

Prefabricated wood I-joists: an industry overview

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Abstract

Wood I-beams, limited to special applications for many years and mass produced only since the late 1960s, have become a preeminent component of light-frame floor and roof systems and are commonly termed "I-joists" as a result of that usage. Currently, nine manufacturers produce more than 95 percent of the total wood I-joist volume in North America. These manufacturers were surveyed in 1987 and again in 1989 on a wide range of topics, including production volume and capacity, products manufactured, materials used, design and use considerations, quality control, code approvals, market barriers, and research needs. The survey results are reported in this paper. In general, facilities are fully utilized and additional growth in the industry is expected in the form of increased capacity at existing facilities and new production locations. Manufacturer catalogs and evaluation reports are the primary sources of information for design, typical installation details, and performance characteristics. Manufacturers indicated few market-acceptance problems. The most crucial research areas identified were connections, fire safety, shear capacity, web openings, and dynamic and long-term system performance.

Wood I-beams are highly efficient, lightweight structural components, available in a variety of designs (Fig. 1). They are well suited for long-span joist and rafter applications, thus the term "I-joists." Used in highly repetitive engineered systems, they can be an attractive economical alternative to traditional solid-sawn lumber.

The engineering community has recognized the uniform stiffness, strength, and light weight of these prefabricated structural products. Yet even though wood I-joists have been site-fabricated or manufactured in limited production settings successfully since the 1920s they were not mass produced until the late 1960s. Since then, the I-joist industry has evolved into a significant supplier for

both nonresidential and residential construction markets. However, little is published about the North American I-joist industry in terms of manufacturing locations, geographic distribution of production, production volumes, and product performance and marketability.

This article presents the results of a survey that was primarily intended to provide an overview of the industry. Research needs also are identified.

Survey methods

The survey was not intended as a statistically precise instrument, nor was its limited scope meant to define specific corporations or market nuances. Instead, we sought a qualitative view of the emerging wood I-joist industry.

Late in 1987 and again in early 1989, ten North American manufacturers were each mailed a questionnaire addressing 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. Pricing information and market strategies were not requested. The returned surveys contain responses from the companies that manufacture more than 95 percent of the total volume produced in North America.

Production overview

The rising cost and limited availability of large, high quality framing lumber and the suitability of I-joists as deep, insulatable structural elements in roof systems

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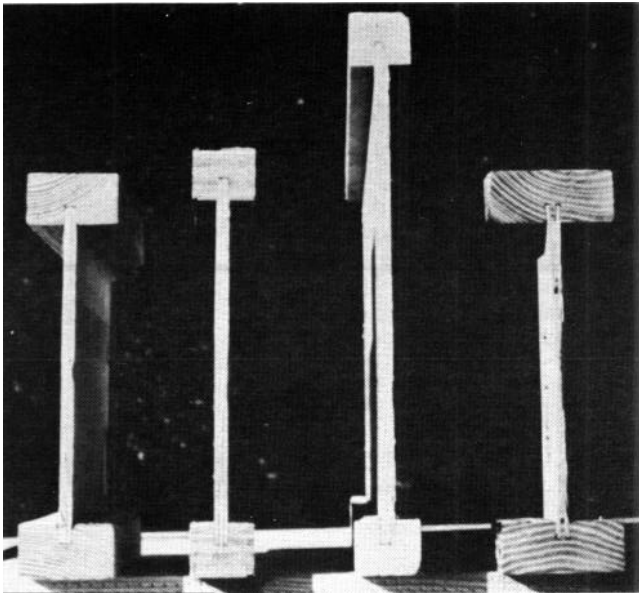


Figure 1. — Cross sections of variously configured wood I-joists.

helped advance the recent transition of the specialty engineered wood I-beam into a mass-produced, lightweight structural I-joist and rafter member. This transition consolidated the industry, precipitating a loss of production by several smaller firms that were not competitive (7). We estimate that nine companies entered and left the market in North America. This survey pertains only to those still in the market at the time of our survey.

Modern mass production of wood I-joists was initiated in 1969 by the Trus Joist Corporation. During the late 1970s, two other manufacturers entered the marketplace, in the 1980s, six more. The most recent entry, located in eastern Canada, was in 1988 (5). At the time of this writing, these nine manufacturers are producing more than 150 million lineal feet¹ of I-joists, and four new corporate entries are anticipated in 1989. The primary I-joist production sites of the nine operational manufacturers in North America are shown in Figure 2a (support sites where cut-up and shipping operations are located are not shown).

In the 7-year period 1980 to 1987, total I-joist production more than doubled and may triple by the end of 1989 (Fig. 3) (1988 and 1989 production figures were estimated by manufacturers). In addition, significant expansion plans, in the form of increased production capacities rather than additional manufacturing locations, are known for two U.S. manufacturers.

For 1987, production capacity nearly matched production volume for most manufacturers. One respondent was operating at only 70 percent of capacity, and one had capacity that exceeded material availability. The other seven were operating at between 90 and 120 percent of capacity.

According to 1986 sales figures, the last complete year of information available at the time of the initial survey,

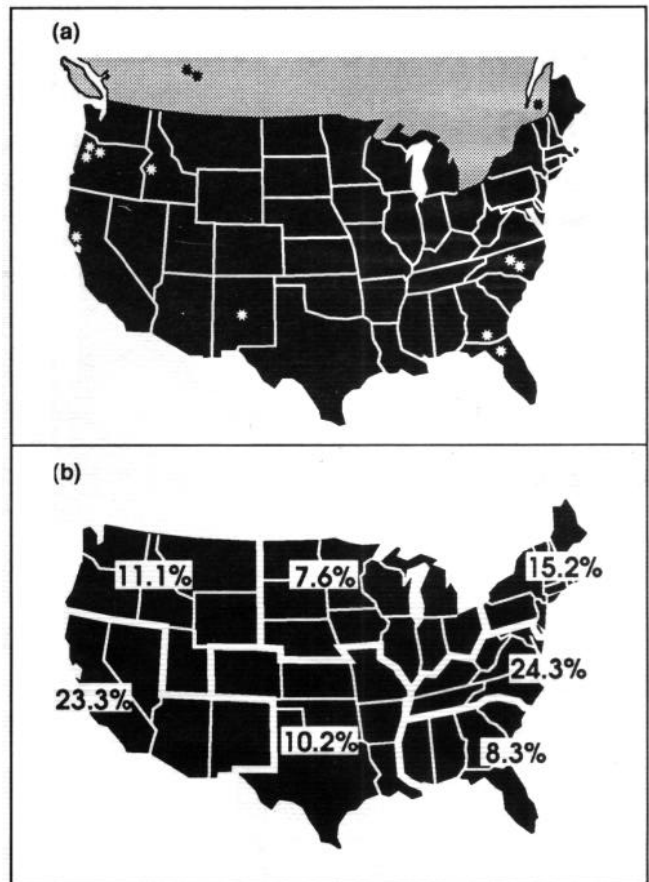


Figure 2. — (a) Location of primary wood I-joist production sites of nine manufacturers in North America, 1988; and (b) regional distribution of I-joist consumption in the United States, 1986.

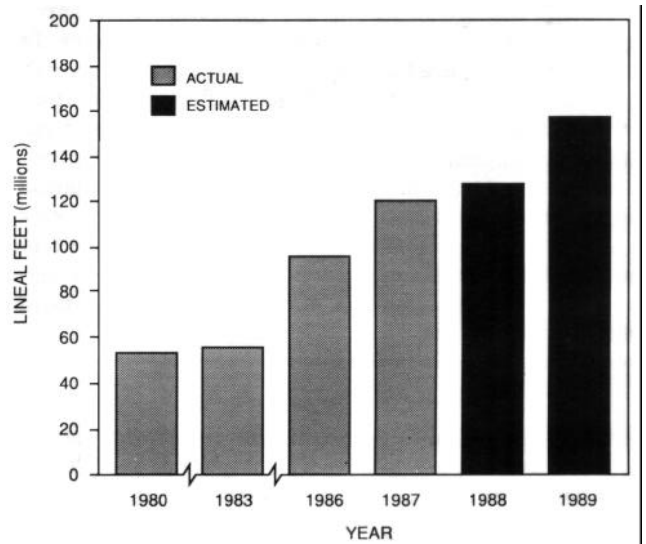


Figure 3. — Production volume of wood I-joists during the 1980s in North America.

the bulk of U.S. consumption is in the northeast and mid-Atlantic states, constituting almost 40 percent of the U.S. total (Fig. 2b). Survey responses suggest that most production (80%) is destined for residential structures. Indeed, three manufacturers service residential markets exclu-

¹ Throughout this article, lineal footage is used as the measure of product volume without regard to I-joist depth.

sively. However, one other still specializes in the engineered "noncommodity" I-beam product. On the basis of total volume, not lineal footage, the disparity between residential and nonresidential production is somewhat reduced because of the deeper, heavier I-joists specified for the longer spans and large loads in commercial and industrial applications.

At present (1989), wood I-joists exported from North America represent less than 2 percent of total production.

Overview of product base

The depth of the commercial wood I-joist is controlled by application. Available depths range from 6 to 30 inches, with most ranging from 9 to 18 inches. Lengths range to 80 feet and weight ranges from 2 to 12 pounds per lineal foot. Most I-joist manufacturers produce members with parallel flanges; however, several manufacturers offer single tapered-straight I-joists, which provide positive roof drainage while maintaining a flat bottom flange.

Flanges

Typically, flanges are made from machine stress-rated (MSR) lumber or composite structural lumber, such as laminated veneer lumber (LVL). Users of MSR usually resaw the lumber to match the flange size needed and then visually and/or machine regrade the lumber before manufacture. Manufacturers report significant rejection rates for visually graded lumber due to the high standards required for the small cross-section flanges. Increasingly, manufacturers prefer composite structural lumber, especially for deeper and longer members, because the material properties of composite lumber products, especially tensile strength, are less variable, and long lengths that do not require end-jointing are readily available.

We found that five manufacturers used MSR exclusively, two used LVL exclusively, and two used both material types for flange stock. The volume of production (based on lineal footage) with LVL flanges is over 70 percent.

Webs

I-joist webs are usually constructed of plywood (CDX, Structural 1 grades) or oriented strandboard (OSB). In North America, the use of hardboard for webs is almost nonexistent; however, it is common in Europe (17), especially for wall sections. Web thickness varies from nominal 3/8 to 7/8 inch, which is controlled in part by product depth. Web panels are typically oriented with the face ply or strand direction perpendicular to the span because this orientation makes the best use of the panel's directional attributes for web compressive strength, rolling shear strength (for plywood), and web stability. However, there is a patented product line, expected to be commercially manufactured in 1989, whose web panel has the face grain or strands oriented parallel to the span.

Web panels are edge-glued by several methods, including butting of square panel edges, scarfing of edges, and shaping a tongue-and-groove type joint. Use of wider, longer OSB panels is gaining acceptance to lower the number of shear-reducing edge-to-edge joints in the web. Efforts have also been made to specify special grades or reinspection of plywood for use as web components to assure that core gaps and splits do not seriously degrade shear strength.

Flange-web joints

A critical part of I-joist integrity – the joint between the flange and the web – is typically the source of patentability of the I-joist and subsequent development of the product line. Many different concepts have been introduced (17) to ensure good shear performance, ease fabrication and gluing, improve the ability to transmit concentrated loads without crushing, avoid splitting the flange stock when either the flange or web changes dimensions, and enhance product uniqueness.

Adhesives

Although individual producers may write their own specifications for adhesives used in the manufacture of wood I-joists, adhesives are generally in compliance with standard specifications for durable structural uses such as ANSI/AITC A190.1(1) for flange-end joints, ASTM D 2559 (3) for web-web and flange-web connections, and PS 1-83 (13) or APA PRP-108 (2) for plywood veneer bonding. Phenol-formaldehydes and phenol-resorcinols are the mainstays of the industry, although some melamine adhesives are also used for flange-web bonding.

Product-design assumptions and considerations

The net area of the flanges (total flange cross section minus the web groove) is used for determining moment of inertia and moment capacity. Composite action between the web and flange is assumed for flexural and shear-deflection calculations. Full-scale testing at a normal-use moisture content (MC) has shown that deflection characteristics of wood I-joists are quite predictable in the design range. Shear capacity is typically established through a verification testing program. In design, consideration is given to shear stresses in the web, rolling shear at the flange-web joint, and shearing action in the web splices.

Deflection criteria for wood I-joists vary with application. Usual serviceability requirements for conventional wood construction limit deflections to prevent unsightly visual effects, ceiling cracks, and/or drainage problems. However, the lighter weight and lower damping capacity of wood I-joists have, in isolated cases, resulted in consumer complaints because of objectionable floor vibrations. Most manufacturers offer suggestions that help the floor-system designer select the appropriate section to avoid such problems. Methods to control floor-vibration amplitude and increase frequencies include the use of heavier I-joist sections, stiffer decking material, nail-glued decking, reduced I-joist spacing, and shortened spans.

End-use and installation considerations

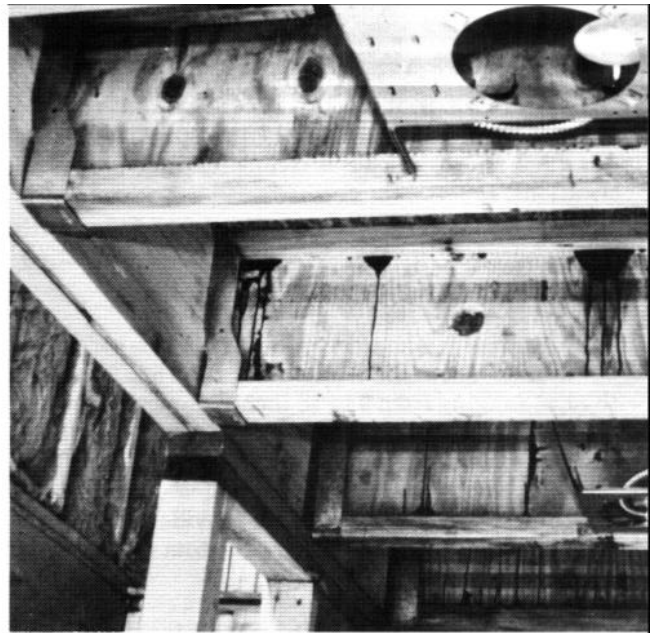
Several end-use and installation requirements, primarily associated with construction practices, must be considered because of the highly engineered nature of pre-fabricated wood I-joists. Typical installation details are provided by manufacturers in their product catalogs.

Web holes

One advantageous feature of wood I-joists is that openings can be cut into the webs for the passage of utilities such as heat ducts and plumbing (Fig. 4a). Manufacturers provide clear, definite guidelines in their product catalogs for the shape (round and rectangular), size, and location of holes in the web. Placement of openings and restrictions



a



b

Figure 4. – Wood I-joint floor system (a) allowing passage of large ducts through the web, and (b) including hangers for connection to glued laminated beam.

on removing web material differ somewhat for round and rectangular holes. More severe restrictions are associated with rectangular shapes because of stress concentrations at the hole corners. Minimum distances from supports and flange edges are also specified. Allowable hole size typically increases toward midspan because large web holes at the supports can lead to beam failure due to shear loading. An exception exists for holes 1-1/2 inches and smaller in diameter, which may be placed anywhere in the web. Some manufacturers even provide small-diameter (about 1-1/2 in.) prepunched knockout holes for contractor convenience. Tables for hole placement are based on experimental testing; field modification by notching or cutting flanges is never recommended.

Web reinforcement

Manufacturers are also specific about the use of web reinforcement at beam supports and points of concentrated loads. Reinforcement is intended to prevent local buckling of the web material, minimize bearing distance at supports, and help transfer shear loads into reactions. A gap is usually specified at the top of the reinforcement block in bearing applications and at the bottom of the reinforcement block under top flange concentrated load. The gap prevents the block from pushing the flanges apart if bending deflection is large. When I-joists are used as band or perimeter joists, manufacturers specify that joists be covered with a heavy sheathing panel over their entire depth to ensure adequate transverse compression capacity under upper-story and/or roof loads.

Construction bracing

Wood I-joists appear to be stable when set in place. Until they are braced, however, even light construction loads may lead to joist buckling and possible rollover. As

with most long-span structural elements, wood I-joists must be adequately braced during installation. Manufacturers' recommendations include required bracing to end walls or existing deck at the ends of building bays. Most recommendations require that all hangers, blocking, band joists, and temporary bracing be installed before workers are allowed on the I-joists. Lateral bracing of the top flanges with 1- by 4-inch wood struts before sheathing is permanently attached is typical.

Hardware and hangers

The cross-section shape of wood I-joists makes the use of specialized hangers and hardware mandatory in many applications. Most structural connections require that the forces are carried in concert by the flange and web to assure continued performance of the flange-web bondline and, ultimately, structural integrity. Metal connector manufacturers specifically tailor their products for use with wood I-joists (Fig. 4b) by modifying existing products for solid wood to accommodate smaller nail sizes and wider nail spacings. These changes reduce the likelihood that small-dimension flange stock will split. Information about attachment hardware and hangers is found in I-joist and connector manufacturers' catalogs.

Marketing

Qualification testing and quality control

The expected performance of a wood I-joist directly depends on the quality of the material used in its construction. Because each manufacturer is likely to use a different material source, as well as a different production process, initial design capacities for production must be established. Moreover, the quality of material from a single source may vary from time to time, and the production-process variance may change. Therefore, a daily production qual-

ity-control program that monitors significant fluctuations in material and process variables is essential.

I-joists must be qualified for moment and shear capacities, flange end-joint performance, and bearing length performance. While shear capacity is typically determined empirically, moment capacity may be determined either empirically from the results of full-scale testing or analytically from the characteristics of the flange materials.

To assure code agencies that quality-control procedures are maintained, each manufacturer typically employs a qualified agency to periodically monitor the total production process. A manufacturing standard written by each manufacturer for each product serves as the basis for this inspection.

Approvals by code agencies

Approvals by code agencies are sought for wood I-joists for structural performance, fire-resistance ratings, and sound-transmission characteristics. These evaluation and acceptance reports describe manufacturing location, materials, design methods, and installation requirements for individual members, and when appropriate, for ceiling and floor systems. Respondents exhibited reports from the Council of American Building Officials (8-12), the International Conference of Building Officials (14-16), Metropolitan Dade County (18) in Florida, the Canada Mortgage and Housing Corporation (6), the Southern Building Code Congress International (20), and the U.S. Department of Housing and Urban Development (21,22). Difficulties for some manufacturers in obtaining approvals for wood I-joists have been relieved by developing a product standard.

Development of standards

The standardization process for wood I-joists was initiated in 1981 by an interested group of producers seeking to establish uniform performance criteria for these products. Consensus regulation allows the design capacities for various producers to be consistent with the associated strength distributions and therefore results in a more uniform application performance. In 1985, the standardization process was shifted to the organizational umbrella of the American Society for Testing and Materials (ASTM) D-7 Committee on Wood. The ASTM draft outlines requirements and procedures for qualification testing, quality control, shear-strength testing, moment-capacity determination, and inspection. The International Conference of Building Officials (14) used an early version of the ASTM standard as a basis for specific manufactured-product needs and have adopted a modified version of it as an evaluation standard for wood I-joists.

Warranties and product reliability

Because wood I-joists are a prefabricated product with relatively consistent properties monitored by quality-control procedures, manufacturers can guarantee product performance. Being relatively new in the tradition-bound light-frame construction market, wood I-joist manufacturers are keen to assist in solving callback problems to assure product reliability.

Problems and barriers

With any new building product, a certain resistance exists in the marketplace because some builders hesitate to use unfamiliar products. Manufacturers indicated some

initial resistance to the use of a glued assembly and OSB web material. Problems were created when, despite instructions about installation procedures in product catalogs, builders failed to install reinforcement blocks at bearing points and concentrated loads because it is a burden to do so. In conversations with builders (4), initial installation experiences were described as slow but improved once procedures and requirements were better understood.

The material cost of wood I-joists can be almost double that of sawn lumber of the same depth, which has led to some marketplace reluctance and minimized direct substitution for dimension lumber. However, a complete cost analysis including labor for cutting and material waste may show cut-to-length I-joists the most economical choice.

Concern has also been raised about the fire safety of lightweight wood components such as metal plate trusses and I-joists (19). With a reduced cross section, these components appear more susceptible to fire than lumber alone and therefore may require additional fire protection. However, 1-hour fire-rated floor, ceiling, or roof systems, described in evaluation and test reports published by the testing or code agencies (9,11), are available from most manufacturers.

When asked about abuses and common complaints, manufacturers were in unanimous agreement: Removal of most or all of the web was the most often cited difficulty. Also noted were notching or cutting of flanges, improper attachment of bearing stiffeners, poor hanger installation, and rough handling at the construction site. As previously mentioned, the dynamic performance of floor systems made with I-joists, compared to those made with traditional solid-sawn joists, prompted some consumer complaints.

Research and development needs

Industrial research and development activity has seen a slight increase in recent years, and some additional but minor increase is expected. We did not solicit information about the level of industrial research and development involving third parties, such as universities, government institutions, private consultants, or other industrial associations.

The questionnaire provided a list of research areas and a fill-in category for respondents to rank them according to perceived importance. Noted as most crucial by respondents were connectors (and connections), fire safety, shear-capacity determination, web openings, dynamic performance, and long-term performance.

Research on connectors is a critical area for the I-joist industry because of the thin web, which does not permit a straightforward attachment, and the small cross section of the flange, which is susceptible to damage and splitting. Additionally, reinforcement of the web at connector locations can make installation more difficult. A simpler means of mechanically attaching these lightweight components to the heavier major structure would save time and expense and improve reliability.

Research needs on fire safety relate largely to fire ratings in nonresidential applications. Improved knowledge of fire-protecting assemblies or direct treatment or coating of the I-joist can provide the level of protection expected, as borne out by the numerous systems that currently have fire ratings. Although it is not now a problem for most

residential applications, the level of protection could become one if code requirements change.

Research needs on determining shear capacity and web openings also relate to the thin web. Manufacturers' concerns here provide researchers with a renewed impetus to investigate new means of modeling the stress and failure states of web materials and methods to characterize the effects of opening size, location, and sensitivity to adjacent openings and bearing points.

Floor systems that employ I-joists have somewhat different dynamic characteristics than traditional-joist floor systems. As such, the consumer may sometimes find the vibrational frequency, amplitude, or damping under normal-use conditions to be objectionable. We need to know more about the characteristics that produce this perception and then must develop criteria that will allow a floor-system designer to circumvent objectionable behavior.

Some knowledge of the long-term performance and effects of various environments and loadings on I-joists has been gathered through modeling and tests. However, the survey indicates that there is still a need to fully characterize wood I-joist systems and establish product performance under environmental cycling and extremes to increase user confidence.

Concluding remarks

Wood I-joists are becoming widely accepted by the design and construction industries. The mass production of these components has grown from a single manufacturer in 1969 to nine in 1989, with most entering the market in the 1980s. Additional growth, as plant expansion and new corporate entries, is expected in the future.

Review of manufacturer literature shows that wood I-joists are not generic. Manufacturer catalogs and evaluation reports are the primary sources of information concerning product availability, typical installation details, and performance characteristics. Differences in beam design and composition have led this industry through a standardization process to ensure performance and reliability. However, as with any fledgling industry, sizes, methods of installation, and supporting products such as web reinforcements, bracing, or hangers have yet to be standardized.

The growth of the I-joist industry in part signals the desire to better utilize available wood resources while improving end product performance and reliability. The diversity of research needs cited in the survey results illu-

strates the different levels of technology resident in each company and reflects corporate marketing thrusts into residential and nonresidential markets.

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