 4 pieces of nominal size 1 by 4 inches (corresponding actual size: 3/4 x 3-1/2 inches) and 2-inch nails. The spacing of the nails for the box columns represented on Fig. 5 was such that the column length was divided into 17 equal parts. The strength of box columns is also compared with that of the equivalent solid and layered columns. It can be seen that a box column is much stronger than its equivalent solid as well as layered columns.

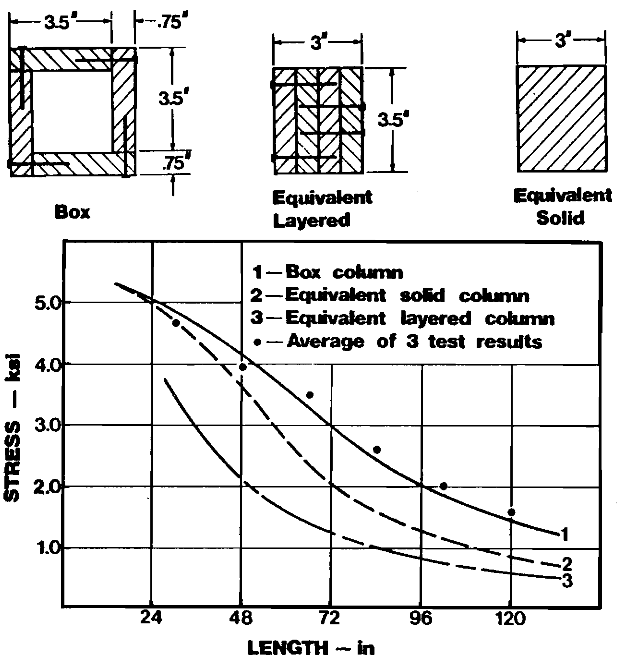

Figure 5. Column stress versus length curves for timber box columns.

Figure 6 shows efficiency curves for different nail spacings in the type of layered column cross section sketched on the figure. Efficiency is defined as the ratio of the strength of a laminated column to the strength of equivalent solid column of same overall dimensions as those of the laminated column. Graphs of the type shown in Fig. 6 can be a useful design aid to designers in selecting an optimum combination of lumber size and connector spacing.

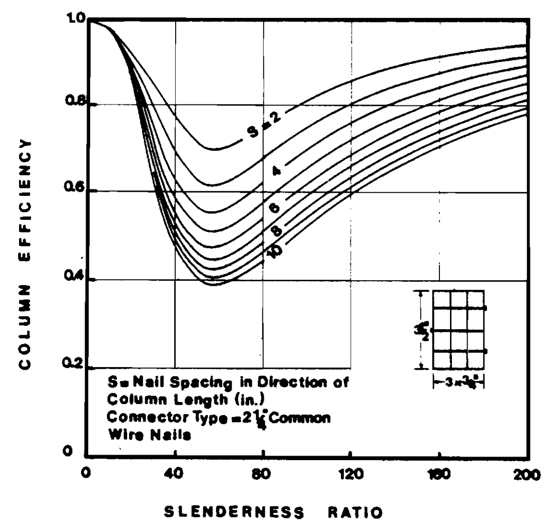

Figure 6. Column efficiency curves for layered columns with various nail spacings.

Special advantages

Nailed laminated structures are quite safe as attested by a survey of such structures built throughout Nova Scotia during the past 50 years [17]. The principal component in the construction is 1-inch by 4-inch lumber which has for many years and is still the cheapest piece of lumber in Nova Scotia, Canada. The inexpensive connectors, common wire nails of local production, are used in the fabrication. The structures are relatively light, resulting in less cost of foundations.

Structures can be erected with unskilled labour using the most rundimentary carpenter's tools. Thus, the nailed laminated construction described in this paper is particularly suitable for community projects, where volunteer unskilled labour can be used. This type of construction is also very well suited to the socio-economic conditions of developing countries.

Conclusions

Nailed laminated timber construction can be used effectively and efficiently in many types of buildings. Special advantages of this type of construction can be quite significant in many local environments and conditions. The potential of wide spectrum of design applications of nailed laminated construction in buildings has been demonstrated in the paper. Based on research and development studies, designs and design procedures for many types of nailed laminated timber structures have been developed. Research is continuing to seek rational approaches for some design aspects that are presently considered on empirical basis.

Acknowledgements

Acknowledge is due to the Maritime Lumber Bureau, National Research Council of Canada and Canada Forestry Service for their financial support of many projects mentioned in the paper. The authors express their thanks to all individuals associated with various aspects of the projects for their assistance.

References

Note: References marked with* are published by Nova Scotia Technical College (NSTC), Halifax, Nova Scotia, Canada, and those marked with+ are published by Department of Civil Engineering at NSTC.

1. American Institute of Timber Consturction. Timber construction manual. John Wiley and Sons, Inc., New York, 1974.

2. Canadian Standards Association (CSA). Code for the engineering design in wood: CSA Standard 086-1976. CSA, Rexdale, Ontario, 1976.
3. Laminated Institute of Timber Construction (LITC). Timber design manual. LITC, Ottawa, 1974.
4. National Forest Products Association (NFPA). National design specification for wood construction. NFPA, Washington, D.C., 1977.
5. U.S. Forest Products Laboratory. Wood handbook: wood as an engineering material, U.S. Department of Agriculture Handbook No. 72. U.S. Govt. Printing Press, Washington, D.C., 1974.
6. Goodman, J.R. and Popov, E.P. Layered wood systems with interlayer slip. Wood Science, Vol. 1, No. 3, 1969.
7. Mazur, S.J. and Malhotra, S.K. Studies in nailed laminated timber structures. Engineering Journal, Vol. 56, No. 4, 1973.
8. Niskanen, E. Investigation of the buckling of compressed columns assembled by nailing. Publication 63, The State University of Technical Research, Helsinki, Finland, 1961.
9. Rassam, H.Y. and Goodman, J.R. Buckling behavior of layered wood columns. Wood Science, Vol. 2, No. 4, 1970.
10. Rodda, E.D. Analysis of nailed indeterminate structures. Forest Products Journal, Vol. 17, No. 6, 1967.
+11. McGraw, A.J., Mazur, S.J. and Choi, M. Economic proportions of roof structures with segmental latticed trusses. Essays on Timber and Timber structures, No. 11, 1965.
*12. Wysocki, J. Economic properties of roof structures with nailed laminated, segmental, latticed timber trusses. M.Eng. thesis, 1967.
+13. Timber Research - NSTC. Segmental latticed trusses 40, 50, 60, 80 and 100 ft. spans. Development Design Drawings, File No. 1, 1965.
+14. Timber Research - NSTC. Warehouse type buildings of 40, 50, and 60 ft. spans. Development Design Drawings, File No. 2, 1965.
+15. Timber Research - NSTC. Industrial buildings of 100 ft. span. Development Design Drawings, File No. 8, 1967.
*16. Arora, S.S. Model analysis of a nailed laminated lattice truss. M.Eng. thesis, 1969.
+17. Choi, M. and Mazur, S.J. A historical and structural study of buildings with nail-laminated timber segmental latticed trusses in Nova Scotia. Essays on Timber and Timber Structures, Nos. 10 and 13, 1965.
*18. Gilkie, R.C. A study of segmental latticed timber trusses with application to highway bridge design M.Eng. thesis, 1964.
+19. Mazur, S.J. and Gilkie, R.C. Interim report on the ultimate load test of segmental latticed. Essays on Timber and Timber Structures, No. 3, 1963.
+20. Mazur, S.J. Tentative specifications for working stresses in nail-laminated timber structures. Essays on Timber and Timber Structures, No. 8, 1965.
+21. McGraw, A.J., Mazur, S.J. and Choi, M. Design of nail-laminated segmental latticed timber trusses. Essays on Timber and Timber Structures, No. 12, 1965.
+22. Choi, M. and Mazur, S.J. Design of nail-laminated two-hinged semi-circular timber arches. Essays on Timber and Timber Structures, No. 15, 1965.
+23. Timber Researach - NSTC. Garage for department of highways, construction equipment - 16, 18 and 20 ft. bays. Development Design Drawings, File No. 4 and 5, 1965.
+24. Timber Research - NSTC. Rigid frame structures and a feasibility study of ice rink. Development Design Drawings, File No. 3, 1965.
25. Ghaboussi, J. Bending of nail-laminated beams of I-section. Transactions, Engineering Institute of Canada. Published in Engineering Journal, Vol. 13, No. A-8, 1970.
+26. Timber Research - NSTC. Built-up wood I-beams for the offices of Maritime Lumber Bureau. Development Design Drawings, File No. 6, 1967.
*27. Liu,C.B. An investigation of nailed laminated built-up timber beams. M.Eng. thesis, 1965.
*28. Kwan, S.P.S. A study of the strength of nailed laminated timber columns. M.Eng. thesis, 1972.
29. Malhotra, S.K. and Van Dyer, D.B. Buckling strength and efficiency of built-up timber columns. Annual meeting of Engineering Institute of Canada Halifax, Nova Scotia, 1976.
30. Malhotra, S.K. and Van Dyer, D.B. Rational approach to the design of built-up timber columns. Wood Science, Vol. 9, No. 4, 1977.
31. Malhotra, S.K. and Van Dyer, D.B. A computerized approach to the analysis and design of machanically connected timber columns. Proceedings of International Conference on Computer Applications in Developing Countries, Bangkok, Thailand, 1977.
32. Malhotra, S.K. and Van Dyer, D.B. Analysis and design of spaced timber columns. Proceedings of Annual Congress of Canadian Society for Civil Engineering, Montreal, 1979.
33. Malhotra. S.K. and Van Dyer, D.B. Buckling strength and efficiency of timber box columns. 16th-Midwestern Mechanics Conf., Manhattan, KS., 1979.
*34. Seenappa, V. Strength of nailed laminated timber beam-columns. M.Eng. thesis, 1980.