In: Sugiyama, Hideo, ed. Proceedings of the 1990 international timber engineering conference; 1990 October 23–25; Tokyo. Tokyo: Steering Committee of the International Timber Engineering Conference: 1990: 460–463. Vol. 2.

WOOD I-JOISTS: A LOOK AT RESEARCH AND PRODUCTION IN NORTH AMERICA

R. H. Falk, Research Engineer
USDA Forest Service
Forest Products Laboratory[1]
Madison, Wisconsin USA

R. J. Leichti, Assistant Professor
Department of Forest Products
Oregon State University
Corvallis, OR

D. J. Sharp, Systems Performance Engineer
Truss Joist Corporation
Boise, ID

Abstract

Wood I–joists, limited to special applications for many years and mass produced only since the late 1960s, have become a important component of light-frame floor and roof systems. This is evidenced by the tremendous growth in both the number of I-joist producers and production volume. Research to characterize the performance of these products has grown as well. A uniform standard for the design of wood I–joists has recently been developed, and the Wood I–Joist Manufacturers Association (WIJMA) has been formed to represent this industry. This paper will overview some important research performed on wood I–joists, examine the growth of the industry, and discuss the development of standards and the role of the WIJMA.

Introduction

The generally accepted definition of a wood I–joist is a composite structural member that is manufactured from sawn or structural composite lumber flanges and structural panel webs, which are bonded together with exterior-type adhesives to form the cross-sectional shape of an "I" (1). I–joists are efficient structural components manufactured for use primarily in floor joist and roof rafter applications. Materials for flanges and webs are selected for their specific strengths, material attributes, and functions. These criteria are chosen such that the flanges and webs will work as a single unit with properties designed to meet the performance criteria of specific end–uses. Typical construction configurations in North America include flanges manufactured from visually graded lumber, machine stress rated lumber (MSR), laminated veneer lumber (LVL), or parallel strand lumber. Webs are manufactured from plywood or oriented strandboard (OSB). I–joists with hardboard webs are not typically used in North America, though their use in Europe is common (16).

The use of I–joists and other structural wood products is expected to become more prevalent as the timber resource in North America changes. Available log size is decreasing and, as a result, the large solid-sawn lumber needed for light-frame and commercial construction systems is becoming increasingly difficult to obtain.

The purpose of this paper is to provide an overview of some pertinent research on wood I–joists, to briefly review the distribution and growth of the I-joist industry in North America, and to describe recent standards and industry association activities.

Research Activities

Early development of the wood I–joist was spurred by military needs of the aircraft industry. Studies conducted by the Forest Products Laboratory of the USDA Forest Service looked into basic I-joist properties and feasibility aspects. In the 1950s and 1960s, studies by European scientists were published, and composite I–joists had become prevalent in European building systems (16). It was not until the 1970s, however, that research papers addressing engineering behavior and the use of I–joists in North American building structures appeared (12). By then, the mass production of I–joists had begun. Today, research focuses on the performance of the I–joist under changing environmental conditions.

The mechanics of I–joists are well understood, and the variables that affect strength and stiffness under static loads have received extensive study by manufacturers (15). Ongoing research addresses a set of more advanced topics such as the effects of web openings, long-term load performance under cyclic moisture conditions, and probabilistic design methods.

One advantage of wood I-joists is that openings can be cut in the webs for the passage of utilities such as heating ducts and plumbing. Manufacturers provide clear, definite guidelines in their product catalogs for the shape, size, and location of openings in the web. Placement of openings and restrictions on removing web material differ somewhat for round and rectangular openings because the effects of a round opening are less pronounced than that of a rectangular opening of the same area (14). Minimum distances from the supports and flange edges are also specified. Allowable opening size typically increases toward the midspan because large web openings at the supports can lead to beam failure resulting from excessive shear forces. Fergus (4) found that the performance of moment-critical beams was not adversely affected when up to 70 percent of the web was removed as a circular opening. However, when the beams were shear critical, web buckling was evident (depending on web material type).

The effect of load duration on the flexural strength of I–joists has received some research attention. Results of static bending tests of plywood and hardboard web beams after up to 5 years of loading suggest little or no strength loss compared to the strength of similar beams tested under short-term loading (17,22). Another study (10) indicated that a load duration effect

[1] The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin. This article was written and prepared by U.S. Government employees on official time, and it is therefore in the public domain and not subject to copyright.

can be detected in wood I-joists. though the effect is not significant enough to warrent an adjustment factor specific for the design of I–joists.

Because extensive loading equipment and facilities under environmental control are required for creep-recovery tests, few research studies have focused on the creep of composite I–joists typical of North American construction. Leichti and Tang (8,10) found that qualitative comparisons of the time-displacement response for conventionally constructed I–joists and solid lumber were not significantly different. The time-dependent response of hardboard webbed I–joists, however. has been found to be significantly affected by repeatedly changing the relative humidity (19). The sequence of the hygrothermal cycle also plays a major role in the creep of both I–joists and solid-sawn lumber. Chen (2) showed that specimens subjected to humid–dry–humid cycles had more severe creep characteristics that those subjected to dry–humid–drycycles. The creep performance of wood I–joists is also affected by the properties of the web. McNatt and Superfesky (17) and Chen et al. (3) indicated that shear modulus and shear strength were important factors affecting creep performance.

Because I–joists are manufactured from materials with known properties and are sized to maximize the efficiency of the individual elements used in their construction. one would expect increased reliability in I-joist performance when compared to that of conventional wood joists. Some theoretical work has examined this attribute. Sharp and Gromala (30) used reliability analysis as a tool to develop application consistency for I–joists. Interacting as a system, the I–joists had multiple failure modes with separate probability distributions. Leichti and Tang (11) performed a second-moment reliability analysis of wood I–joists assuming creep deflection was the limit state. They found that statistical means of the creep model variables controlled the length of reliable lifetime whereas the variability increased or decreased reliability at any given time. With the current move in the United States toward the development of a probabilistic design format for mood products, I–joists will have some market advantage.

Though the knowledge of engineering design for fire is growing, current procedures may require more evolution to provide efficient design practices. However, structural engineering design for fire is becoming accepted in Europe and will likely become standard practice in the United States (5). The ability to model the performance of gravity loaded building systems under fire has gained greater sophistication and accuracy. A subcommittee of the National Fire Protection Association (NFPA) is actively involved with fire modeling in wood structures. The question of lightweight structural systems in fire has been the topic of several papers in recent years. such as the study by Mittendorf (18). The wood I–joist has been included in NFPA discussions.

Fire-rated systems are available for wood I–joists (6,21). The information for these systems is developed through testing programs supervised by a certifying agency such as the International Council of Building and Code Officials (ICBO). The Uniform Building Code (6) lists a 1-hour floor-ceiling, assembly that can be used generically for any manufacturer's product. The fire-rated system consists of two layers of 5/8-in. (l6-mm) Type–X or Type–C gypsum board directly attached to the lower flanges of the I–joists (21).

Until recently, only research on prismatic I–joists had been reported in the literature. New manufacturing methods have made the production of nonprismatic I–joists possible, and research to support a design method for these members is being developed. Leichti (7) utilized the finite-element method to analyze single-tapered joists. He found that the maximum bending stresses occur in the horizontal bottom flange, with magnitude a function of the taper. Although the design of prismatic I–joists ignores the shear stress in the flanges, the shear capacity of the web, flange-web joint. and the flange should be considered in tapered I–joist design.

I- Joist Industry

The wood I-joist industry was recently surveyed to determine in a generic sense manufacturing locations, geographic distribution of products. production volumes, and product performance and marketability (13). Although the survey was not designed to be statistically precise (that is, a tool to identify specific corporations or market nuances), it did provide a qualitative view of the industry. Ten North American manufacturers were questioned about production volume and capacity, product lines and materials. design and end-use considerations. product evaluation and code approvals, warranties and services. market barriers. and research needs. The companies questioned manufactured more than 95 percent of the total volume of I–joists produced in North America.

The I-joist industry is rapidly expanding. Between 1980 and 1957, total I-joist production more than doubled from about 50 million lineal feet (15.2 x 10^6 m) (all depths considered) to about 120 million lineal feet (36.6 x 10^6 m). This figure was estimated to triple by 1989 to over 150 million lineal feet (45.7 x 10^6 m) (estimate based on information provided by manufacturers in 1988; actual values not available). Leichti et al. (13) recently cited nine I-joist manufacturers. Today, 12 companies are manufacturing I–joists at various locations in North America (Fig. 1).

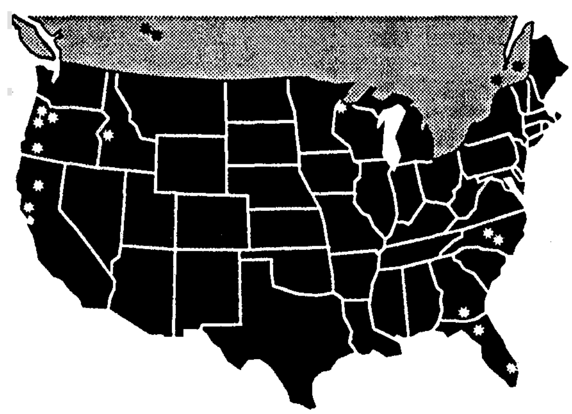

Fig. 1. Location of primary wood I-joist production sites of 12 manufacturers in North America. 1990.

According to 1986 sales figures, the last complete year of information available at the time of the initial survey, the bulk of U.S consumption of I–joists was in the northeast and midatlantic states, consuming about 40 percent of production; about 30 percent was destined for the west coast, and the balance was used in the midwest and south. Less than 2 percent of production was exported from North America.

Standards for Wood I–Joists

Prior to the early 1970s, the only available North American standard for the manufacture of wood I–joists was that of the American Plywood Association, which was intended to apply to field-built members. During the same decade, the prefabricated mass-produced wood I–joist appeared, and proprietary standards were developed.

By 1980. a number of producers had entered the market. The producers were characterized by the combinations used to manufacture I–joists. Each of these producers approached building code groups in the United States for acceptance reports under "Alternate Material and Methods of Construction" provisions of the codes. Similar reports were produced in Canada by the Canadian Mortgage and Housing Corporation. These code group evaluations were hampered by a lack of applicable reference standards. This resulted in a diversity of approaches to the establishment of design values and the requirements of quality assurance progams.

In 1981, I-joist producers met and agreed that some form of uniform standard was necessary if problems were to be avoided in this rapidly expanding industry. An ad hoc committee of producers, code officials, and general interest wood industry representatives was formed to work on a standard. By the end of 1985, the standard, considered generally complete in important features. had been developed and submitted to code bodies as a suggested interim basis for evaluating wood I–joists. The ad hoc committee then decided that a consensus standard was desired and requested that the American Society for Testing and Materials (ASTM) Committee D7 on Wood promulgate such a standard. The ASTM standard is now complete and is being published as ASTM D5055 "Specification for Establishing and Monitoring Structural Capacities of Prefabricated Wood I–Joists" (1).

The ASTM standard is as performance based as was found practical. That is. it is the intent of the standard that each producer have design values consistent with the statistics of the structural properties of their products. This standard covers the establishment of shear and bending design capacities. Shear capacity determination is strictly empirical, requiring a consideration of the several modes of shear failure, whereas moment capacity can be derived either analytically based upon flange material properties or emprically from the results of full-scale bending tests. The standard contains provision for initial qualification of new products: when structural tests are required to qualify shear and bending capacity. the same tests are required as part of the plant quality assurance program. Regular inspections by an independent agency are required. The quality control data generated are used to reevaluate structural capacities on a periodic basis.

I-Joist Manufacturers Association Activities

As an offshoot of the activities to develop standards, manufacturers representing most North American I-joist production agreed to form an association. The Wood I-Joist Manufacturers Association (WIJMA) was incorporated in 1989. The activities of this association are limited to technical issues of general interest to all producers. Associate members include representatives of related industries, code groups. and independent inspection agencies, as well as representatives with general interest. A number of cooperative activities are ongoing or have been completed by members of this association. A few examples follow.

1. A local code group had concerns about the durability of I–joists with OSB webs when the joists were exposed to expected job site weathering. A testing protocol was developed with the code official and other interested parties. Three WIJMA members provided joists for the test.

2. Technical bulletins are being developed that address frequently misunderstood details of I-joist production such as the need for and proper installation of web stiffeners. For example. a document in work describes requirements and procedures for I–joists that may differ from that used for solid timbers. This work is part of the North American Load and Resistance Factor Design (LRFD) project for wood design, which is discussed in other sessions of this conference.

3. A series of fire tests that explores automatic sprinkler requirements for exposed I-joist systems has been conducted. These tests are addressing the concern of fire officials and sprinkler experts chat deep joists may require a sprinkler head in the space between each joist to prevent heat buildup and ignition of the joists prior to the operation of the sprinkler heads below the joist. Tests show that such ignition can occur, but depending on sprinkler density and fire intensity. the joist fire is extinguished when the sprinkler heads operate. Reports are now being studied by interested groups and further investigations may be underway.

At present, WIJMA continues to operate on a relatively informal basis, meeting when and where convenient. No staff is employed or contemplated. The association raises funds for cooperative investigations through voluntary contributions from interested members. Such an association can obviously provide a valuable contribution to both the producers and users of wood I–joists.

Concluding Remarks

Wood I–joists are structural components that have been studied in short- and long-term applications. Research and experience have yielded I-joist designs that are efficient in material use and perform well. The I-joist industry is continuing to grow in the number of manufacturers and in the volume of production. The standard promulgated through the ASTM process for establishing and monitoring I-joist capacities gives all I-joist producers a code-accepted tool for development and quality control. An association of manufacturers has been formed to address special issues with a common effort, a move that is expected to benefit the manufacturers as well as teh general public.

References

1. American Society for Testing and Materials, "Standard Specification for Establishing and Assuring Design Capacity for Prefabricated Wood I-Joists," ASTM-D5055, American Society for Testing and Materials, Philadelphia, Pa., (in press).
2. Chen, G.-H. "Effect of Environmental Conditions on the Mechanical Behavior of Wood Composite I-Beams," Ph.D. dissertation, Auburn University, Ala., 1988, 216 pp.
3. Chen, G.-H., Tang, R. C., and Price, E. W., "Creep of Wood Composite I-Beams and Southern Pine Lumber Under Changing Humidity," Proceedings of the International Conference on Timber Engineering, Vol. 1, Forest Products Research Society, Madison, Wis., 1988, pp. 624-628.
4. Fergus, D. A., "Effect of Web Voids and Stiffeners on the Structural Performance of Composite I-Beams," Ph.D. dissertation, Purdue University, West Lafayette, Ind., 1979, 255 pp.
5. Fitzgerald, R. W., and Barnett, J. R., "Cracking the Fire Code," Civil Engineering, Vol. 69, No. 5, 1989, pp. 60-62.
6. International Conference of Building Officials, "Uniform Building Code," International Conference of Building Officials, Whittier, Calif., 1988.
7. Leichti, R. J., "Straight Single-Tapered Composite I-Beams of Orthotropic Materials—A Finite Element Appraisal," M.S. thesis, Auburn University, Ala., 1990, 145 pp.
8. Leichti, R. J., and Tang, R. C., "Creep Analysis of Wood Composite I-Beams," Proceedings of Southeastern Conference on Theoretical and Applied Mechanics, Vol. 2, University of South Carolina, Columbia, S.C., 1986.
9. Leichti, R. J., and Tang, R. C., "The Effect of Creep on the Reliability of Sawn Lumber and Wood Composite I-Beams," Mathematical and Computer Modelling, Vol. 12, No. 2, 1989, pp. 153-161.
10. Leichti, R. J., and Tang, R. C., "Comparative Performance of Long-Term Loaded Wood Composite I-Beams and Sawn Lumber," Wood and Fiber Science, Vol. 2, No. 2, 1989, pp. 142-154.
11. Leichti, R. J., and Tang, R. C., "Predicting the Load Capacity of Wood Composite I-Beams Using the Tensor Polynomial Strength Theory," Wood Science and Technology, Vol. 23, 1989, pp. 102-121.
12. Leichti, R. J., Falk, R. H., and Laufenberg, T. L., "Prefabricated Wood I-Beams: A Literature Review," Wood and Fiber Science, Vol. 22, No. 1, 1990, pp. 62-79.
13. Leichti, R. J., Falk, R. H., and Laufenberg, T. L., "Prefabricated Wood I-Joists: An Industry Overview," Forest Products Journal, Vol. 40, No. 3, 1990, pp. 15-20.
14. Maley, J. D., "Wood I-Joists: A Closer Look," Proceedings of Structures Congress '87, American Society of Civil Engineers, New York, 1987.
15. Maley, J. D., "Special Design Considerations for Wood I-Joists," Wood Design Focus, Vol. 1, No. 1, 1990, pp. 12-15.
16. McNatt, J. D., "Hardboard Webbed Beams: Research and Application," Forest Products Journal, Vol. 30, No. 10, 1980, pp. 57-64.
17. McNatt, J. D., and Superfesky,M. J., "Long-Term Load Performance of Hardboard I-Beams," USDA Forest Service Research Paper FPL 441, Forest Products Laboratory, Madison, Wis., 1983, 10 pp.
18. Mittendorf, J., "Joist-Rafter Versus Lightweight Wood Truss," Fire Engineering, Vol. 141, No. 7, 1988, pp. 41-47.
19. Mohler, K., "Observations on Fatigue Tests with Nail Joints and Trusses with Hardboard Webs," Holz Roh-Werkst., Vol. 19, No. 3, 1961, pp. 118-121.
20. Sharp, D. J., and Gromala, D. S., "'Systems' Behavior of Single Composite Structural Members," Proceedings, 1988 International Conference on Timber Engineering, Seattle, Wash., Vol. 1, (in press), pp. 635-643.
21. Soderquist, D. C., "Efficient I-Joist Design," Wood Design Focus, Vol. 1, No. 1, 1990, pp. 9-11.
22. Superfesky, M. J. and Ramaker, T. J., "Hardboard-Webbed I-Beams: Effects of Long-Term Loading and Loading Environment," USDA Forest Service Research Paper FPL 306, Forest Products Laboratory, Madison, Wis., 1978, 12 pp.

Printed on recycled paper