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WOODEN JOIST OR BEAM

Original Filed June 5, 1964

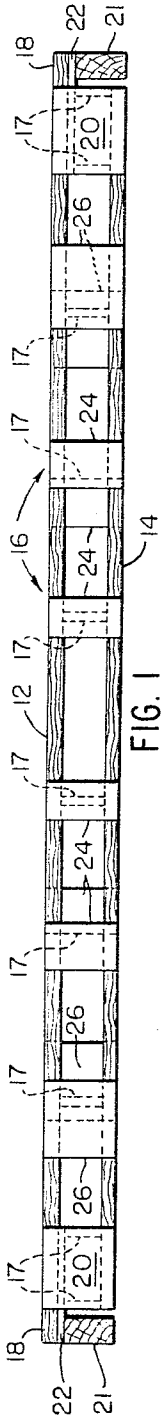


FIG. 1

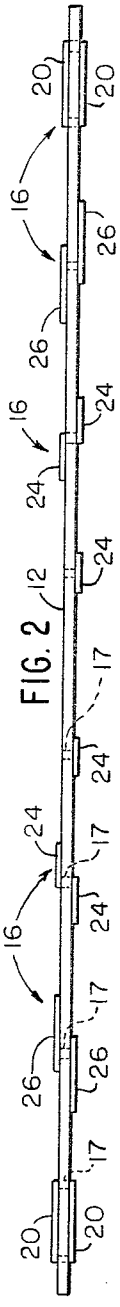


FIG. 2

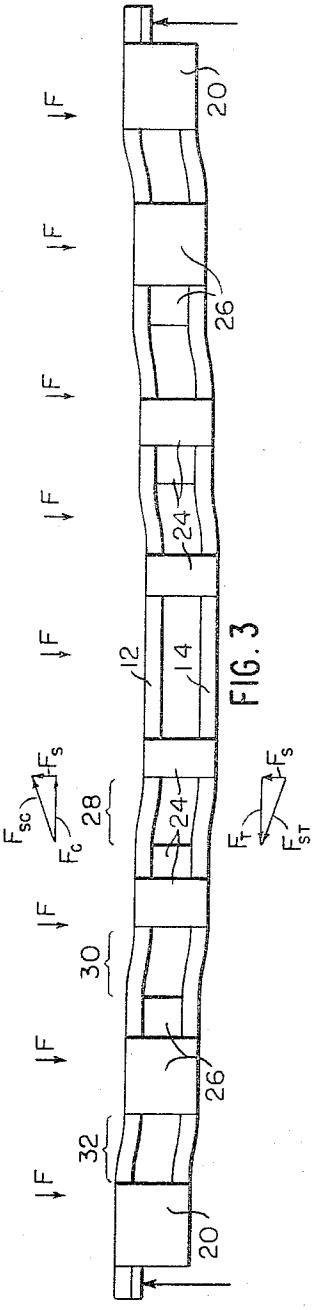


FIG. 3

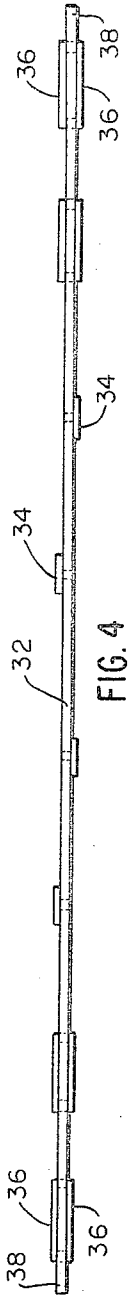


FIG. 4

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WOODEN JOIST OR BEAM

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4 Claims. (Cl. 52—690)

This is a continuation of application Ser. No. 372,870 filed June 5, 1964.

The present invention relates generally to wooden joists or beams employing upper compression and lower tension chords. More particularly, it relates to improvements in wooden bar joists or beams which permit the minimization of material costs through the strategic location and design of the structural components.

In typical conventional building construction, where the load and the unsupported span of a joist or beam preclude the use of 2-inch framing lumber, a steel I-beam or a reinforced concrete beam is employed. While these means are adequate to provide load-bearing capabilities without excessive deflection, the materials are more costly than wood. It is a principal object of this invention to provide a wooden beam or joist which is adequate for greater spans and loads formerly not carried economically except by use of more expensive materials.

Proposals hitherto advanced for long-span wooden joist or beam construction have not been generally satisfactory because of the cost of labor or materials, or both, and because the depth of the beam from the top to the bottom chord has been prohibitively large in many design applications. Such proposals, in general, have been based upon a box beam or some form of truss construction. The plywood box beam contemplates connecting webs or sheets extending between the side edges of the chords continuously from end to end of the beam, and typically uses multiple-member top and bottom chords. This construction is expensive because it takes insufficient or no account of the fact that the stresses within the beam vary from point to point along its length, and every section of such a uniform beam is usually made strong enough to withstand the largest stresses, while it is known that for uniform loading the fiber stresses are maximum only in the center of the beam, and the shear stresses are maximum only at the ends adjacent the supports under the usual conditions of uniform loading. Certain of the more complicated and expensive box beams have material distributed so as to provide heavier and lighter sections, varying with the stress distribution, but generally the saving in material is not sufficient to make such forms practicable.

The typical wooden truss construction, while having struts distributed and located diagonally between the chords as a function of the load distribution, is designed for mechanically connected joists using rings, bolts, plates, or toothed connectors. The design of such connections with usual safety factors ordinarily imposes dimensional requirements that result in bulky, expensive construction which is not competitive with the steel and concrete alternatives.

With the foregoing object and others hereinafter more clearly appearing in view, the features of this invention reside in a novel joist or beam construction which is predicated on a principle involving the controlled distribution of secondary stresses resulting from localized deflections occurring in unreinforced sectors of the chords adjacent to rigidly supported sectors thereof.

The principle of the invention may be understood in

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part if one first considers a hypothetical board, the ends of which are respectively rigidly clamped to two relatively movable frames. If one of the frames were shifted in relation to the other in a direction transverse to the principal dimension of the board, the board would be deflected so as to produce sectors of opposite curvature, or a Z-shape. This results in setting up tension stresses in the convex curved portions and compression stresses in the concave curved portions.

A phenomenon of this kind was long ago embodied in the so-called "Vereendeel beam," which was designed with spaced vertical steel struts between two parallel steel chords. Each strut had large gussets which effectively transferred bending moments from struts to chords, being in that sense similar to rigid clamps. A loaded beam so constructed experienced appreciable bending only in the sectors intermediate the struts, and in such sectors there was a Z-deflection of the kind mentioned in the above example. The stresses in these latter sectors of the chords included, as in the usual beam, two major "primary stresses": the longitudinal fiber stresses resulting in bending moments and the transverse shear stresses, both produced by the over-all load. To these usual stresses were added "secondary stresses" produced by the Z-shaped deflections. These Vereendeel beams were also so designed that the struts themselves experienced a Z-deflection counteracting the secondary bending moments induced by the Z-deflections of contiguous chords.

The intrinsic construction features of the Vereendeel beam were such that the application of any of its principles to wooden construction evidently has not been previously recognized. Nor has it been recognized until the present invention that the use of such principles can be made to effect substantial economies of material in wooden beam construction.

More specifically, the construction features of this invention include the use of strategically distributed wooden joining panels adhesively bonded between the chords of the beam, with the dimensions and spacing of the panels being determined as functions of the resultant stress distribution, the purpose being to equalize the resultants of the primary and secondary stresses induced in the chords throughout the length of the beam. Beams of this construction may be made so as to hang upon or overlie the supporting girders.

A further feature resides in the use of joining panels adjacent the overhanging ends of the compression chords in trusses or beams of this type which are designed to be hung on girders, so as to confine the stresses in such chords adjacent such overhanging ends substantially to a transverse stress in shear. Coupled with this feature, I may employ reinforcing shear members contiguous to the overhanging ends and similarly bonded to the adjacent joining panels to increase the strength in transverse shear to the desired extent.

Other features of the invention reside in certain details of construction, arrangements and configurations of the parts which will be more fully understood from the following description thereof, having reference to the appended drawings in which:

FIG. 1 is a side elevation of a preferred embodiment of the invention;

FIG. 2 is a plan view of the beam or joist shown in FIG. 1;

FIG. 3 is a side elevational of the embodiment of FIGS. 1 and 2 under a uniformly distributed load with the secondary deflections somewhat exaggerated for purposes of illustration; and

FIG. 4 is a plan view similar to FIG. 2, illustrating an alternative form of construction according to this invention.

Referring first to FIGS. 1 and 2, the beam or truss includes an upper, or compression chord 12, a lower or tension chord 14, and a plurality of joining panels collectively designated 16, shown in this embodiment as of substantially rectangular form, rigidly adhesively bonded to the portions of the chords which they overlap. It will be apparent that other than rectangular shapes may also be employed, if desired.

Between the chords and against the panels 16 are adhesively bonded a number of woden stiffeners 17, the function of which is to reinforce the panels against buckling. These stiffeners preferably have the same thickness as the chords so that they may be bonded to panels on either or both sides of the chords. The chords 12 and 14 are typically of 2-inch lumber, such as two-by-fours. The joining panels 16 are of structural plywood of the type commonly available, generally of the thinnest sizes, typically 5/16- and 3/8-inch or slightly thicker, the panel thickness depending upon the span, the load distribution, and the number, size and location of the stiffener members 17.

The chord 12 is made longer than the chord 14 to provide overhanging ends 18 if the beam is to be hung. If the bottom of the beam is to be rested upon supporting girders instead, the chord 12 may be of the same length as the chord 14; or one or both of the chords may be extended beyond the support on either side, either in cantilever fashion or as a beam. Reinforcing shear members 22 of wood underlie the ends 18 and extend between the adjacent end joining panels 20, to which they are likewise adhesively bonded. The illustrated beam is hung upon wooden girders 21.

The joining panels 16 are rigidly bonded to the chords 12 and 14 and to the reinforcing strips 22 under pressure, for example by gluing in a press. Another but somewhat less satisfactory method is to nail the parts together after gluing, the function of the nails being primarily to apply pressure during the setting-up of the glue.

The arrangement of FIG. 2 provides good efficiency in use of materials. Two end joining panels 20 are applied in opposed relation to both sides of the beam at each end. The intermediate portions of the beam have the joining panels either arranged singly or in partially overlapping opposed relationship, with the spaces between joining panels toward the ends of the beam being smaller than in the center. Conversely, the joining panels 24 near the center have smaller lengths along the principal dimension of the chords than panels 26 further removed from the center, and the panels 26 have smaller corresponding lengths than the end panels 20. Alternatively, these lengths may be uniform if the spacing is appropriately adjusted along the length of the beam. These features are specifically designed as a function of the load distribution along the beam, so as to achieve the objects hereinabove stated, as will be more fully understood by considering FIG. 3 which depicts the beam under a uniformly distributed load depicted by arrows F.

As in a conventional beam of uniform section, there are primary longitudinal or fiber stresses in the chords 12 and 14 which are tensile in the chord 14 and compressive in the chord 12. These stresses are greatest in the center of the beam, the location of the maximum bending moment, and they decrease to zero at the ends. There are also primary transverse or shear stresses which are substantially zero at the center and increase linearly toward maximum values at the supported ends.

At the center of the beam the stress on the chord 14 is purely tensile and longitudinal, or horizontal. There is no stress in shear. At a sector 28 somewhat removed from the center, the transverse or shear stress in the chord 14 is substantial and causes the resultant of the shear and tensile stresses to swing substantially away from the horizontal. This is also true of sectors 30 and 32 further removed from the center, with the vertical shear stress being increasingly larger and the horizontal fiber stress increasingly smaller, approaching the ends.

The primary forces of the chord 14 on the first panel 24 to the left of center in the sector 28 are depicted by vectors F_S and F_T, respectively, representing the shear and tensile forces, with a resultant force F_{ST}. In the same sector 28, there are forces of the chord 12 on the same panel, represented by a shear vector F_S, a compression vector F_C and a resultant vector F_{SC}.

The reactions of the panels to these forces are such as to cause the chords to assume a Z-configuration (exaggerated in the drawing) in the unsupported sectors. This configuration is the result of the fact that the panels permit no deflection in the bonded sectors, and the curvatures experienced by the chords in applying these resultant forces are accompanied by opposite and substantially equal inverse curvatures in each case.

The sizes of the respective primary stresses depicted by the vectors vary with the position along the beam. In addition to these primary stresses there are secondary stresses of compression in the concave portions of curvature and of tension in the convex portions of curvature. These secondary stresses are a function of the extent of the secondary Z-deflection, which is in turn the result of the sizes and directions of the resultant primary stresses and of the spacing between the panels along the chords. If the panels are close together, the secondary deflection is minimal, and the secondary stresses add little to the primary stresses. Conversely, if the panels are far apart and the resultant primary stresses are both substantially out of the horizontal and of substantial magnitude, the secondary deflection is large and contributes substantial secondary stresses to the primary stresses at the particular sector. The secondary stresses in each sector tend to oppose the primary stresses in portions of one secondary curvature and to augment the primary stresses in contiguous portions of the reverse secondary curvature.

The latitude in design of the beam which these phenomena permit is that the spacing of the panels may be increased, thereby reducing the number of panels required in portions of the beam where the total primary and secondary stresses are not large, or where the primary stresses are most closely aligned with the direction of the member. The result is that no panels need be provided at the center of the beam where the secondary deflections are small, and the panels may be spaced relatively far apart in the adjacent sectors near the center because the resultant primary stresses F_{ST} and F_{SC} are not far from the horizontal, and they are small enough so that substantial secondary stresses may be added to them without exceeding a given stress limit.

On the other hand, at sectors closer to the ends, the panels must be spaced relatively closer together because the resultant primary stresses F_{ST} and F_{SC} are further from the horizontal and are of such magnitude that only relatively smaller secondary stresses may be added to them without exceeding the same given stress limit.

By means of this design one obtains a beam which, at the sufferance of some added deflection under load caused by the secondary deflections, has the wood distributed so as to equalize the stresses along its length, thereby permitting a given load to be carried with a more efficient use of materials. In addition, the secondary deflections for a typical design are not prohibitively great, being minimized to a very large extent by the rigid bonding of the panels to the chords.

It will be understood, therefore, that in the design of a joist or beam according to this invention, the procedure is to select chords of a cross section sufficient to withstand the maximum moment forces at the center of the beam, and at the same time to determine the depth of the beam or distance between chords so as to hold the deflection under load within tolerated limits, giving due consideration to the additional effect of secondary Vereendeel de-

flections. One may then determine the primary stress distribution on the tension chord **14** and on the compression chord **12**, and also determine for this loading the maximum secondary deflections permissible along the chords between joining panels without varying substantially from a given total or resultant stress at any sector along the beam. This will determine the longitudinal spacing permissible between panels. At the same time, the length of each joining panel along the principal dimension of the beam is made sufficient to insure a rigid bond that will withstand the racking stresses on the panel without deflection or buckling. This also entails consideration of the unit stresses on the bond between the panels and the chords.

Proceeding on this basis, one may design a beam such as that shown in FIGS. 1 and 2 wherein the joining panels **16** are distributed on opposite sides of the chords, not only in directly opposed relationship, but also in alternating and partially overlapping arrangement. Also, a beam may be designed in which the joining panels are distributed only in directly opposing pairs. FIG. 4 is a plan view similar to FIG. 2 of still another embodiment. In FIG. 4, an upper chord **32** and a similar parallel lower chord, not shown, have bonded between them substantially rectangular, alternating joining panels **34**, the panels **34** being spaced further apart nearer the center than toward the ends. Also, the lengths of the joining panels along the principal dimensions of the chords are greater nearer the ends than nearer the center, as in the embodiment of FIGS. 1 and 2.

The structures of FIGS. 1 and 4 have in common the property that the joining panels **20** and **36** at the ends thereof, respectively, confine the stresses at the overhanging ends **18** and **38** of the compression chords, respectively, to substantially transverse shear stresses, at right angles to the grain of the chords. This is very advantageous, since wood is stronger in shear transversely of the grain than it is in tensile strength parallel to the grain.

In those cases in which the compression chords must be reinforced against the shear stresses at the projecting ends **18** and **38** thereof, the reinforcing shear members **22** are provided. These members **22** can have any desired cross sectional area, but are of the same thickness as the compression chords and underlie the compression chords from the ends thereof to the opposite edges of the next adjacent connecting panel **20** or **36**. In this manner, the reinforcing members **22** can be bonded to the joining panels **20** or **36**, as well as to the compression chords **12** or **32**, if desired. The reinforcing members **22** rest upon the supporting girders **21**.

The top compression chord and bottom tension chord may each be constructed of a single piece of lumber, or it may be two or more pieces joined end to end, or it may be of laminated construction with two or more pieces. In any case, the design is based upon the controlled secondary deflections which occur in the particular chord construction with the given stress distribution along the length of the joist or beam. In following this principle of construction, it has been found that a substantial reduction in the amount of structural material has been accomplished, of the order of half the material that would be required for a comparable wooden truss construction of conventional form, joined by mechanically connected joints with bolts and bearing plates.

For example, in a beam or joist spanning 30 feet with only end supports, openings between joining panels may range in size from 2 feet to 4 feet, while at the same time the depth of the joist is closely similar to the depth of a typical steel bar joist designed for the same span.

The improved wooden truss or beam according to this invention is extremely light, and beams for spans up to 50 feet in a typical construction can be carried and put in place by two men.

The improved construction also has certain dimensional advantages. The large open areas between the joining panels and within the space between the chords allow for the passage of piping and duct work. Over-all height of the construction can also be reduced by hanging the members upon the supporting girders as illustrated, instead of resting the bottom chords upon the girders as is usually necessary with timber structures. The simplification of design achieved by hanging the members can be realized even where large air conditioning ducts and other utilities must be accommodated, since these may be run transversely through the beams in the manner mentioned above. The reduction in over-all height which this permits is a major source of economy in construction.

These features result in a beam design which permits substantially higher loads to be borne without objectionable deflection for a given total amount of material. Furthermore, the economies in the use of wood are such that in a typical joist construction, it is economically feasible to place the joists with closer spacing than for comparable construction with steel joists, with the result that the materials to cover the joists, such as roofing or flooring, will not be required to span as great a distance. Similarly, the ceilings can be applied directly to the joists rather than to strips applied across the joists. These features result in an indirect, although far from insubstantial, economy in the use of construction materials.

Having thus described the invention, I claim:

1. A beam comprising an elongated wooden tension chord, an elongated wooden compression chord longer than the tension chord and in spaced, generally parallel relation thereto, the chords each having a generally rectangular cross section, and a plurality of flat plywood joining panels each overlying and rigidly adhesively bonded to an edge surface of each chord, each bonded edge surface extending a substantial distance along the principal dimension of the chord, the panels being distributed between both sides of the chords along said principal dimension, the lengths of the panels in the direction of said principal dimension increasing from the center toward the ends of the chords, the spacing between the panels along said principal dimension decreasing from the center toward the ends of the beam and being sufficient to permit an appreciable Z-deflection of the chords between the papnels under a predetermined load, the panels extending to an end of the tension chord so as to define a hanging projection at an end of the compression chord.

2. The combination according to claim **1** including a reinforcing shear member underlying the hanging projection and a substantial portion of an adjacent joining panel, and being rigidly bonded to said projection and joining panel.

3. A beam comprising an elongated wooden tension chord, an elongated wooden compression chord in spaced, generally parallel relation to the tension chord, the chords each having a generally rectangular cross section, and a plurality of flat plywood joining panels each overlying and rigidly adhesively bonded to an edge surface of each chord, each bonded edge surface extending a substantial distance along the principal dimension of the chord, the panels being distributed between both sides of the chords along said principal dimension, the lengths of the panels in the direction of said principal dimension increasing from the center toward the ends of the chords, the spacing between the panels along said principal dimension decreasing from the center toward the ends of the beam and being sufficient to permit an appreciable Z-deflection of the chords between the panels under a predetermined load.

4. A beam comprising an elongated wooden tension chord, an elongated wooden compression chord in spaced, generally parallel relation to the tension chord, the chords each having a generally rectangular cross section, and a plurality of flat plywood joining panels each overlying

and rigidly adhesively bonded to an edge surface of each chord, each bonded edge surface extending a substantial distance along the principal dimension of the chord, the panels being distributed between both sides of the chords along said principal dimension, the spacing between the panels along said principal dimension decreasing from the center toward the ends of the beam and being sufficient to permit an appreciable Z-deflection of the chords between the panels under a predetermined load.

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