LAMINATED OAK FRAMES FOR A 50-FOOT NAVY MOTOR LAUNCH COMPARED TO STEAM-BENT FRAMES

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LAMINATED OAK FRAMES FOR A 50-FOOT NAVY MOTOR LAUNCH COMPARED TO STEAM-BENT FRAMES[1]

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Summary

The use of glued laminated construction in boats has greatly increased in recent years. This construction has been used successfully for skegs and keels, and the growing scarcity of white oak suitable for frames has suggested its use for this purpose.

At the request of the Bureau of Ships an investigation of the relative merits of steam-bent and laminated frames for a 50-foot motor launch was made. The work was based on the pattern for frames in the midships section of a 50-foot motor launch.

The material used for investigation was of a quality normally used for boat frames at the Navy Yard, Norfolk, Virginia.

For purposes of this study only that portion of the frame with severest curvature was tested. The tests included steam-bent frames of the full cross section (2 by 2.6 inches) used in the standard design, laminated frames of the same cross section, laminated frames of reduced cross sections, and solid and laminated straight pieces of the full cross section.

As received, the material was at a high moisture content, but all fabricated parts were seasoned to approximately 12 percent moisture before test.

The tests showed that steam-bent frames are considerably excelled in bending strength and stiffness by laminated frames of the same cross section.

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[1] This work was performed in cooperation with the Bureau of Ships, U. S. Navy Department.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Laminated frames approximately seven-eights as large in each cross sectional dimension have about the same strength and stiffness within the useful working range as steam-bent frames.

The set that remains after the imposition and release of stress within a useful working range is small and is about the same for steam-bent frames as for laminated frames lessened in each cross-sectional dimension by the factor seven-eights.

Steam-bent frames may be bent or deflected much farther under a force that tends to straighten them than can laminated frames, and when subjected to such a force their full strength is developed only at extreme deformations. This behavior causes the steam-bent frame to absorb before breaking several times as much energy as a laminated frame under a force or blow applied to the outside of a boat between the keel and the gunwale.

Introduction

The growing scarcity of white oak of the quality considered necessary for steam-bent frames has suggested the possibility of using laminated frames, for which there is a more abundant supply of material.

The usual practice in fabricating laminated products is to bend and glue the laminations simultaneously in a dry condition. The laminations are limited to such thicknesses that the desired curvatures can be attained without significant injury to the material. Conversely, steam-bent frames are normally formed to radii such that the wood fibers, particularly those on the concave or compression side are seriously injured. It is to be expected, therefore, that laminated and steam-bent frames of the same size may differ considerably in properties and that equality of behavior may be achieved by using different cross-sectional dimensions in the two types.

Purpose

The purpose of this study is the comparison of strength and stiffness between laminated and steam-bent frames of the same size, together with the determination of the dimensions of laminated frames that equal in strength and stiffness steam-bent frames of standard size.

Material

The white oak from which parts for test were made consisted of some twenty 4- by 6-inch by 12-foot pieces and twenty 4- by 6-inch by 6-foot pieces obtained from the Anchor Lumber Company at Marietta, Ohio. These were selected by a representative of the Bureau of Ships, Washington, D. C., from flat-grained white oak, stock No. 39-L-2405, normally used for boat frames at the Navy Yard, Norfolk, Virginia. The material conformed to the requirements of Bureau of Ships Ad Interim Specification 39-0-6 (Int) dated 1 November 1943, Oak, White, and Elm, for Bending except for moisture content.

The stock was in a partially air-dried condition and contained some surface checks when received at the Forest Products Laboratory. Samples from a few of the pieces had a moisture content of about 70 percent. A few of the pieces also contained some visual defects, such as cross grain, small knots, and worm holes.

Preparation of Members for Test

Tests were made on steam-bent and laminated frames and solid and laminated specimens all of the cross-sectional dimensions used for steam-bent frames in the standard design (2.0 inches wide by 2.6 inches deep) and on laminated frames reduced by the same proportion in the two cross-sectional dimensions to give section moduli 7/8, 3/4, 5/8, and 1/2 as great. The timbers previously described were so converted and reassembled that the items to be compared would be as nearly alike as possible with respect to character of wood.

The 12-foot material was ripped and crosscut to obtain from each piece a set of four blanks as indicated in figure 1. As the material was flat-grained, this procedure resulted in side- and end-matching of blanks, each of which was approximately 3 by 4 inches in cross section by 6 feet long. Each set of four blanks furnished a steam-bent frame, a solid straight specimen, a laminated frame, and a laminated straight specimen. All frames and straight pieces from the 12-foot material were 2 by 2.6 inches in cross section.

A laminated frame of reduced section side-matched to a bent frame of full section was obtained from each of the 6-foot lengths as shown in B of figure 1.

The frames were of reduced length (about 6 feet) as compared to the full pattern but were sufficiently long to include a straight portion on either side of a curve of proper radius and angle.

Solid Straight Specimens

Each blank for a solid straight specimen was first cut to a cross section of 2-5/16 by 2-7/8 inches, the 2-7/8 inches being in the radial direction. These blanks were then placed in a kiln and conditioned to approximately 12 percent moisture, after which each was surfaced in a planer to form a test specimen 2 inches wide by 2.6 inches deep.

Steam-Bent Frames

Each blank for a steam-bent frame was surfaced to 2-1/2 by 3 inches in cross section, the 3 inches being in the radial direction. (In the actual boat construction, the frames are approximately 2-1/2 inches wide by 3 inches deep at the time of bending so that later it will be possible to obtain the proper bevel and a finished depth of 2.6 inches.) These blanks were first kiln-dried to about 25 percent moisture content and then stored in a room at 97 percent relative humidity. Preparation for bending was by steaming for 2 hours in a retort at atmospheric pressure. Bending was over a wooden form of 22.8-inch radius and was started at the middle of the length and continued until the end portions formed a right angle.

A heavy steel strap having adjustable end brackets was used together with the form and a tackle arrangement in producing the bends.[3] Figure 2 shows the complete assembly of the bending equipment. The purpose of the strap and end brackets was to prevent appreciable stretch or tension stress on the convex face during the bending. The bending produced a shortening of the periphery on the concave side of about 4.7 inches or 11.6 percent of the original length of the portion that became curved. To prevent a change in the curvature of the bent frames subsequent to the bending operation and removal from the form, the ends of a thin metal strap that was located between the heavier metal strap and each bent frame during bending were joined by means of another metal strap and turnbuckle. In addition, a wood stay was nailed to each side of the frame near its ends (fig. 3). The frames were then placed in a kiln and conditioned to about 12 percent moisture content. To facilitate drying, the thin metal straps were removed from the frames a couple of days after starting the conditioning.

Subsequent to conditioning, the frames were sized to a width of 2 inches and a depth of 2.6 inches. Approximately equal amounts of material were removed from the convex and concave surfaces. This was accomplished with a shaper and special jig, as shown in figures 4 and 5.

Laminated Straight Specimens

Each blank for a laminated straight specimen was resawed into six 1/2-inch flat grain boards (figs. 1 and 6A). To replace material lost in resawing, additional material of the same size and approximately the same grain and density was furnished as fillers. After the 1/2-inch boards were conditioned to 12 percent moisture content, they were sized to a thickness of five-sixteenths inch. The laminations were then assembled in the order as shown in figure 6B. With this arrangement each outer lamination was tangentially matched to the corresponding part of the solid piece, as is indicated by figure 6A. A total of nine laminations were used for making one specimen and filler material was placed in the central portion of the depth where it would have the least effect on the bending

[3] Forest Products Laboratory Report, "The Bending of 2-1/2- by 3-inch by 6-foot Appalachian White Oak Boat Frames for Strength Tests," by C. A. Jordan describes in detail the process of steam bending oak frames.

strength. The gluing was with a low-temperature-setting phenol formaldehyde glue in accordance with the Bureau of Ship's Specification R-39-0-7 and at a pressure of 150 pounds per square inch. The specimens were subsequently cured in a room maintained at a temperature of 210° F. and a relative humidity of about 82 percent for a period of about 16 hours. Later they were sized to 2 by 2.6 inches by 6 feet 0 inch, equal amounts of material being taken from opposite faces.

Laminated Frames

The blanks for the laminated frames were handled in much the same manner as those for the laminated straight pieces. Subsequent to the conditioning to 12 percent moisture content, the 1/2-inch flat-grained boards were planed to a thickness of 5/16-inch, and assembled in accordance with table 1 and figure 6B. The 5/16-inch thickness is the maximum permitted for a radius of curvature of 23 inches by Specification R-39-0-7, dated December 1, 1944.

The assemblies of lamination were bent over a wooden form of 22.9 inch radius (fig. 7); the bending was started in the central portion of the length and continued until the end portions were at 90° with each other. The gluing and curing conformed to the procedure used for the straight laminated specimens. The pressure of 150 pounds per square inch was applied to the bent member through clamps attached to the wooden form. Cauls or liners of proper thickness were placed on the wooden form prior to the placing of the laminations for frames of reduced cross section to provide the same radius of curvature of the convex face of the frames of the various depths.

After the bending process, an equal amount of material was surfaced from opposite faces in the manner described for the steam-bent frames. Table 1 shows the net cross section of the various laminated frames.

Storage

After processing, all frames were kept in a 12 percent equilibrium moisture content room until tested.

Numbering System

The forty 4- by 6-inch white oak pieces from which the frames were obtained were numbered from 21 to 60, inclusive. Letters were suffixed to these numbers to designate the type of item obtained from the material.

The following are the letters used:

Letter	Designation
S	Solid
L	Laminated
B	Bent
C	Control or straight specimen
F	Frame
R	Reduced cross section

For example, the number 60 LB-FR means that this frame was obtained from piece No. 60 and was a laminated frame of reduced cross section.

Method of Tests

Tests were made by transverse and end thrust loading.

Transverse Tests of Bent Frames

One-half the 2- by 2.6-inch laminated and steam-bent frames were tested under tranverse loading (fig. 8). The load was applied to the specimen through a bearing block having a radius of curvature of 8 inches. The load to the bearing block was transmitted through a wedge-shaped piece attached to the head of the testing machine. The ends of the frames were supported in fixtures which allowed them to pivet on knife edges as they rotated with the application of load. The ends (fig. 8) of the laminated-bent frames were cut to an angle of 5° and the steam-bent frames to a 20° angle, so that the angle at the end of the test was approximately the same as at the beginning but on the opposite side of the horizontal. A set of rollers under each support permitted horizontal movement of the end fixtures and prevented any horizontal thrust on the frame. The span between supports prior to loading was approximately 54 inches. Vertical deflection at the midpoint of the curved member, and full-chord and half-chord lengths were measured on scales graduated to one-hundredth of an inch and read through telescopes. Readings of set for increments of load were also taken.

Load was applied at a rate of 0.7 inch per minute throughout the test, except for the final run on each unit in which the speed was doubled when the load was well past the proportional limit. Load-deflection readings were taken until the load, after reaching the maximum, decreased to one-half the maximum. Work or energy absorbed by the member up to this point is herein termed total work and is expressed in inch-pounds. Figures 9 and 10 show typical failures of a laminated and a steam-bent frame.

End-Thrust Tests of Bent Frames

One-half the 2- by 2.6-inch laminated and solid steam-bent frames were tested under end-thrust loading (fig. 11). The load was applied to the ends of the framing members through the same two fixtures as were used as supports in the transverse loading tests. The ends were cut to the same angles with the horizontal and for the same reason as described for tranverse tests. The distance between the ends prior to loading was approximately 54 inches. The testing procedure was similar to that for tranverse loading. Set and load-deflection readings were taken in the same manner. Likewise load-deflection readings were taken until the load, after reaching maximum. decreased to one-half the maximum. Load was applied at the rate of 0.7 inch per minute throughout the test, except for the final run on each unit in which the speed was doubled when the load was well past the proportional limit. Figures 12 and 13 show typical failures of a steam-bent and a laminated frame.

Transverse Tests of Straight Specimens

The 2- by 2.6-inch straight specimens were tested over a 62-inch span under center loading at the rate of 0.35 inch per minute (fig. 14). This 62-inch span is approximately the span of bent frames at maximum load under transverse loading. The load was applied to the member through a bearing block of 8-inch radius rigidly attached to the head of the machine. The specimens were supported near their ends on roller bearings which were allowed to pivet on metal knife edges. Load-deflection readings were taken until the load, after reaching the maximum, decreased to one-half the maximum.

Tables and Charts

Figures 15 to 19, inclusive, give detailed information on individual frames tested under transverse loading. Figure 20 presents composite load-deflection curves for laminated frames of various cross sections and for steam-bent frames of full cross section. Figure 21 shows composite graphs of load versus chord-lengthening for laminated frames of various cross sections and for steam-bent frames of full cross section.

Figures 22 to 26, inclusive, give detailed information on individual frames tested under end-thrust loading. Six of the steam-bent frames prepared for test under end-thrust loading were inadvertently tested at a moisture content of about 20 percent. These and those tested at lower moisture content are averaged separately in table 3 and are separately identified in figure 22.

Figure 27 presents composite load-deflection curves for laminated bent frames of various cross sections and solid steam bent frames of full cross section. Figure 28 shows composite graphs of load versus chord-shortening for laminated frames of various cross sections and for steam-bent frames of full cross section. Curves G in figures 27 and 28 represent only the 13 frames tested at the lower moisture condition of about 10 percent, while curve F represents all steam-bent frames tested under end-thrust loading. Figure 29 includes composite load-set and load deflection curves for laminated and steam-bent frames of 2- by 2.6-inch cross section under transverse loading. Figure 30 presents composite load-set and load-deflection curves for laminated frames of 1.71- by 2.22-inch cross section and steam-bent frames of 2- by 2.6-inch cross section under transverse loading. Figure 31 includes composite load-set and load-deflection curves for laminated and for steam-bent frames of 2- by 2.6-inch cross section under end-thrust loading. Curves C and D of this figure represent only the 13 steam-bent frames tested at a moisture content of about 10 percent. Figure 32 presents composite load-set and load deflection curves for laminated frames of 1.71- by 2.22-inch cross section and for steam-bent frames of 2- by 2.6-inch cross section under end thrust loading. Curves E and F of this figure are duplication of curves C and D of figure 31. Figure 33, which presents load-set curves for white oak frames tested under transverse loading, differs from the load-set curves of figures 29 and 30 in that the set is shown at a greatly enlarged scale. Figure 34 presents similar load-set curves for frames under end-thrust loading.

Table 1 includes a schedule of tests and descriptive data on laminated boat frames. Table 2 includes results of transverse tests on laminated and steam-bent frames. Table 3 includes results of end-thrust tests on laminated and steam-bent frames, while table 4 includes results of transverse tests on the laminated and solid straight specimens.

Discussion

The load-deflection curves for laminated and steam-bent frames of full (2 by 2.6 inches) cross section under the transverse load (fig. 15) show that the steam-bent frames are much lower than the laminated frames in strength and stiffness. The steam-bent frames also have an exceptionally large deflection at maximum load, while the laminated frames fail at a relatively small deflection. Most of the deflection of the steam-bent frames, however, occurs after the proportional limit has been passed. Figure 16 shows that laminated frames 1.92 by 2.47 inches in cross section also are considerably stronger and stiffer than steam-bent frames of full section. Laminated frames 1.82 by 2.36 inches in cross section are slightly higher in strength and stiffness than steam-bent frames of full cross section (fig. 17). Figure 18 shows a close agreement between the load-deflection curves for laminated frames of 1.71- by 2.22-inch cross section and those for steam-bent frames 2 by 2.6 inches in cross section up to the point at which failure of the laminated frames took place. Laminated frames 1.59 by 2.06 inches in cross section are definitely lower in strength and stiffness than steam-bent frames of full cross section, as shown in figure 19. From figure 20, which presents composite load-deflection curves, it may be seen that within reasonable working limits (below proportional limit) the load-deflection curve (D) for laminated frames 1.71 by 2.22 inches in cross section agrees closely with that for steam-bent frames of full cross section.

Figure 22 includes individual load-deflection curves for steam-bent and matched laminated frames 2 by 2.6 inches in cross section under end-thrust loading. As in the tests under transverse loading, the steam-bent frames are definitely lower in strength and stiffness than the laminated frames. Also, laminated frames 1.92 by 2.48 inches in cross section show higher strength and stiffness than steam-bent frames (fig. 23). Laminated frames 1.82 by 2.36 inches in cross section are about equal or slightly superior to the steam-bent frames of full cross section as shown in figure 24, while figure 25 shows that laminated bent frames 1.71 by 2.22 inches in cross section are definitely inferior to the steam-bent frames in both strength and stiffness. The composite curve G of figure 27 for steam-bent frames tested at about 10 percent moisture content, as well as composite curve F representing all steam-bent frames of the standard size, appears between curve D for laminated frames of 1.71 by 2.22 inches in cross section and curve C for those 1.82 by 2.36 in cross section. The conclusion could be drawn from these data that laminated frames of approximately seven-eights the cross-sectional dimensions of steam-bent frames will have about the same strength and stiffness within useful working range as steam-bent frames.

Other measures of the stiffness of the frames are the load-chord-lengthening and -chord-shortening relationships shown in figures 21 and 28. These charts also indicate that laminated frames of about seven-eights the cross-sectional dimensions of steam-bent frames would have about the same stiffness.

Figure 29 shows a comparison between steam-bent and laminated frames of the full cross-section with respect to set and deflection of frames following transverse loading to various loads. This chart shows that set as well as deflection is considerably greater for the steam-bent frames. The set, however, either for the laminated or the steam-bent frames is not large. Figure 30 indicates that set for laminated frames 1.71 by 2.22 inches in cross-section when tested under transverse loading agrees closely with that of steam-bent frames of full cross section, and the deflections under load in the earlier stages are also similar. Figures 31 and 32, which present set and defelction curves for frames under end-thrust loading, give results similar to those for frames under transverse loading, although the set is somewhat larger. Figure 33 presents information on set at a considerably expanded scale over figures 29 and 30 for bent frames under transverse loading. The set for steam-bent frames for various loads is about midway between those for laminated frames 1.71 by 2.22 inches in cross section and 1.82 by 2.36 in cross section. Figure 34 shows that the set for steam-bent frames under end thrust is somewhat less than for laminated frames 1.82 by 2.36 inches in cross section, whereas under transverse loading, as just mentioned, it was somewhat greater.

A comparison between matched groups (the first group of 10 frames in table 2 and the second group of 10 specimens in table 4) shows that in average maximum bending stress under transverse loading the laminated frames are about 5 percent lower than the laminated straight specimens. This would indicate that there may be some reduction in strength caused by the bending of the laminations incident to making the frames. A similar comparison for laminated frames under end-thrust loading and solid straight specimens (tables 3 and 4) shows a deficiency in strength of about 15 percent. This is not unexpected, since the maximum stresses of full-sized laminated frames under end-thrust loading were considerably lower than for laminated frames of the same size under transverse loading. The difference in stress of well-matched curved members between end-thrust and transverse loadings has been observed in other tests.[4] From mathematical considerations[5] it has been shown that the maximum stress of curved members so loaded that the radius of curvature is decreased, as in the present tests under end-thrust loading, is consideably less than when the loading is such as to increase the radius of curvature, as in the tests under transverse loading. As previously pointed out, however, the data from both types of test indicate that steam-bent frames of full cross section are approximately equaled in strength and in stiffness within useful working range by laminated frames about seven-eights as large in each cross sectional dimension.

In successful steam bending, no tension failure takes place at the convex face, and the concave face remains smooth with no localized buckling, folding, or wrinkling in spite of the fact that, since wood can be stretched only to a very small extent, the major portion of the difference in length between the two faces must take place as shortening or upset, which is a maximum at the concave face and decreases to zero near or at the convex face.

The stretch that is possible without tension failure is on the order of 1 percent or less. In the present instance, the difference in length is nearly 12 percent (3-inch depth divided by the outer radius of 25.8 inches gives 11.6 percent) which, since stretch was largely inhibited by the use of straps, consists almost entirely of upset along the concave periphery of the bend.

A striking feature of the behavior of steam-bent material is illustrated by figure 10. The piece illustrated has been bent in the central portion of its length to a curvature in the opposite direction to that to which it was formed. As shown by figure 15, failure and maximum load in the transverse tests were in most instances at a deflection nearly as great as or somewhat greater than the original offset of 16.9 inches. As is also shown by figure 15, these deflections were many times as great as for laminated frames. A major portion of the deflection of the steam-bent frames is the result of stretching back to its original length wood which was shortened in the bending process. For steam-bent frames under end thrust in which the stresses are of the same character as those imposed in formation of the bends, the defelctions at maximum load and at failure are similar to those for laminated frames.

The earlier suggestion of an equivalence ratio of seven-eights was based on the similarity between the load deflection curves for steam-bent frames of the standard size (2.0 by 2.6 inches) and those for two sizes of laminated frames (1.82 by 2.36 inches and 1.71 by 2.22 inches in cross section). Approximately the same value is found from a consideration of figures 35 and 36 in which values for steam-bent frames are compared to graphs that average the data from laminated frames of all the sizes tested. Figure 35 indicates that steam-bent frames are equaled in maximum load, under either transverse or end-thrust loading by laminated frames having a section modulus about 64 percent as great,

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[4] Forest Products Laboratory Report, "A Comparison of Laminated and Conventional Structural Parts for Small Landing Boats" by A. M. McLeod.

[5] "Strength of Materials," by Edward R. Maurer and M. O. Withey, First Edition Revised, 1929, p. 212.

which corresponds to cross-sectional dimensions 86 percent as great ($\sqrt[3]{0.64}$ = 0.86). Figure 36 indicates ratios of moment of inertia of 53 percent for transverse loading and 60 percent for end-thrust loading corresponding to ratios of dimension of 85 percent ($\sqrt[4]{0.53}$ = 0.85) and 88 percent ($\sqrt[4]{0.60}$ = 0.88).

Figure 35 is not fully realistic as a comparison between steam-bent and laminated frames, particularly with respect to the transverse tests, which simulate the action of frames subjected to forces or shock applied between the keel and the gunwale. As shown by figures 15 to 21, steam-bent frames develop their full load only at extreme distortions. Presumably a boat would be completely wrecked by breakage of planking and by other failures long before such distortions were reached. Hence, use of the full transverse load for steam-bent frames in considering equivalent dimensions for laminated frames seems fully conservative. For similar reasons, any comparison of "work" values from the data of table 2 should be made with the load-deflection graphs in mind and with the recognition that a very large proportion of the energy absorbed by the steam-bent frames was the result of distortions far beyond any reasonable working range.

The data for steam-bent frames apply specifically only to the particular bend from which they were derived. For more severe bends (greater ratio of radial dimension of the frame to the radius of curvature) lower values of strength and stiffness may be expected, and conversely. Hence, an equivalence factor derived from the present tests cannot be considered as applying to frames that differ greatly in ratio of radial dimension to radius of curvature from those tested.

An advantage of the laminating process is that wood of high density and strength can be placed in the parts of the cross section where it is most effective, the remaining parts being of wood of lower quality.

Although the white oak supplied for these tests was selected as suitable for bent frames and as complying with Bureau of Ships specifications for bending oak, the modulus of rupture (average of 10,785 pounds per square inch for solid and laminated specimens tested at an average moisture content of 12.5 percent) was low as compared to the average (15,200 pounds per square inch at 12 percent moisture content) as recorded in USDA Bulletin 479 for white oak (quercus alba) from other sources (Stone County, Arkansas, Hendricks, Marion, and Morgan Counties, Indiana; and Richland and Winn Parishes, Louisiana). The specific gravity (based on weight and volume of ovendry wood) was also low, 0.65 as compared to 0.71; as was the modulus of elasticity, 1,385,000 as compared to 1,780,000 pounds per square inch.

Conclusions

(1) Steam-bent frames are excelled in strength and stiffness by properly fabricated laminated frames of the same cross section. In the present tests, steam-

bent frames were approximately two-thirds as strong as laminated frames of the same size and the stiffness was one-half to two-thirds as great.

(2) Steam-bent frames of the pattern tested are equaled in strength and stiffness by laminated frames whose cross-sectional dimensions are each seven-eighths as great as those of the steam-bent frames. The strength and stiffness of steam-bent frames may be expected to decrease with an increase in the relative curvature (ratio of depth or radial dimension of the frame to the radius of curvature) and the factor of seven-eighths is not applicable to frames whose relative curvature differs greatly from that of the frames tested.

(3) The wood at the concave face is greatly shortened (11.6 percent for the pattern tested) in the formation of a steam-bent frame, and when the frame is subjected to a force that tends to straighten out or reverse the original bend the stretching of the inner face to and beyond its original length before a break occurs permits a much greater deflection than is true of a laminated frame. This causes the steam-bent frame to be capable of absorbing several times as much energy as a laminated frame under a force or blow applied to the outside of a boat between the keel and the gunwale.

(4) The sets or residual deflections after release of loads that are within a reasonable working range are comparatively small and do not seem to differ significantly between steam-bent and laminated frames.

Table 1.--Schedule for the preparation and testing of laminated frames

Number of tests: End thrust loading	Number of tests: Transverse loading	Number of laminations per frame	Cross section of lamination at time of fabrication: Width	Cross section of lamination at time of fabrication: Thickness	Dimension reduction factors for the frames[1]	Cross section of frames at time of test: Width	Cross section of frames at time of test: Depth	Estimated maximum load of frame to estimated maximum load of a frame 2.0 x 2.6 inches
(1)	(2)	(3)	(4)	(4)	(5)	(6)	(6)	(7)
			Inches	Inches		Inches	Inches	Percent
10	10	9	2-1/2 x	5/16	1.000	2.0 x	2.6	100.0
2	2	9 (8	2-1/2 x	5/16	.9565	1.91 x	2.49	87.5
		(1	2-1/2 x	3/16				
4	4	8 (6	2-1/2 x	5/16	.9086	1.82 x	2.36	75.0
		(2	2-1/2 x	11/32				
2	2	8 (6	2-1/2 x	5/16	.8550	1.71 x	2.22	62.5
		(2	2-1/2 x	17/64				
2	2	8 (6	2-1/2 x	5/16	.7937	1.59 x	2.06	50.0
		(2	2-1/2 x	3/16				

[1] Dimension reduction factors for both width and depth were obtained by taking the cube root of the actual values in column 7. Example: $\sqrt[3]{0.875} = 0.9565$; $0.9565 \times 2.6 = 2.49$; also $0.9565 \times 2.0 = 1.91$, etc.

Table 2.--Results of transverse tests on white oak laminated bent and solid steam bent bent frames - center loading

Specimen number	Cross section	Moisture content	Specific gravity[1]	Maximum load	Maximum bending stress	Deflection at maximum bending stress: Vertical at midpoint	Deflection at maximum bending stress: Horizontal increasing chord lengthening	Work: Maximum load	Work: Total	Permanent set[2] after being loaded to (pounds): 200	300	400	500	600	700	800	900	1000	1100	1300	1500	Combined slope of spiral and diagonal grain	Description of failure
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
	In.	Percent		Lb.	Lb. per sq. in.	In.	In.	In.-lb. per frame	In.-lb. per frame	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.		
Laminated bent frames																							
311B-F	2.00 x 2.60	12.6	0.643	1,600	10,040	1.14	2.56	1,560	1,565	0	......	......	+0.01	......	+0.01	......	+0.07	......	+0.10	+0.13	+0.16	1:11	Simple and slight cross grain tension
321B-F	2.00 x 2.60	11.9	.691	1,410	8,850	2.13	2.95	1,900	1,900	......	......	......	-.04	......	.01	......	.10	......	.37	.36	......	Straight	Simple tension
331B-F	2.00 x 2.59	12.2	.646	1,600	10,260	2.19	2.95	2,090	2,340	......	......	......	0	......	.01	......	.05	......	.38	.12	.20	Straight	Tension starting at small knot 10 inches off center followed by splintering tension
341B-F	1.99 x 2.60	13.8	.593	1,800	11,910	2.48	3.18	2,880	4,580	......	......	......	.31	......	0	......	.04	......	.06	.12	.20	1:15	Splintering tension
351B-F	2.00 x 2.60	12.8	.646	1,760	11,720	2.48	4.27	3,230	5,780	......	......	......	.32	......	.01	......	.06	......	.07	.18	......	Straight	Splintering tension
361B-F	2.00 x 2.61	11.6	.647	1,740	11,000	2.75	3.55	3,370	......	......	......	......	-.02	......	-.02	......	0	......	.13	.07	.16	1:30	Simple and splintering tension
371B-F	1.99 x 2.68	12.0	.674	2,000	12,830	2.71	3.67	3,940	3,940	......	......	......	.04	......	.03	......	.05	......	.15	.09	.14	Straight	Splintering and simple tension
381B-F	1.99 x 2.61	12.2	.592	1,600	10,390	2.55	3.15	2,810	2,700	......	......	......	0	......	0	......	0	......	.08	.07	.14	1:18	Simple and slight cross grain tension
391B-F	2.00 x 2.67	11.9	.637	1,450	9,690	1.66	2.32	1,940	1,920	......	......	......	-.01	......	.08	......	.04	......	.06	.08	......	Slight	Simple tension
401B-F	2.00 x 2.66	12.0	.658	1,750	11,140	2.35	3.18	2,710	2,710	......	......	......	.01	......	.02	......	.01	......	.02	.03	.10	Slight	Simple and splintering tension
Average		12.2	.656	1,650	10,580	2.39	3.14	2,550	3,012	......	......	......	0	......	.02	......	.04	......	.07	.11	.15		
511B-FR	1.92 x 2.47	11.6	.590	1,350	9,940	3.65	3.62	2,829	2,960	0	-0.01	0.01	.01	0.04	.02	0.08	.19	......	......	......	......	Straight	Simple tension
521B-FR	1.92 x 2.47	11.8	.704	1,780	13,190	2.40	3.95	3,600	5,150	0	0	0	......	-.02	0	0	0	......	......	......	......	Straight	Splintering tension
Average		11.5	.647	1,560	11,590	3.00	4.78	3,220	4,060	0	0	0	0	.02	.03	.04	.10	......	......	......	......		
531B-FR	1.82 x 2.36	11.9	.667	1,190	11,250	2.41	3.29	2,120	2,350	0	-.01	-.08	.01	.05	.05	.04	.09	0.16	......	......	......	Straight	Simple tension
541B-FR	1.82 x 2.37	12.4	.663	1,150	9,510	1.81	2.28	1,310	1,490	0	0	0	.01	.05	.06	.29	.10	.16	......	......	......	Straight	Simple tension
551B-FR	1.81 x 2.36	12.1	.719	1,570	13,390	2.67	3.49	2,850	4,030	0	0	.02	.04	.07	.07	.25	.09	.18	......	......	......	1:11	Cross grain tension
561B-FR	1.82 x 2.37	11.5	.617	1,080	8,390	2.25	2.35	1,160	1,540	0	.02	.02	.04	.03	.11	......	......	......	......	......	......	Straight	Simple tension
Average		12.0	.664	1,260	10,630	2.30	2.55	1,500	2,350	0	0	.01	.02	.04	.06	.07	.08	.14	......	......	......		
571B-FR	1.71 x 2.32	11.6	.610	980	10,020	2.75	3.65	1,850	1,950	0	0	.02	.01	.11	.14	......	......	......	......	......	......	Slight	Simple tension
581B-FR	1.71 x 2.31	11.7	.652	1,100	11,450	4.24	4.19	2,510	2,510	0	-.03	.02	.03	.10	......	......	......	......	......	......	......	Slight	Simple tension
Average		11.6	.631	1,040	10,740	3.00	3.90	2,160	2,280	0	-.01	+.02	.04	.10	.14	......	......	......	......	......	......		
591B-FR	1.58 x 2.06	11.7	.598	680	8,780	3.16	3.16	1,560	1,560	0	.02	.30	......	......	......	......	......	......	......	......	......	1:8	Cross grain tension
601B-FR	1.59 x 2.07	11.5	.745	1,030	12,890	2.76	1.75	1,370	1,370	0	.01	.02	......	.07	.16	.26	......	......	......	......	......	1:14	Cross grain and simple tension
Average		11.6	.670	860	10,830	2.96	3.50	1,460	1,460	0	0	.06	......	.07	.16	.20	......	......	......	......	......		
Solid steam bent frames																							
311B-F	2.03 x 2.59	11.5	.634	990	6,990	8.25	8.51	7,160	7,130	0	.02	.06	.02	.05	.10	.31	......	......	......	......	......	Very	Break tension at local grain irregularity and a knot hole
321B-F	2.00 x 2.60	11.4	.698	1,560	1,860	14.98	12.52	17,570	13,470	0	0	0	.01	......	......	......	......	......	......	......	......	Slight	Simple tension
331B-F	2.03 x 2.59	10.8	.692	1,260	7,870	15.00	12.70	15,180	17,850	0	-.01	-.01	-.01	.03	.12	......	......	......	......	......	......	Slight	Compression followed by local cross grain tension 10 inches from center
341B-F	2.02 x 2.58	10.0	.652	1,600	9,180	16.32	11.75	14,140	15,650	0	-.02	-.02	.02	.06	.10	.31	......	......	......	......	......	Slight	Compression followed by simple tension
351B-F	2.05 x 2.61	10.4	.692	1,120	8,160	16.75	10.72	11,370	11,530	0	0	-.01	.02	.02	.20	.14	......	......	......	......	......	Straight	Compression followed by simple tension
361B-F	2.00 x 2.60	10.7	.666	1,290	8,900	17.50	11.60	14,160	16,920	0	.02	-.01	.01	.01	.27	.13	......	......	......	......	......	Slight	Compression followed by simple tension
371B-F	2.00 x 2.60	13.4	.672	1,030	7,250	18.00	11.16	15,520	13,520	0	0	.02	-.05	.17	......	......	......	......	......	......	......	Slight	Slight compression, excessive bend
381B-F	2.00 x 2.59	12.1	.696	1,290	9,030	10.29	11.49	16,150	16,150	......	......	......	......	......	......	......	......	......	......	......	......	Slightly wavy	Compression followed by simple tension
391B-F	2.01 x 2.58	11.1	.696	1,170	8,330	14.05	10.98	15,790	13,500	0	-.01	.02	.02	.02	.07	.16	......	......	......	......	......	Slight	Compression followed by simple tension
401B-F	2.00 x 2.59	11.3	.675	1,130	8,090	17.05	13.70	17,160	17,160	0	.01	0	.01	.06	.16	.22	......	......	......	......	......	Straight	Compression followed by simple tension
411B-F	2.00 x 2.50	12.6	.660	930	6,610	18.40	11.63	11,330	12,530	0	-.02	0	.08	.20	......	......	......	......	......	......	......	Slight	Simple tension
421B-F	2.00 x 2.60	11.0	.704	1,050	7,280	7.58	8.14	7,550	5,950	0	0	-.01	0	.06	.72	.17	......	......	......	......	......	Slight (local)	Break tension at local grain irregularity
531B-F	2.01 x 2.61	10.1	.706	1,700	6,740	16.25	12.35	17,240	17,240	0	-.01	0	.03	.08	.10	.11	......	......	......	......	......	Slight	Compression followed by break tension
541B-F	2.01 x 2.60	11.1	.590	1,080	7,380	6.40	7.04	6,130	9,840	0	.06	.10	.11	......	......	......	......	......	......	......	......	1:3	Cross grain compression
551B-F	2.01 x 2.59	10.2	.702	1,270	9,050	10.25	9.85	11,810	11,260	0	.01	-.02	-.01	.02	.32	.04	......	......	......	......	......	1:8	Cross grain tension
561B-F	2.01 x 2.59	11.0	.610	940	6,800	19.45	10.74	10,180	10,180	0	.04	.06	.09	.20	......	......	......	......	......	......	......	Straight	Slight compression followed by simple tension
571B-F	1.99 x 2.59	11.4	.614	990	7,010	14.90	11.75	11,910	11,960	0	-.09	.08	.02	.00	......	......	......	......	......	......	......	Slight	Compression followed by simple and splintering tension
581B-F	2.01 x 2.58	10.3	.670	1,020	7,380	15.07	11.56	14,590	14,395	0	.06	.06	.01	.10	.27	......	......	......	......	......	......	Straight	Compression followed by simple tension
591B-F	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	Specimen broke during steam bending process because of a large check
601B-F	1.96 x 2.59	11.7	.760	1,350	9,960	11.00	11.50	20,050	20,550	0	-.05	0	0	.04	.05	.39	......	......	......	......	......	1:70	Compression followed by simple tension
Average		11.5	.670	1,180	7,980	14.05	10.96	13,670	14,180	0	0	.01	.02	.05	.09	.19	......	......	......	......	......		

[1] Based on weight and volume at test, oven dry.

[2] Set values were obtained by running load up to value shown in column heading, decreasing load to 100 pounds, then increasing load to 200 pounds, taking this deflection reading at the midpoint and subtracting deflection obtained on initial run to 200 pounds.

Z M 63713 F

Table 3.--Results of end thrust tests on white oak laminated bent and solid sawn bent boat frames

Specimen number	Cross section	Moisture content	Specific gravity[1]	End thrust loading: Maximum load	Maximum bending stress	Maximum bending and compressive stress	Deflection at maximum bending stress: Lateral at midpoint	Deflection at maximum bending stress: Vertical measuring chord shortening	Work: Maximum load	Work: Total	Permanent set[2] after being loaded to (pounds): 200	300	400	500	600	700	800	900	Combined slope of spiral and diagonal grain	Description of failure
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
	In.	Percent		Lb.	Lb. per sq. in.	Lb. per sq. in.	In.	In.	In.-lb. per frame	In.-lb. per frame	In.	In.	In.	In.	In.	In.	In.	In.		
Laminated bent frames																				
21LB-F	2.01 x 2.60	10.3	0.681	1,010	8,650	8,880	2.96	5.88	2,480	2,630	0	-0.06	-0.06	+0.02	+0.05	+0.10	......	+0.22	1:20	Simple tension
22LB-F	2.00 x 2.60	13.4	.575	870	7,560	7,730	2.39	4.33	2,120	2,150	0	.01	.01	.05	.11	.17	......	......	Slight	Simple tension
F3LB-F	1.99 x 2.60	12.1	.596	930	7,890	8,030	2.22	4.04	2,550	2,590	0	-.07	-.02	.08	.05	......	......	......	Slight	Simple tension followed by cross grain tension in third lamination from tension face
24LB-F	2.00 x 2.60	12.4	.684	1,140	10,350	10,570	2.33	5.53	4,560	5,680	0	-.01	0	0	.01	.08	.08	......	1:20	Simple, splintering and slight cross grain tension
25LB-F	2.01 x 2.60	10.8	.647	1,100	10,140	10,360	3.39	6.84	3,190	5,300	0	.01	0	.02	.06	.12	......	......	1:25	Splintering tension
F6LB-F	2.00 x 2.60	12.9	.686	1,100	9,950	10,160	3.24	5.98	4,510	4,840	......	.01	.02	.01	.03	.05	......	......	Straight	Simple tension
F7LB-F	2.00 x 2.60	13.1	.599	970	8,290	8,480	1.87	5.35	2,340	2,340	0	-.04	0	0	.03	.06	.13	......	Slight	Simple tension
28LB-F	2.01 x 2.60	12.6	.647	1,180	10,150	10,370	3.05	5.83	4,560	4,550	0	0	.01	.03	.06	.06	......	......	1:15	Slight cross grain and simple tension followed by splintering tension
29LB-F	2.00 x 2.60	12.4	.597	980	8,650	8,840	2.30	4.95	2,800	3,150	0	-.01	0	.02	.02	.03	......	......	1:9 (local)	Cross grain tension followed by splintering tension
30LB-F	2.00 x 2.60	12.0	.636	1,050	9,450	9,680	3.07	5.40	4,520	5,390	0	-.03	.01	.03	.04	.03	......	......	Straight	Simple and splintering tension
Average		12.6	.646	1,030	9,180	9,300	2.74	4.98	3,620	3,990	0	-.01	0	.03	.06	.08	.11	.22		
41LB-FN	1.91 x 2.46	11.8	.674	990	10,800	10,230	2.15	3.90	2,620	2,740	0	.02	.01	.06	.09	.13	.18	......	1:9	Cross grain tension
42LB-FN	1.92 x 2.46	11.4	.746	1,180	11,110	11,390	2.12	4.10	3,190	4,320	0	0	.03	-.01	.02	.06	.11	......	Slight	Splintering tension
Average		11.6	.710	1,040	10,950	10,790	2.14	4.00	2,825	3,530	0	.01	.02	.02	.06	.10	.15	......		
[illegible]	1.83 x 2.36	11.2	.616	690	8,280	8,540	2.87	5.10	2,460	2,610	0	.08	.10	.18	......	......	......	......	Straight	Simple tension
[illegible]	1.82 x 2.36	11.7	.601	580	6,970	7,100	2.42	4.80	2,000	2,000	0	-.04	.07	.20	......	......	......	......	1:11	Simple tension
[illegible]	1.82 x 2.36	11.7	.638	710	8,480	8,640	2.37	4.60	2,380	2,430	0	-.02	0	.06	.18	......	......	......	1:9 (local)	Cross grain tension followed by simple tension
[illegible]	1.87 x 2.36	11.6	.630	740	9,170	9,390	2.75	4.10	2,720	2,720	0	-.01	.05	.11	.19	......	......	......	Slight	Simple tension
Average		11.6	.621	680	8,220	8,390	2.61	4.90	2,380	2,440	0	0	.06	.14	.17	......	......	......		
[illegible]	1.70 x 2.22	11.2	.638	770	11,670	11,870	3.44	6.72	3,960	5,000	0	.03	.08	.15	......	......	......	......	Straight	Splintering tension
[illegible]	1.79 x 2.22	11.7	.655	550	7,310	8,050	2.50	5.00	1,960	1,960	0	-.03	.05	.29	......	......	......	......	Straight	Simple tension
Average		11.4	.646	660	9,490	9,960	2.97	5.86	2,960	3,480	0	0	.06	.22	......	......	......	......		
[illegible]	1.58 x 2.07	11.6	.686	650	8,420	8,560	3.23	6.60	2,310	2,310	0	......	......	......	......	......	......	......	Slight	Simple tension
[illegible]	1.59 x 2.06	11.8	.683	510	11,640	11,890	3.75	7.42	1,650	1,730	0	.11	.34	......	......	......	......	......	Straight	Splintering and simple tension
Average		11.7	.680	590	10,030	10,200	3.49	7.21	1,980	2,020	0	.11	.34	......	......	......	......	......		
Solid sawn bent frames																				
21SB-F	2.00 x 2.50	23.9	.583	580	5,670	5,790	3.10	6.13	2,670	3,120	0	.05	.13	.25	......	......	......	......	1:22	Splintering tension
22SB-F	2.00 x 2.50	24.7	.565	540	4,690	4,690	2.60	5.05	1,970	2,030	0	.09	.14	.30	......	......	......	......	1:17	Simple tension
F3SB-F	2.00 x 2.50	21.6	.573	520	4,450	4,560	2.39	4.68	1,060	1,180	0	0	.11	......	......	......	......	......	Slight	Simple tension
P4SB-F	2.00 x 2.50	18.7	.568	625	5,720	5,850	2.58	5.83	2,520	4,500	0	.04	.08	.10	......	......	......	......	1:22	Splintering and simple tension
F5SB-F	2.00 x 2.50	18.1	.602	640	5,090	6,170	3.30	7.04	3,540	3,520	0	-.01	0	.13	......	......	......	......	1:25	Splintering and simple tension
26SB-F	2.00 x 2.50	15.0	.588	660	6,390	6,590	2.56	5.25	2,060	5,200	0	.04	-.03	.10	......	......	......	......	1:25	Splintering and simple tension
Average		20.0	.614	600	5,540	5,560	2.87	5.64	2,480	4,040	0	.03	.06	.22	......	......	......	......		
[illegible]	1.58 x 2.51	10.8	.398	700	6,450	6,590	2.25	4.25	2,090	2,120	0	-.01	.01	.08	.13	......	......	......	Straight	Simple tension
[illegible]	1.56 x 2.51	10.5	.550	570	5,260	5,370	1.75	3.45	1,300	1,390	0	+.02	.05	.05	......	......	......	......	1:16	Tension at knot on tension face and simple tension
F5SB-F	......																			Specimen broke during steam bending process due to severe cross grain
30SB-F	1.58 x 2.58	10.7	.521	790	7,690	7,740	3.13	6.20	3,550	3,690	0	-.01	.01	.04	.08	......	......	......	Straight	Simple tension
41SB-F	1.58 x 2.57	10.2	.630	620	5,800	5,790	1.50	4.53	1,920	2,050	0	.02	.06	.11	......	......	......	......	1:10	Simple and slight local cross grain tension
42SB-F	1.58 x 2.57	10.1	.596	660	6,010	6,190	4.75	7.18	1,640	1,840	0	.03	.09	.06	.07	......	......	......	1:7	Cross grain tension
43SB-F	1.57 x 2.57	11.0	.603	770	5,360	5,530	2.82	6.54	1,690	1,690	0	0	.05	.12	......	......	......	......	1:10	Brash and cross grain tension
44SB-F	1.58 x 2.58	10.4	.708	690	6,380	6,590	2.50	4.30	2,280	2,280	0	.03	.04	.09	.16	......	......	......	1:6 (local)	Brash and local cross grain tension
45SB-F	1.58 x 2.58	9.3	.636	590	5,860	5,990	1.75	3.30	1,350	1,110	0	.04	.07	.09	.15	......	......	......	1:20	Splintering and simple tension
46SB-F	1.58 x 2.57	9.8	.655	540	5,830	5,980	2.25	4.32	1,700	1,760	0	.03	.03	.12	......	......	......	......	Slight	Simple tension
47SB-F	1.58 x 2.58	10.1	.642	510	8,780	7,070	2.79	7.50	4,860	4,880	0	0	.08	.13	......	......	......	......	Slight	Simple tension
48SB-F	1.58 x 2.60	10.3	.641	560	5,070	7,170	2.25	4.27	1,640	1,670	0	.04	.06	.11	......	......	......	......	Slight	Simple tension
49SB-F	1.58 x 2.57	9.5	.623	530	4,790	5,890	2.10	4.00	1,300	1,320	0	0	.04	.17	......	......	......	......	Slight	Brash tension
50SB-F	1.58 x 2.57	10.6	.714	770	7,450	7,600	2.88	5.88	3,340	3,290	0	0	.01	.03	.12	......	......	......	Straight	Simple tension
Average		10.4	.652	603	6,700	6,330	2.38	4.63	2,180	2,290	0	.02	.04	.09	.12	......	......	......		
Grand average		13.4	.647	642	5,960	6,060	2.54	4.75	2,080	2,820	0	.02	.05	.17	......	......	......	......		

[1] Based on weight and volume at ovendry wood.

[2] Set values were obtained by applying load up to value shown in column heading, decreasing load to 100 pounds, then increasing load to 750 pounds, taking this deflection reading at the midpoint and subtracting deflection obtained on initial 750 to 700 pounds.

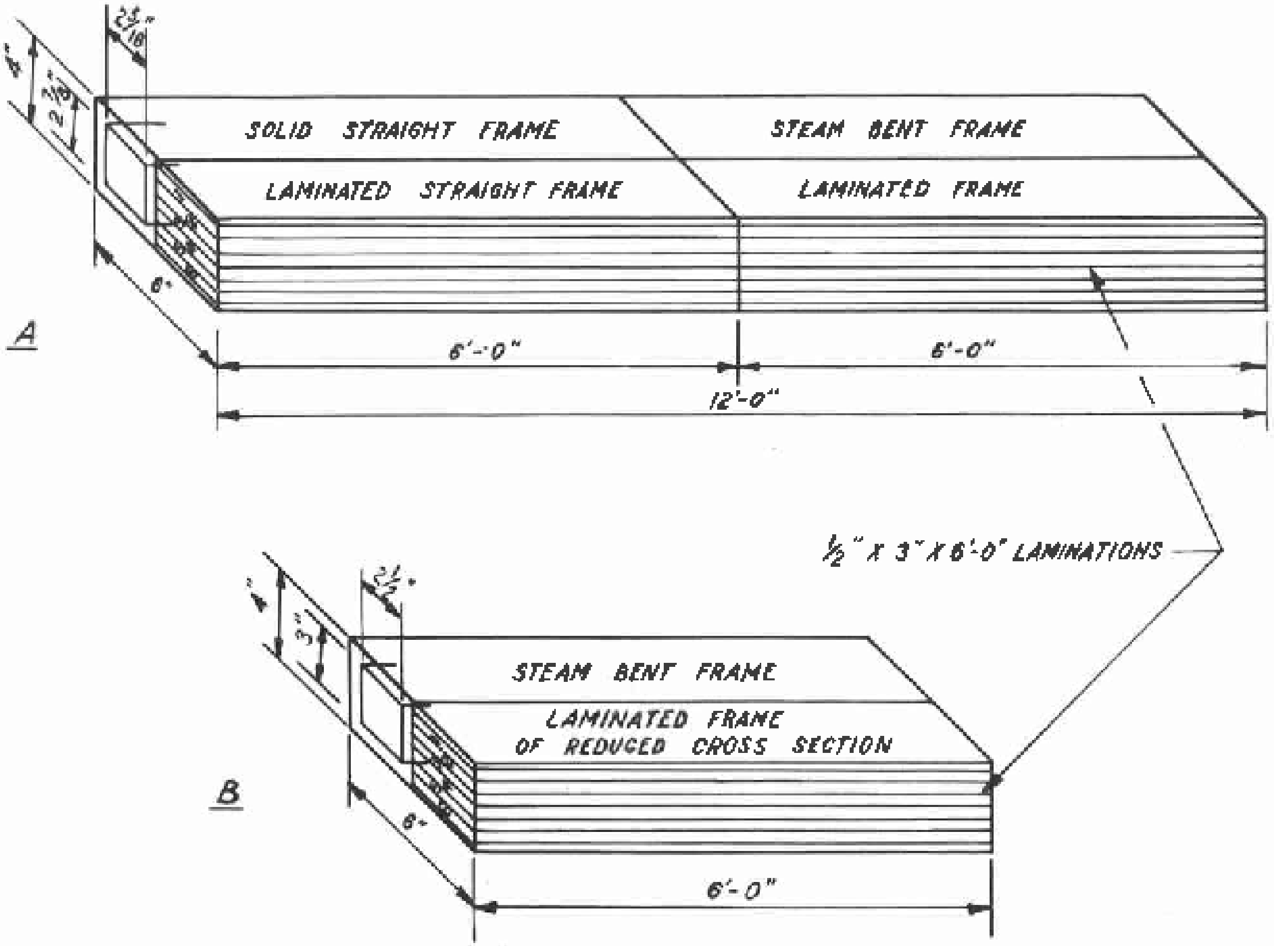
Z M 63714 F

Table 4.--Results of transverse tests on white oak laminated and solid straight pieces - center loading
(Pieces matched to test boat frames)

Control specimens	Specimen number	Cross section	Moisture content	Specific gravity[1]	Static bending: Stress at proportional limit	Static bending: Modulus of rupture	Static bending: Modulus of elasticity	Static bending: Work: Proportional limit	Static bending: Work: Maximum load	Static bending: Work: Total	Combined slope of spiral and diagonal grain	Description of failure
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
		In.	Percent		Lb. per sq. in.	Lb. per sq. in.	1,000 lb. per sq. in.	In.-lb. per cu. in.	In.-lb. per cu. in.	In.-lb. per cu. in.		
							Laminated					
	2110-F	2.00 x 2.60	11.9	0.649	6,080	11,990	1,320	1.52	12.4	13.2	1:17	Cross grain tension followed by splitting between fifth and sixth lamination from top
Matching	2210-F	2.00 x 2.60	11.9	.617	6,530	8,600	1,380	1.72	3.3	4.6	1:4 (local)	Cross grain tension
	2310-F	2.00 x 2.60	11.5	.637	5,840	10,840	1,350	1.40	8.5	10.4	Straight	Simple tension
and thrust	2410-F	2.00 x 2.60	11.5	.670	6,190	12,250	1,590	1.42	15.7	16.6	1:11 (local)	Slight cross grain tension followed by simple tension
tests	2510-F	2.00 x 2.60	11.8	.687	5,820	11,580	1,280	1.48	11.5	11.6	1:25	Simple and splintering tension
	2610-F	2.00 x 2.60	11.7	.695	6,310	12,680	1,430	1.54	12.2	12.2	Straight	Simple tension
	2710-F	2.00 x 2.60	12.0	.687	5,190	10,940	1,490	1.34	7.1	7.1	1:15 (local)	Simple tension
	2810-F	2.00 x 2.60	11.6	.664	5,800	11,710	1,360	1.24	9.0	9.0	1:14	Simple tension
	2910-F	2.00 x 2.60	12.0	.734	5,350	8,000	1,135	1.41	4.0	4.0	1:4 (local)	Cross grain tension
	3010-F	2.00 x 2.60	11.6	.658	5,900	12,300	1,420	1.18	13.8	16.4	1:14	Splintering tension
Average			11.8	.664	5,925	11,040	1,380	1.42	9.8	10.5		
	3110-F	2.00 x 2.50	11.4	.610	6,880	10,180	1,400	1.82	5.7	6.1	1:11	Slight cross grain tension followed by simple tension
Matching	3210-F	2.00 x 2.50	11.8	.645	4,450	8,370	1,030	1.08	5.6	5.6	1:25	Simple tension
	3310-F	2.00 x 2.50	11.8	.656	6,200	13,080	1,450	1.47	12.0	12.0	Straight	Simple tension
	3410-F	2.00 x 2.50	11.8	.687	5,160	10,110	1,300	1.14	7.6	7.6	1:15	Simple tension
transverse	3510-F	2.00 x 2.50	11.4	.685	6,190	13,340	1,570	1.35	12.6	14.4	Straight	Splintering tension
	3610-F	2.00 x 2.50	11.7	.658	6,140	11,960	1,600	1.32	14.4	14.4	1:25	Splintering tension
tests	3710-F	2.00 x 2.50	12.0	.680	7,300	13,840	1,580	1.88	11.8	14.9	1:28	Splintering and simple tension
	3810-F	2.00 x 2.50	12.1	.675	5,730	8,610	1,160	1.57	5.1	5.1	Straight	Simple tension
	3910-F	2.00 x 2.50	12.1	.661	6,840	11,020	1,360	1.94	7.6	8.1	1:17	Simple tension
	4010-F	2.00 x 2.50	11.7	.671	5,500	12,180	1,470	1.14	10.7	13.5	1:30	Simple tension
Average			11.8	.657	6,040	11,240	1,390	1.46	9.4	10.2		
							Solid					
	2180-F	2.00 x 2.60	13.0	.621	6,435	11,390	1,300	1.77	10.6	10.6	1:12	Cross grain tension
	2280-F	1.86 x 2.60	13.3	.590	4,460	8,100	1,320	.90	4.3	4.3	1:6 (local)	Cross grain tension
	2380-F	1.92 x 2.77	13.3	.620	5,700	10,830	1,390	1.30	11.0	11.0	1:30	Simple tension
Matching	2480-F	2.00 x 2.76	12.4	.674	5,190	10,650	1,540	.97	8.3	14.7	1:6 (local)	Local cross grain tension followed by simple tension
and thrust	2580-F	1.87 x 2.77	12.9	.612	5,180	9,930	1,230	1.24	8.7	8.7	1:18	Simple tension
	2680-F	1.99 x 2.60	13.0	.676	7,420	13,160	1,680	1.83	11.0	19.6	1:50	Splintering tension
tests	2780-F	1.99 x 2.60	12.3	.671	5,290	11,310	1,460	1.47	9.9	9.9	1:25	Simple tension
	2880-F	2.00 x 2.60	12.1	.658	5,480	11,680	1,360	1.66	10.6	10.6	1:12	Slight cross grain and simple tension
	2980-F	1.71 x 2.74	15.3	.688	4,000	5,100	1,290	.71	1.3	1.3	1:4	Cross grain tension
	3080-F	1.99 x 2.59	13.2	.598	5,290	9,350	1,310	1.15	6.2	7.2	1:21	Simple tension followed by slight cross grain tension
Average			13.1	.641	5,680	10,190	1,370	1.30	8.2	9.8		
	3180-F	1.94 x 2.60	16.1	.602	6,710	9,640	1,360	1.98	6.7	11.5	1:9	Cross grain tension followed by simple tension
	3280-F	1.99 x 2.60	12.4	.626	5,090	8,240	1,080	1.31	5.7	5.7	1:12	Mostly simple tension followed by cross grain tension
Matching	3380-F	1.99 x 2.60	13.4	.665	5,890	11,420	1,450	1.32	8.4	8.9	Straight	Simple tension
	3480-F	1.99 x 2.60	12.8	.626	5,180	10,290	1,290	1.71	10.2	10.8	1:15	Simple tension
stationary	3580-F	1.99 x 2.60	12.5	.677	6,920	12,660	1,880	1.43	11.9	16.0	Straight	Splintering tension
	3680-F	2.00 x 2.60	13.8	.693	5,530	11,490	1,580	1.97	15.6	18.0	1:14	Mostly splintering tension followed by slight cross grain tension
tests	3780-F	2.00 x 2.60	13.0	.613	5,510	12,590	1,440	1.13	12.4	17.0	Slight	Splintering tension
	3880-F	1.98 x 2.60	13.5	.632	5,340	8,730	1,120	1.35	5.1	5.1	1:36	Simple tension
	3980-F	2.00 x 2.60	13.6	.635	5,510	9,530	1,380	1.39	5.6	5.6	1:25	Simple tension
	4080-F	2.00 x 2.60	13.9	.679	6,280	11,940	1,530	1.39	9.5	15.2	Slight	Simple and splintering tension
Average			13.5	.644	5,740	10,670	1,405	1.51	9.1	11.3		

[1] Based on weight and volume of oven-dry wood.

Z M 63715 F



Z M 63737 F

Figure 1.--Method of matching.

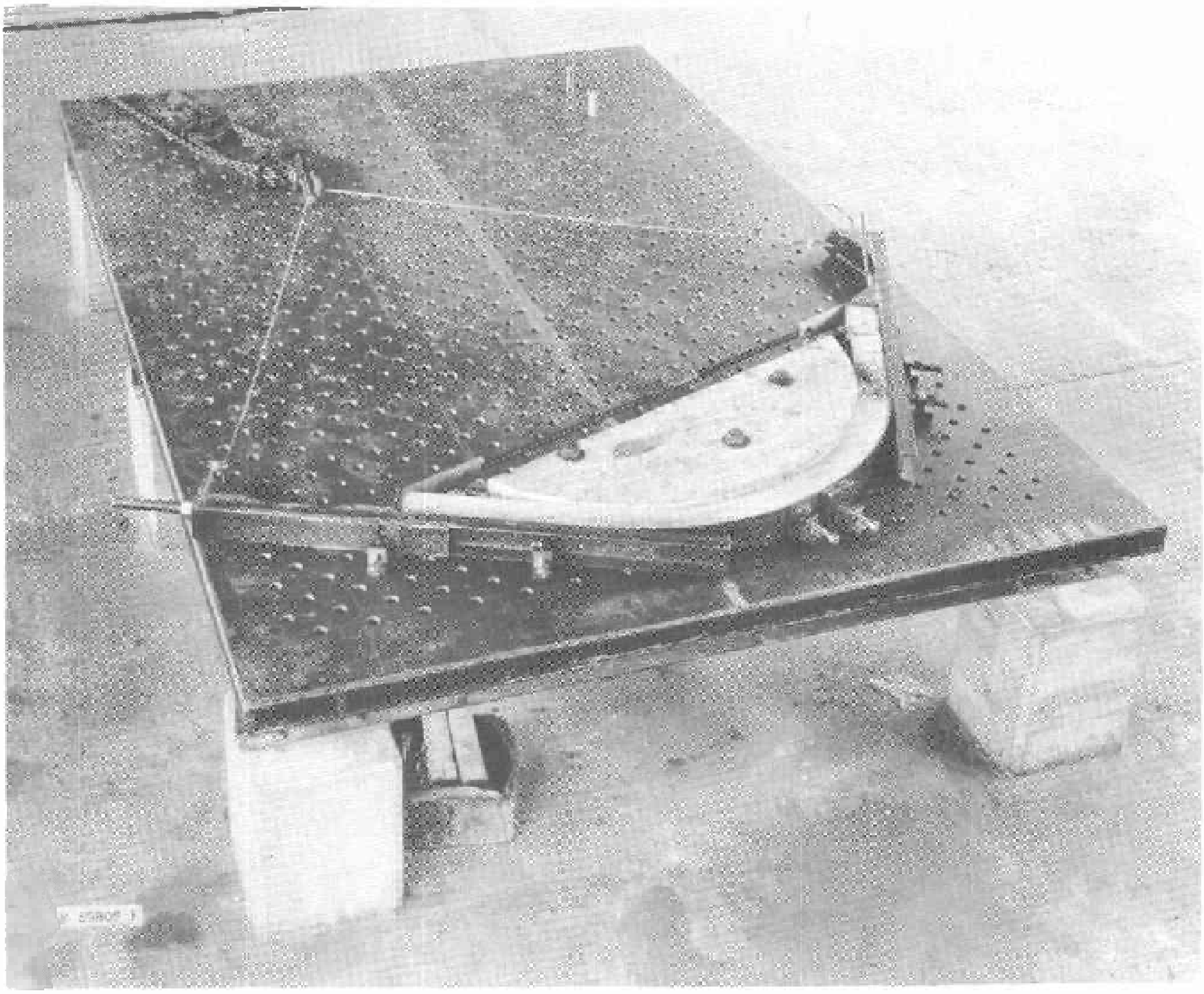
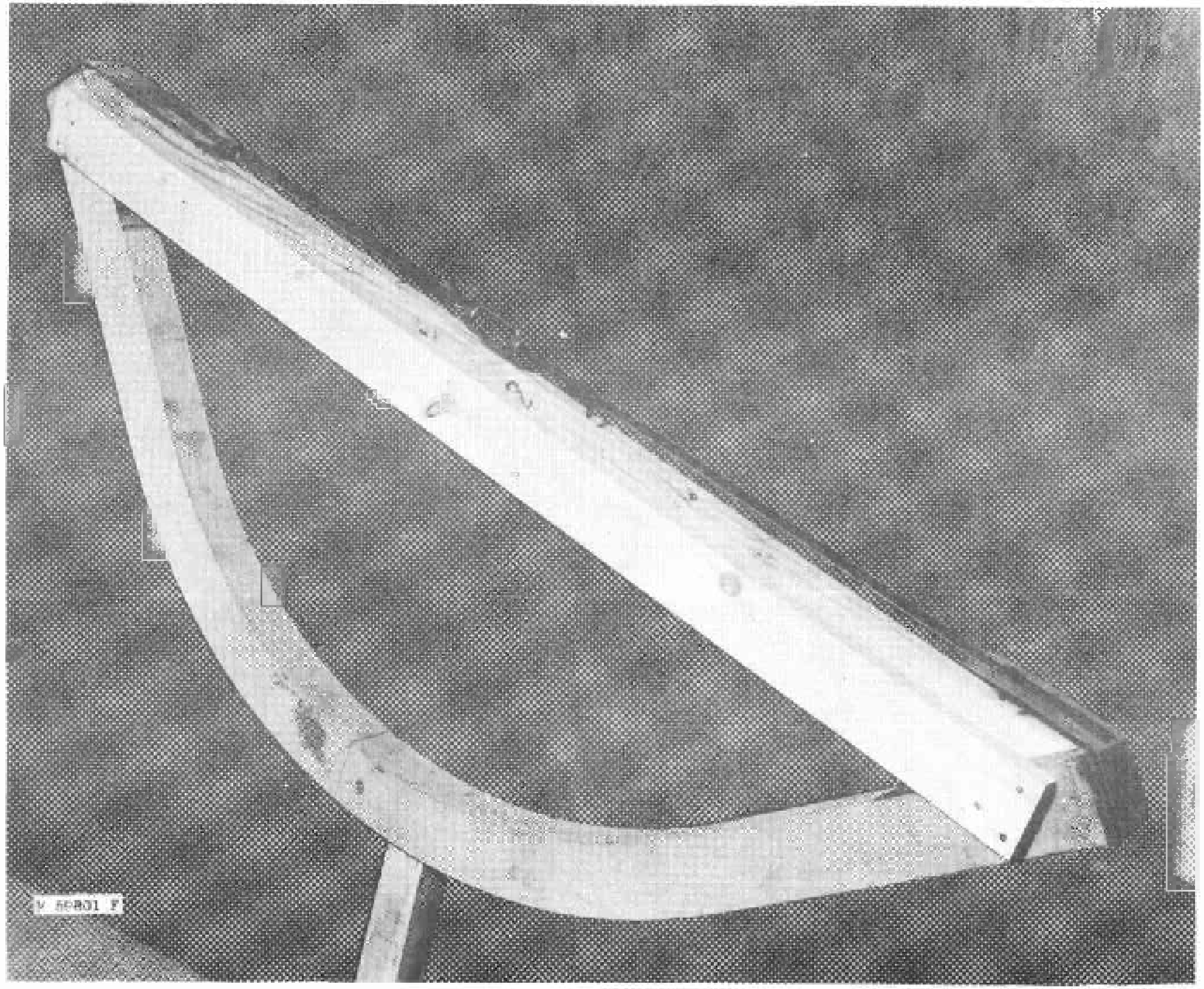


Figure 2.--Complete assembly of equipment for steam bending frames. The frame, which is between the wooden form and a metal strap, was forced into the position shown with use of the tackle arrangement. End brackets attached to the steel channels prevent excessive tension stresses on the convex side of the frame during the bending process.

Z M 67737 F



3.--Method of reta... of steam-bent frames during subsequent s...
...str... joined by another metal strap and
... each side of the bent frame near its ends

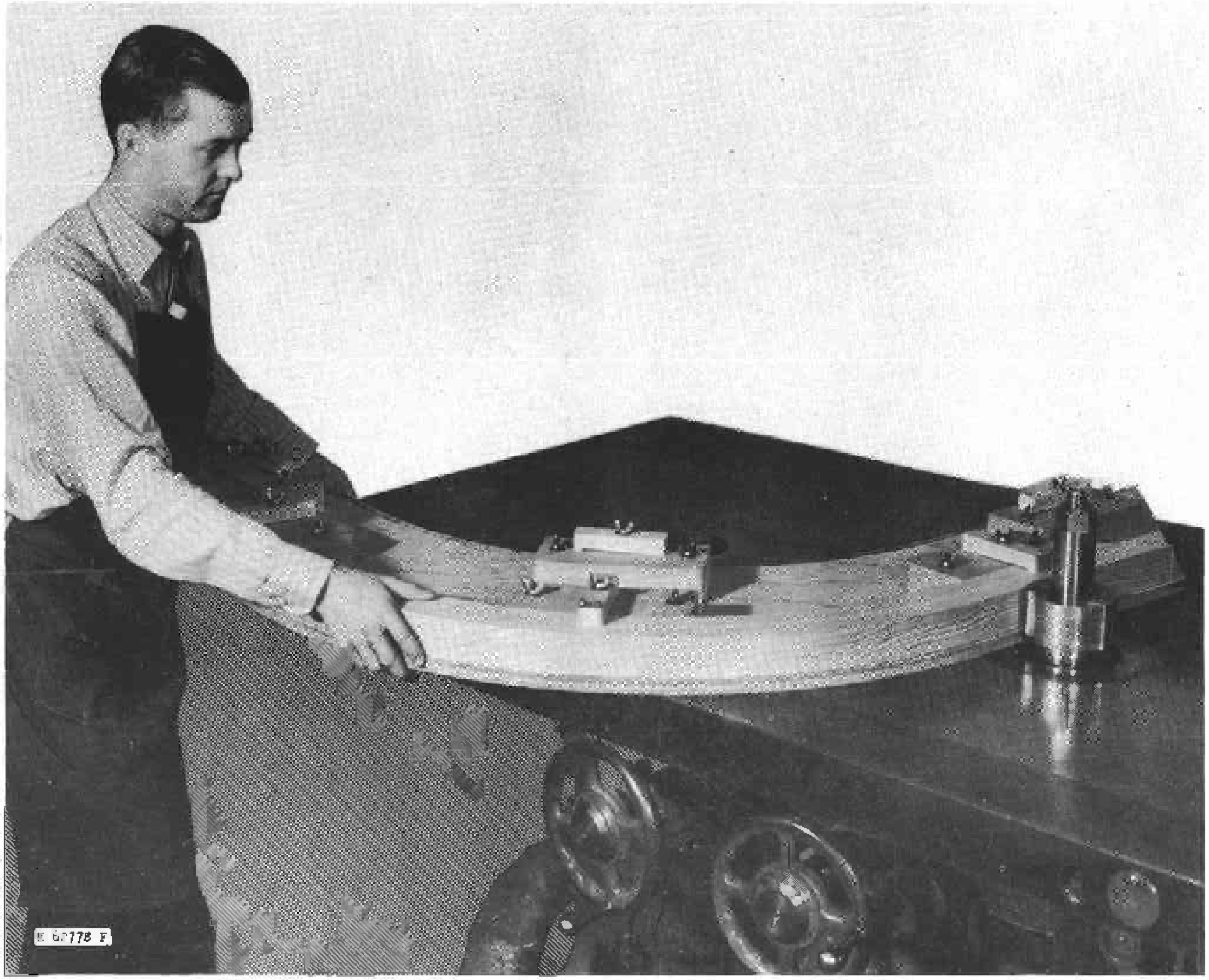


Figure 4.--Jig used for surfacing the laminated and steam-bent frames to the required depth and curvature. A laminated frame is in place for the surfacing of the convex face.

Z M 67739 F

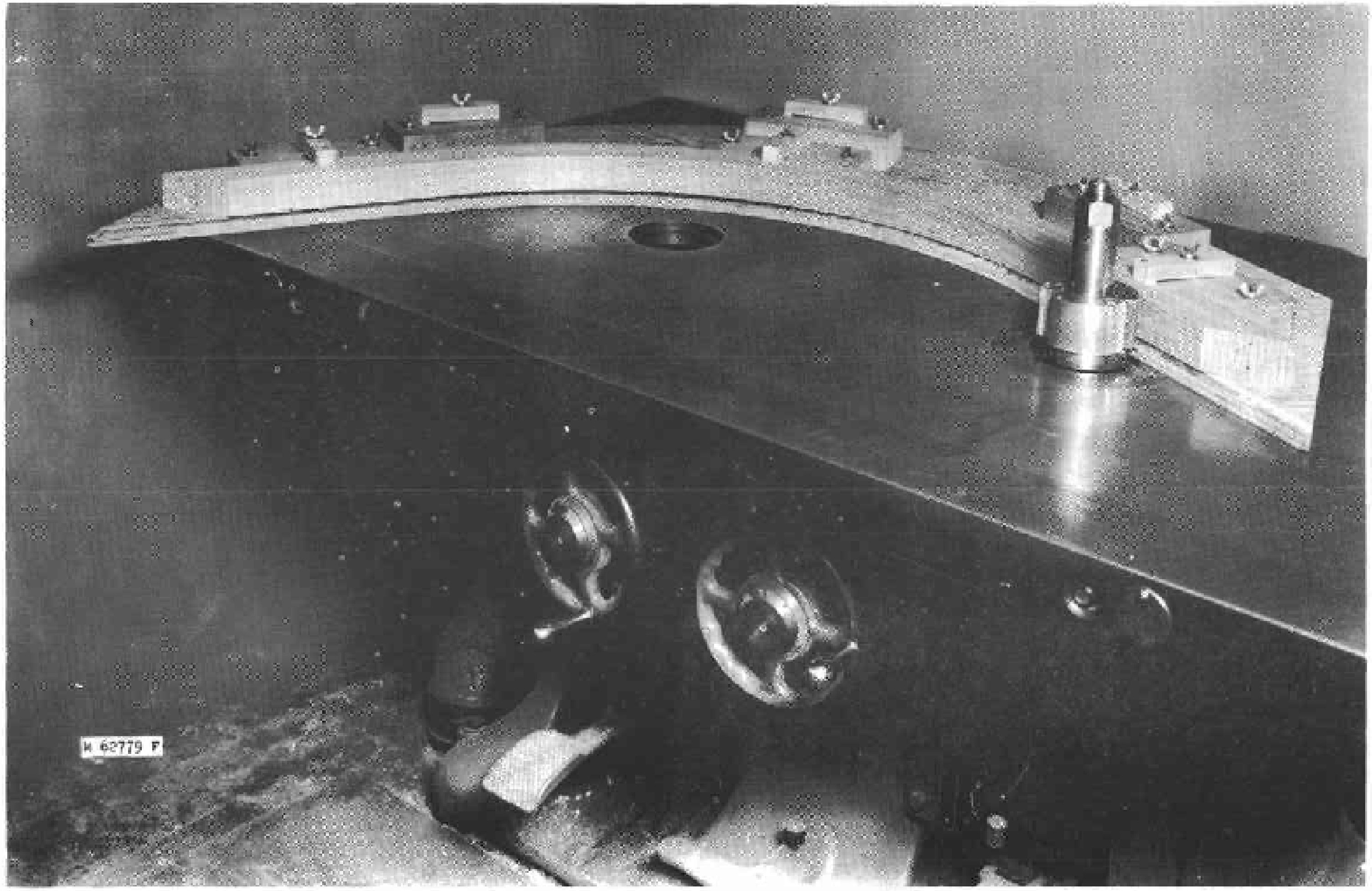
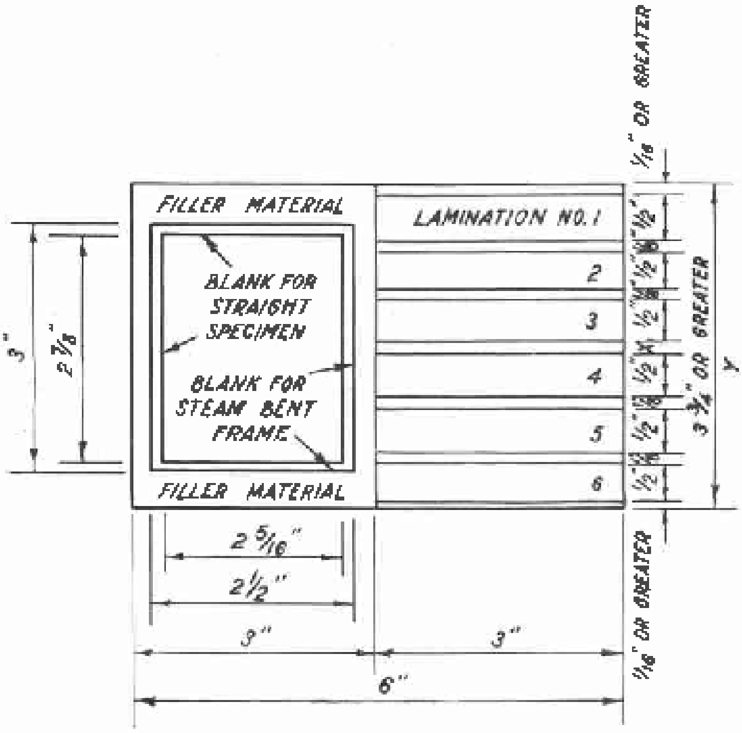


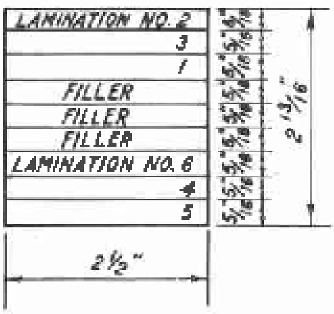
Figure 5.--Jig used for surfacing the laminated and steam-bent frames to the required depth and curvature. A laminated frame is in place for the surfacing of the concave face.

Z M 67740 F

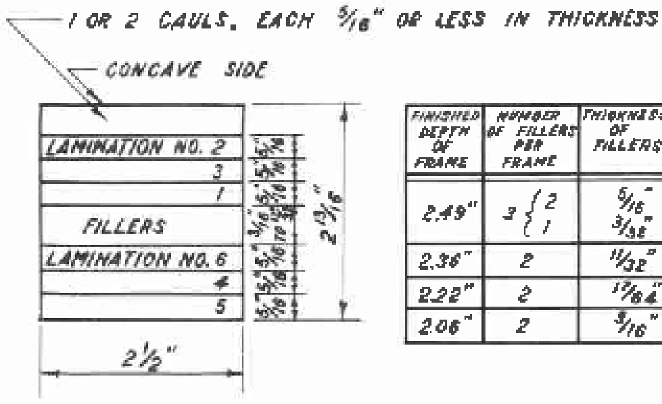


Y	X
4" OR GREATER	3/8"
3 15/16"	5/16"
3 7/8"	1/4"
3 13/16"	3/16"
3 3/4"	1/8"

A.- CUTTING DIAGRAM FOR FRAMES



SPECIMENS AND FRAMES
2" X 2.6" IN CROSS SECTION



FINISHED DEPTH OF FRAME	NUMBER OF FILLERS PER FRAME	THICKNESS OF FILLERS
2.49"	3 {2, 1}	5/16", 3/32"
2.36"	2	11/32"
2.22"	2	17/64"
2.06"	2	3/16"

FRAMES OF REDUCED CROSS SECTION

B. - LAMINAE ASSEMBLY DETAILS

Figure 6.--Details of matching material for frames and straight specimens.

ZM 83738 F

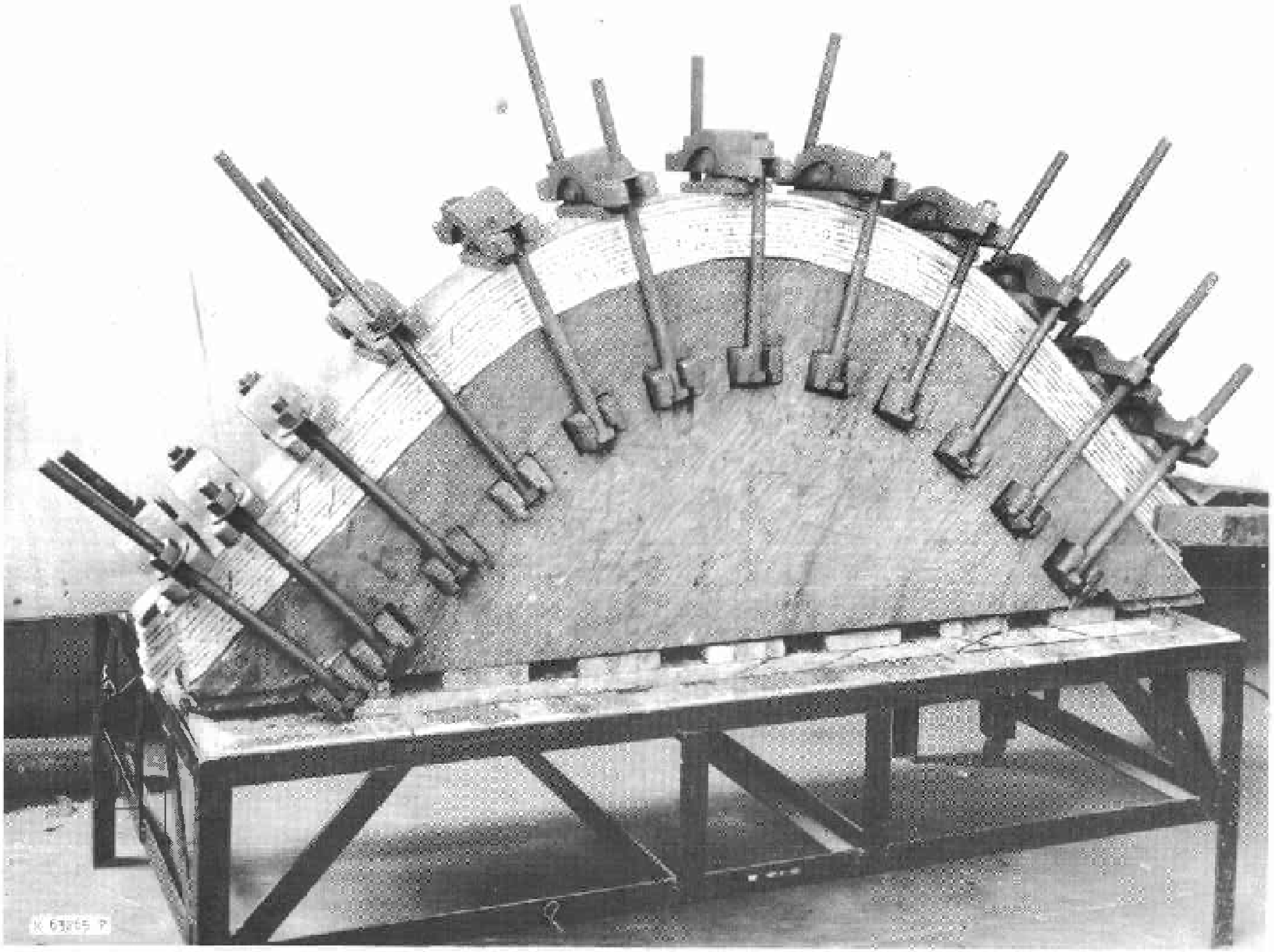


Figure 7.--Complete assembly of equipment for bending laminated boat framing members. Two laminated frames are shown clamped in place over the wooden form of 22.9-inch radius. Plywood sides were glued to the wooden form for holding the clamps in place.

Z M 67741 F

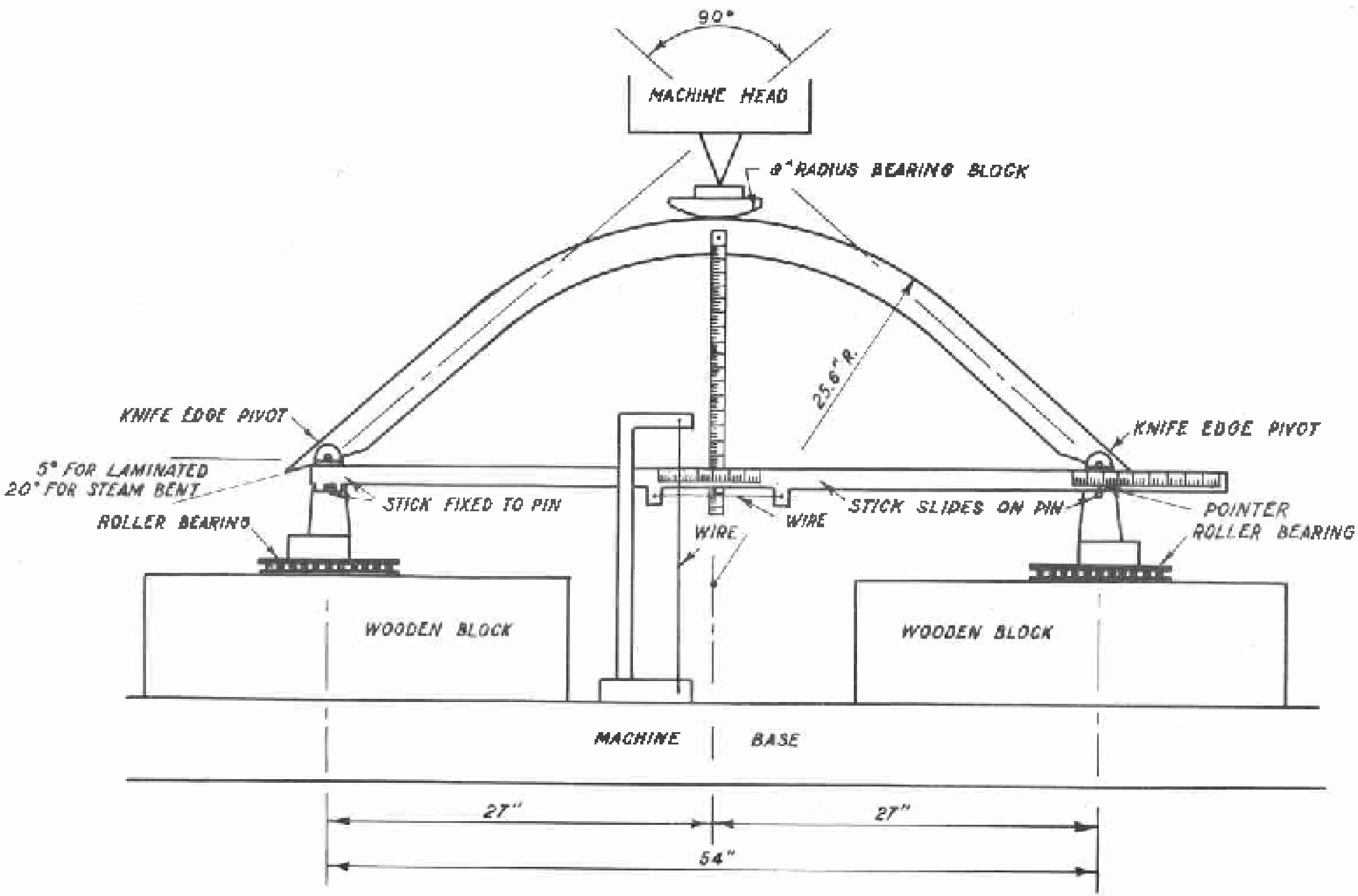


Figure 8.--Transverse test for boat frame.

Z M 63709 F

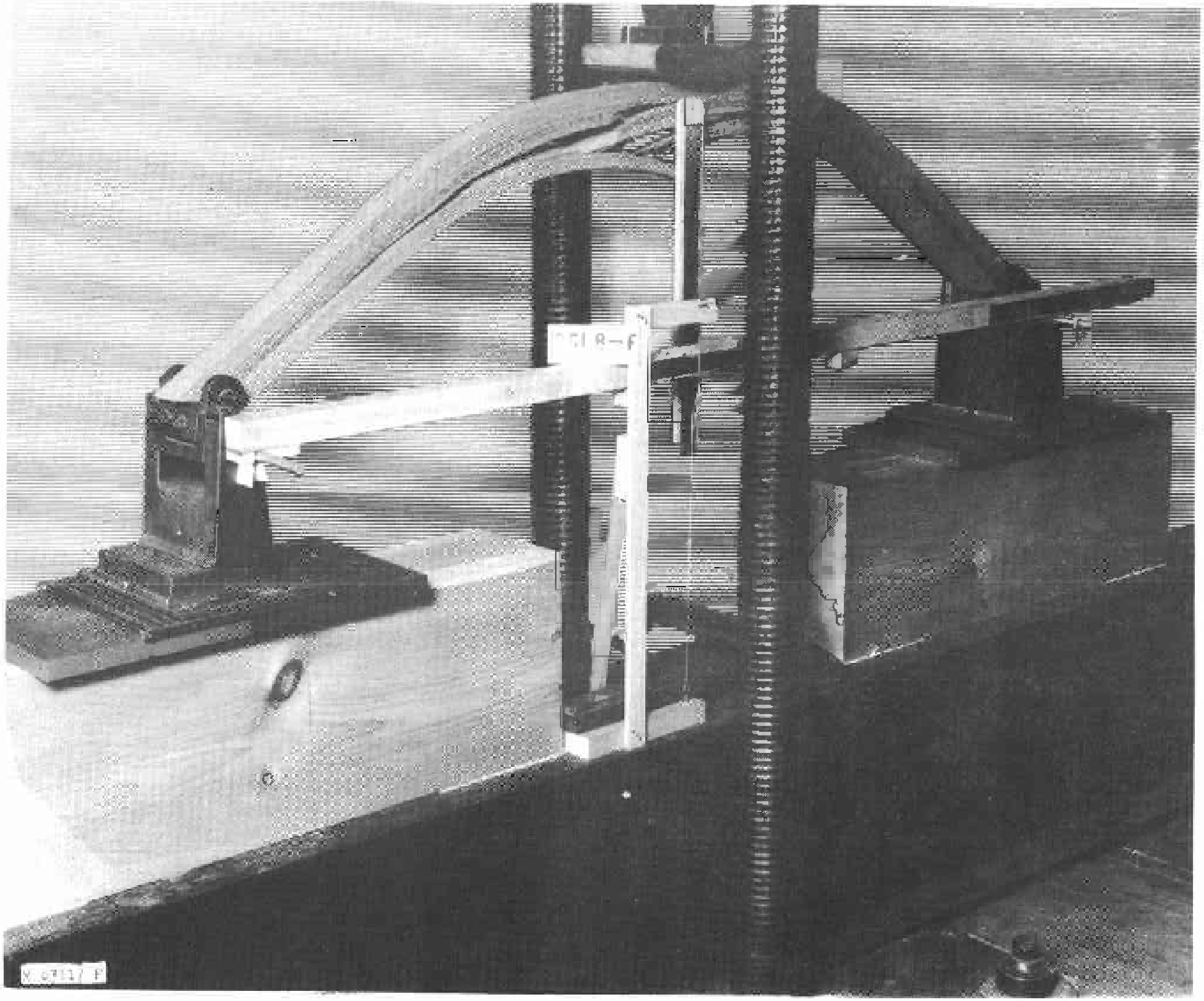


Figure 9.--Laminated frame in testing machine showing a typical failure under transverse loading.

Z M 67745 F

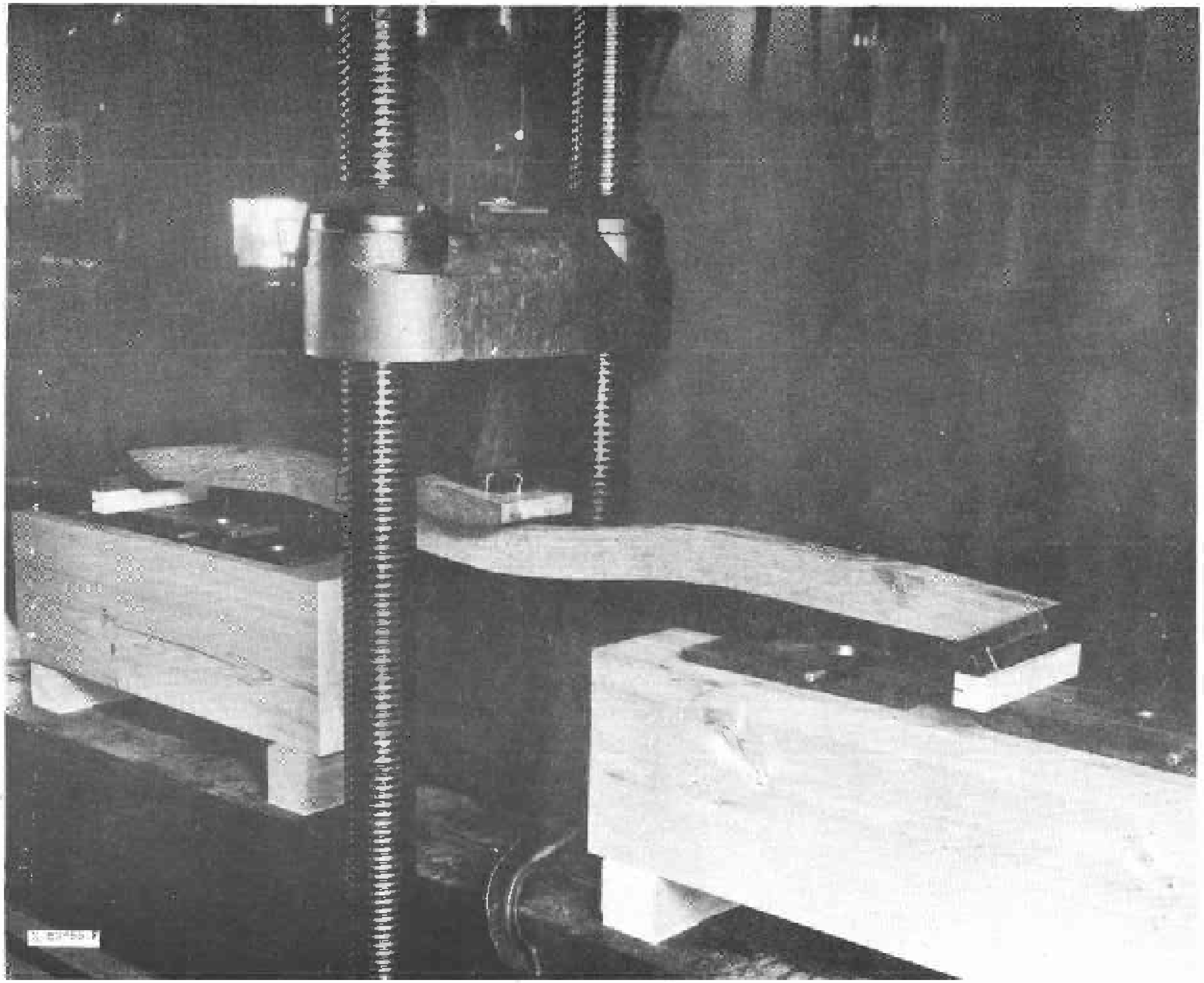


Figure 10.--Steam-bent frame in testing machine showing degree of bend prior to complete failure under transverse loading.

M 67746 F

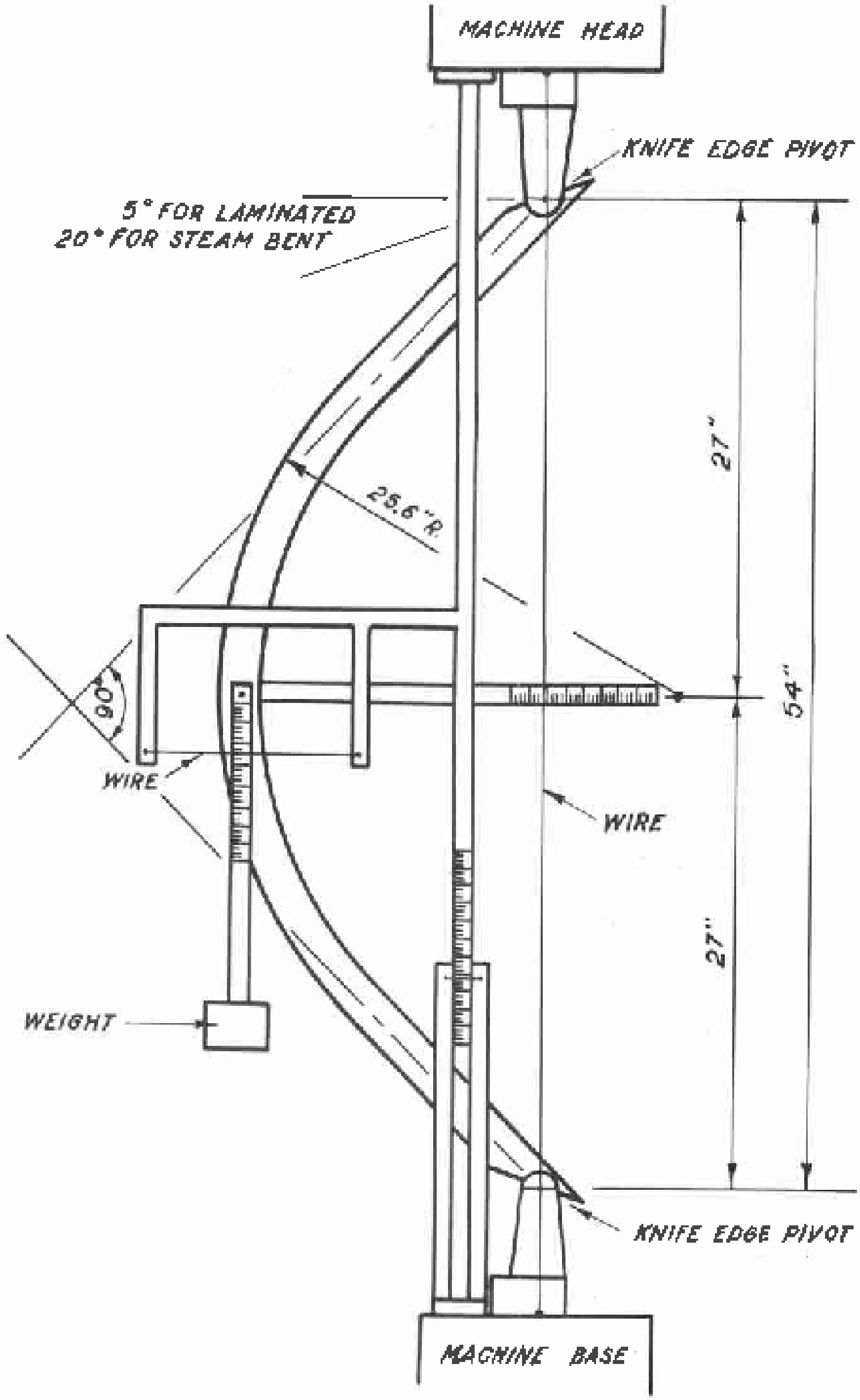


Figure 11.--End thrust test for boat frame.

Z M 63710 F

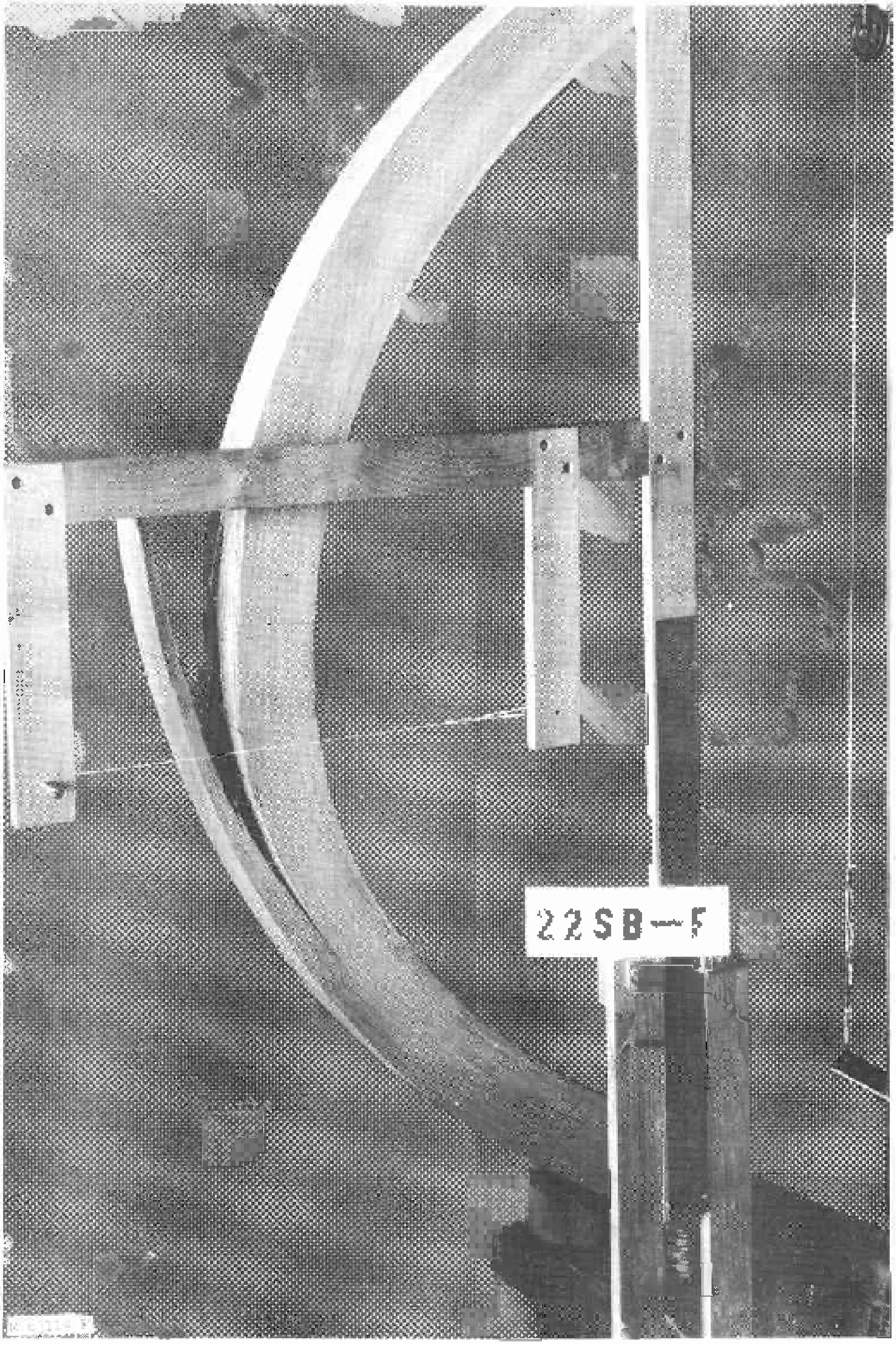


Figure 12.--Steam-bent frame in testing machine showing a typical failure under end-thrust loading.

Z M 67742 F

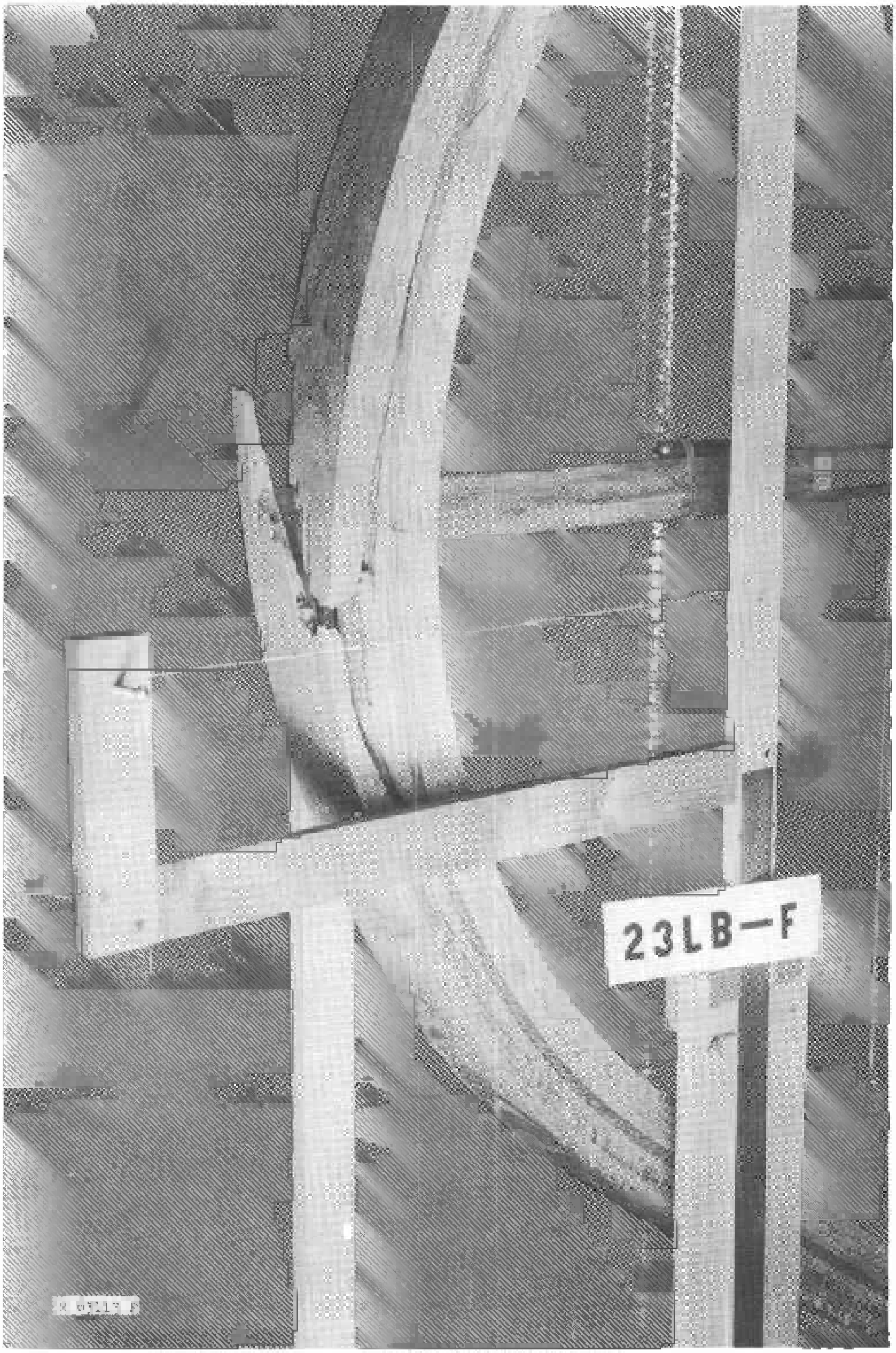


Figure 13.--Laminated frame in testing machine showing typical failure under end-thrust loading.

Z M 67743 F

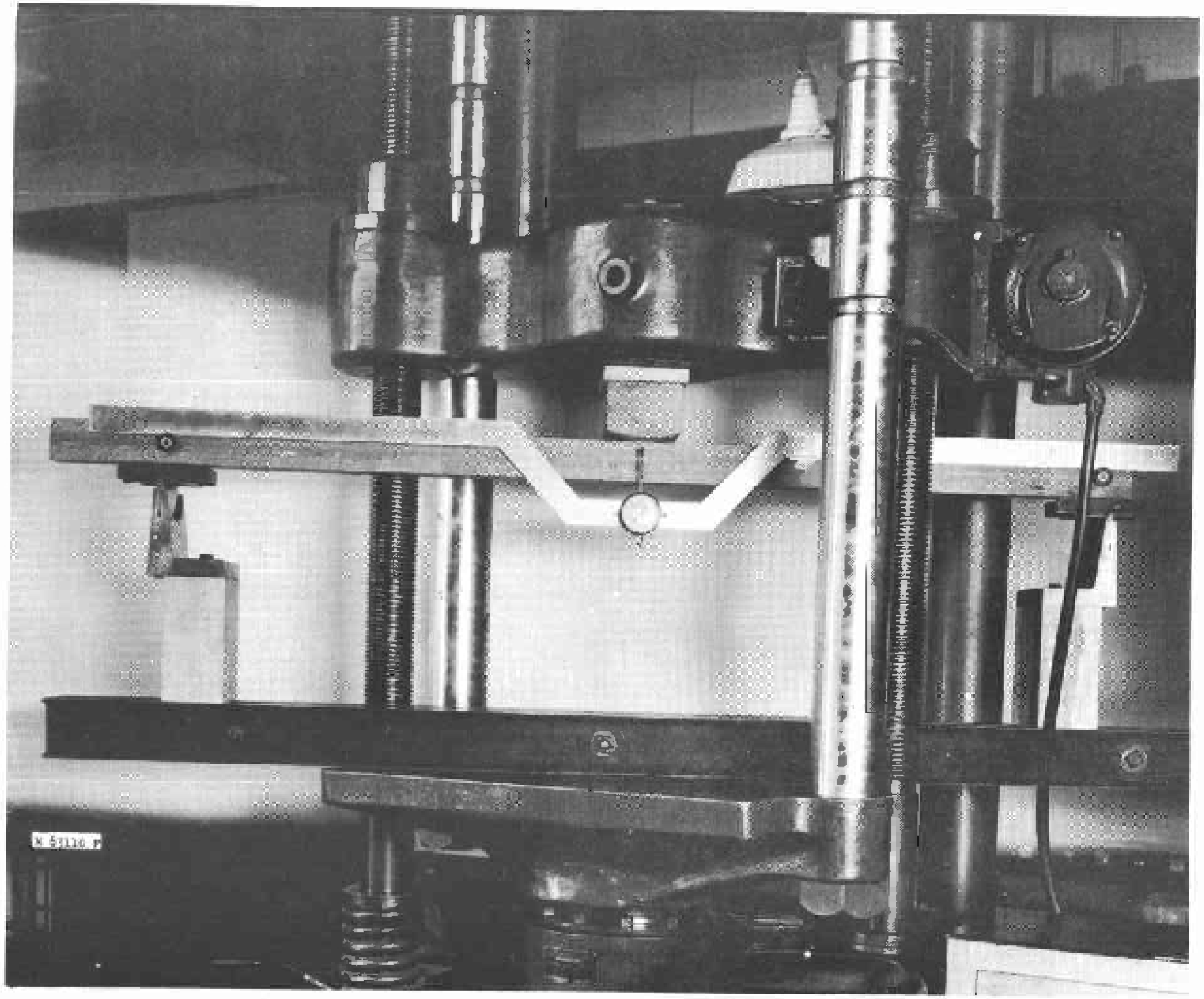


Figure 14.--Method of conducting transverse tests of 2.0- by 2/6-inch by 6-foot straight controls over a 62-inch span, showing: the 8-inch radius bearing block rigidly attached to the head of the testing machine; dial attached to a yoke for measuring center deflections corresponding to load increments; roller bearings over the knife edges at the supports.

Z M 67744 F

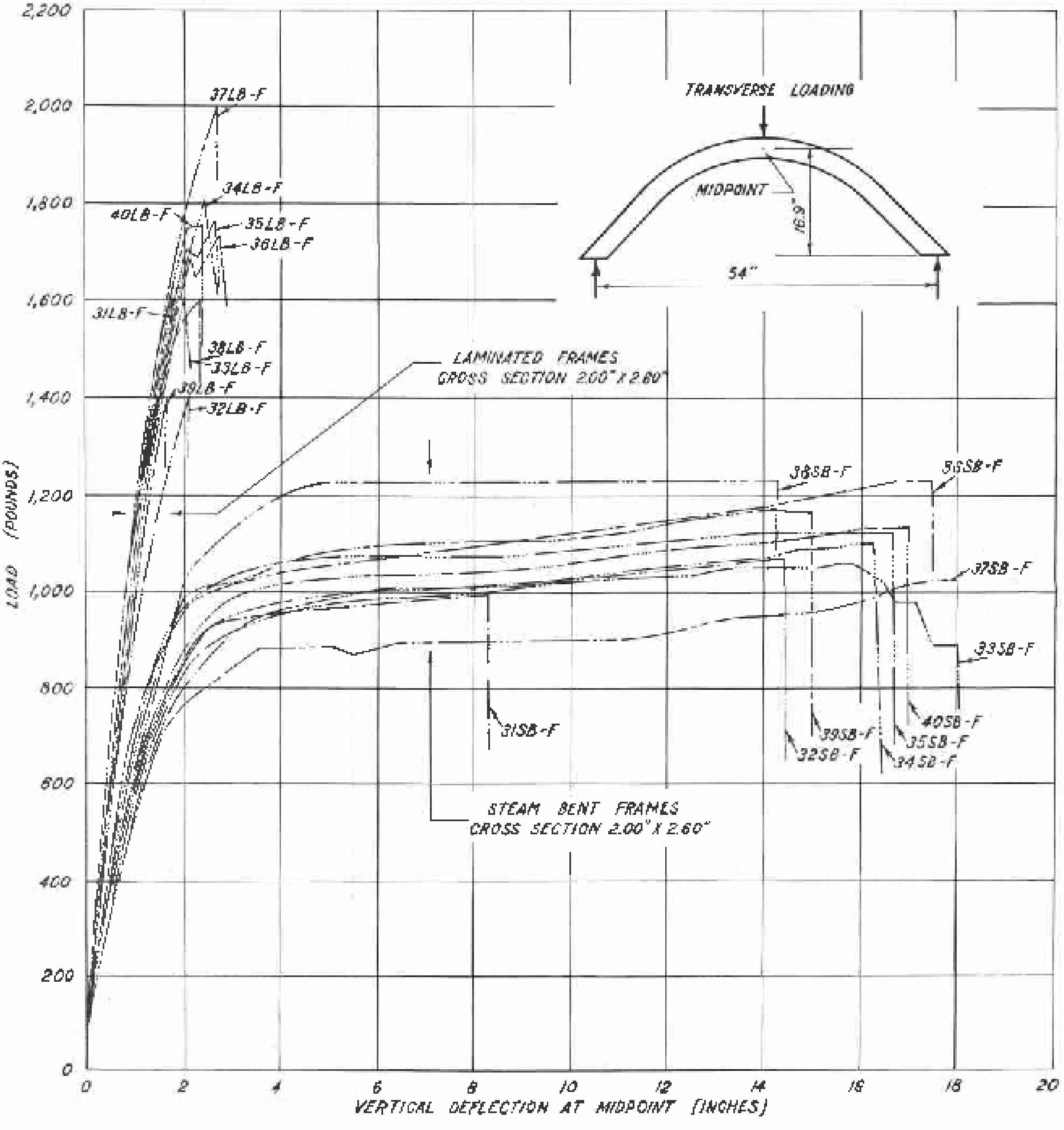


Figure 15.--Load-deflection curves for white oak laminated bent and solid steam bent frames.

Z M 63598 F

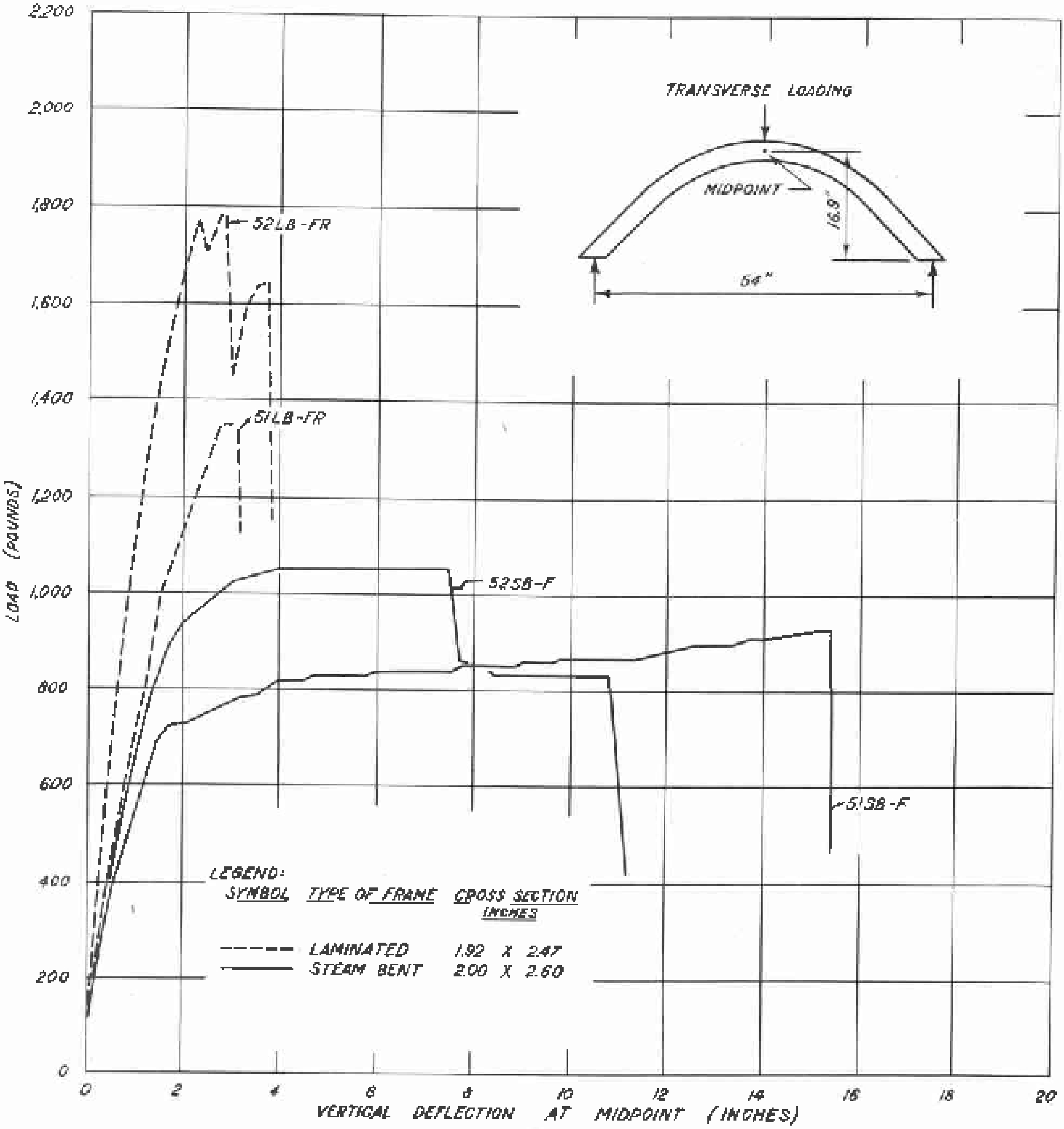


Figure 16.--Load-deflection curves for white oak laminated bent frames of reduced cross section and solid steam bent frames of full cross section.

Z M 63599 F

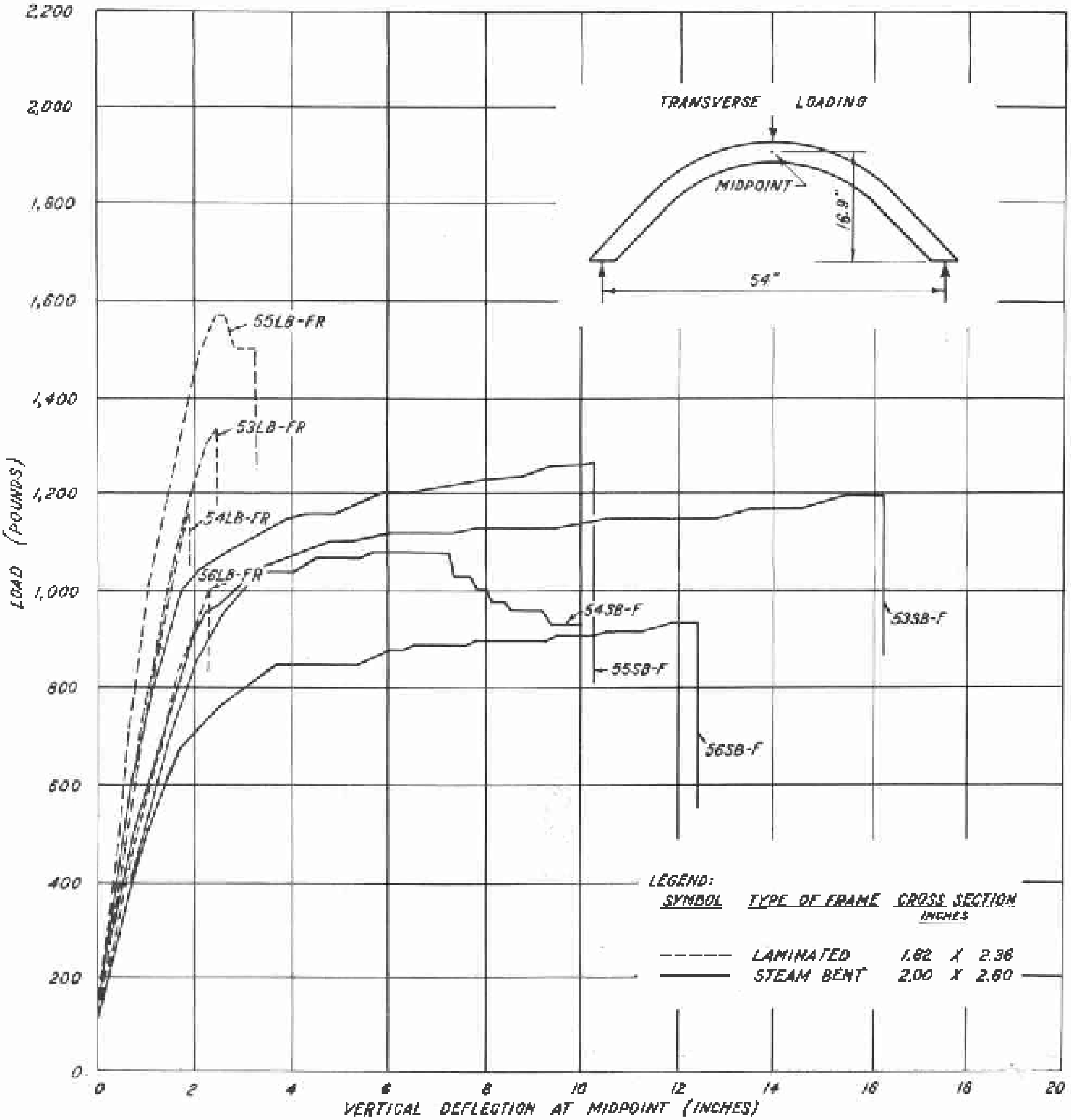


Figure 17.--Load-deflection curves for white oak laminated bent frames of reduced cross section and solid steam bent frames of full cross section.

Z M 63600 F

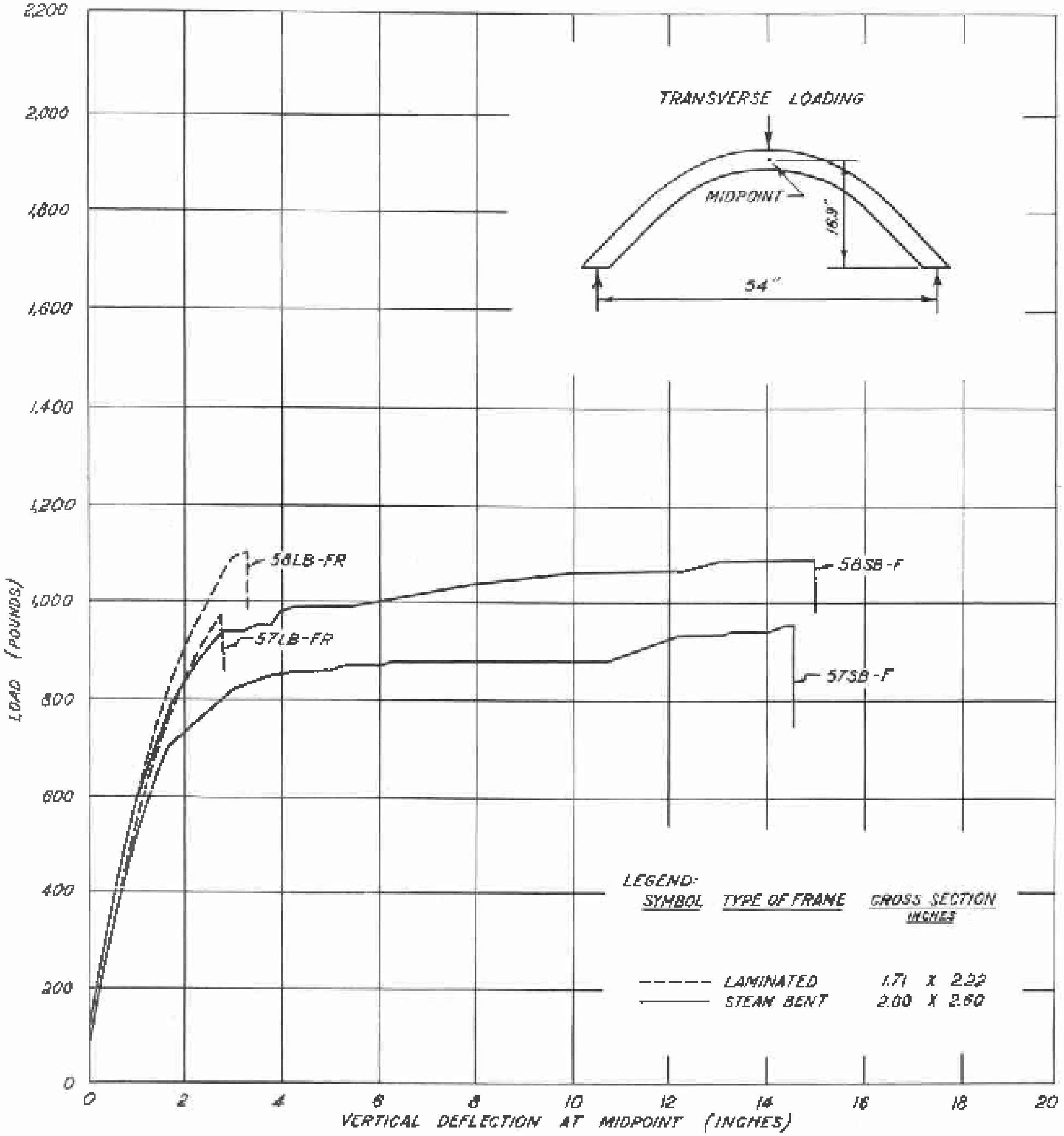


Figure 18.--Load-deflection curves for white oak laminated bent frames of reduced cross section and solid steam bent frames of full cross section.

Z M 63601 F

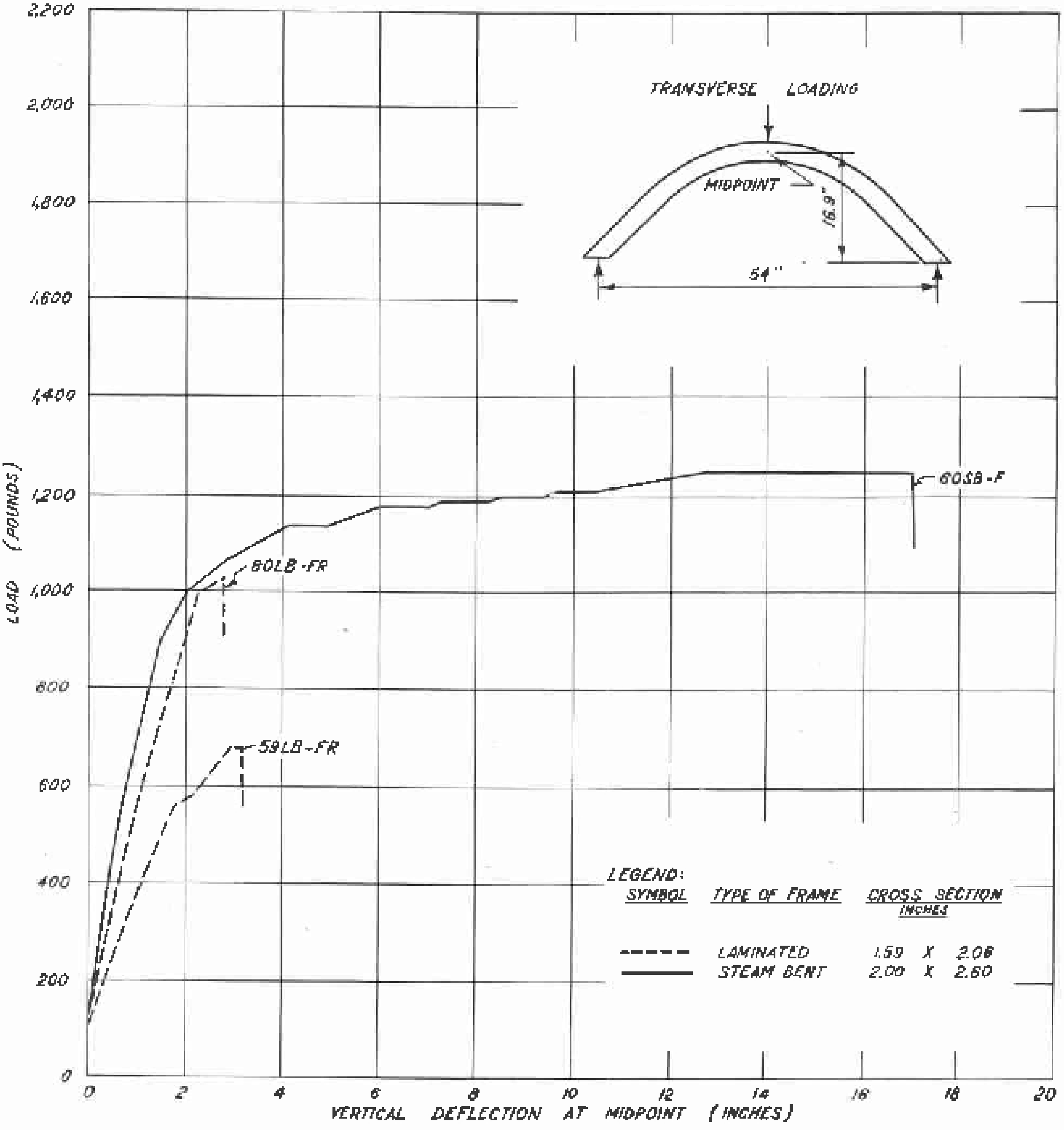


Figure 19.--Load-deflection curves for white oak laminated bent frame of reduced cross section and a solid steam bent frame of full cross section.

Z-M 63602 F

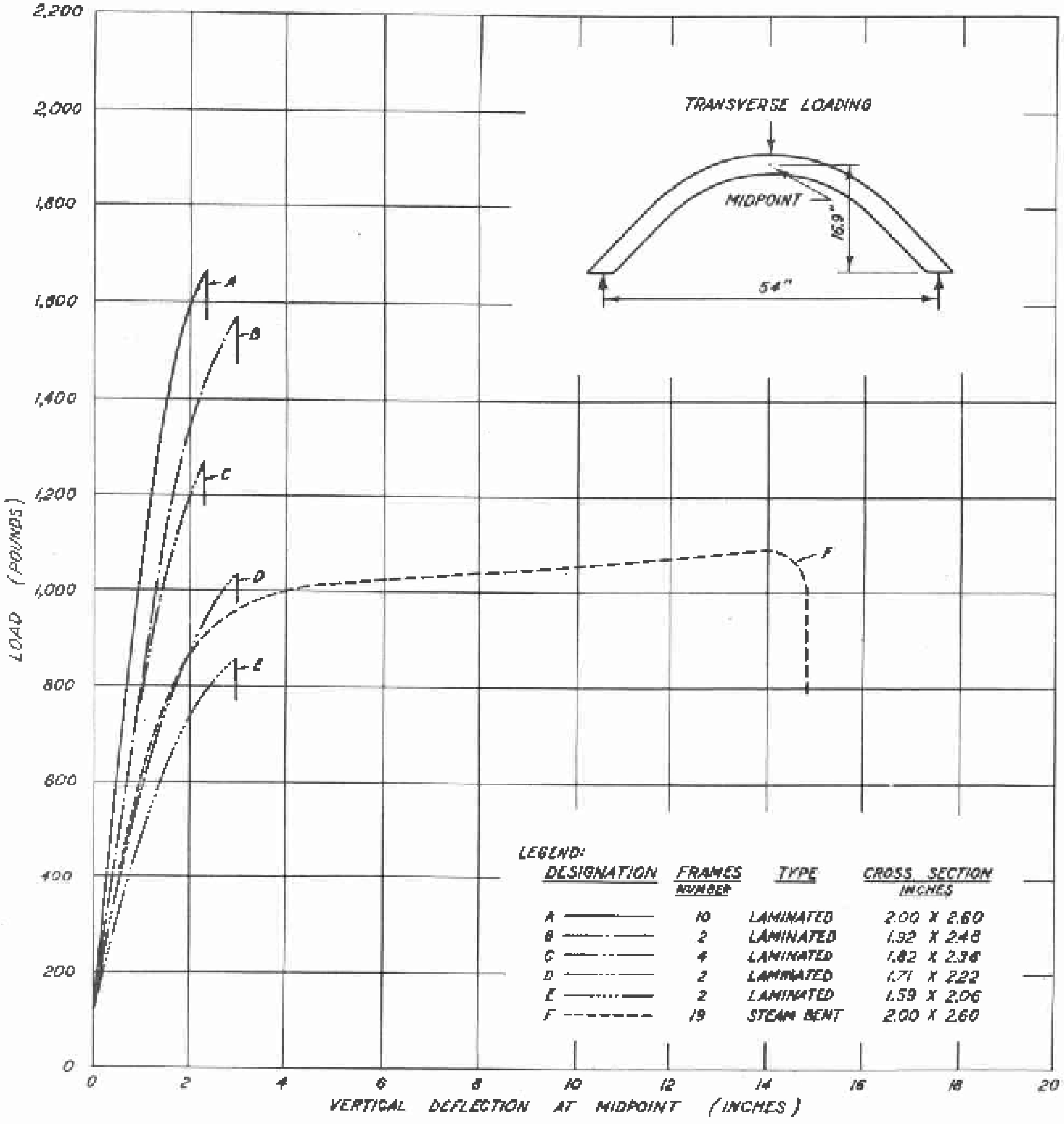


Figure 20.--Composite load-deflection curves for white oak laminated bent and solid steam bent frames.

Z M 6x60? R

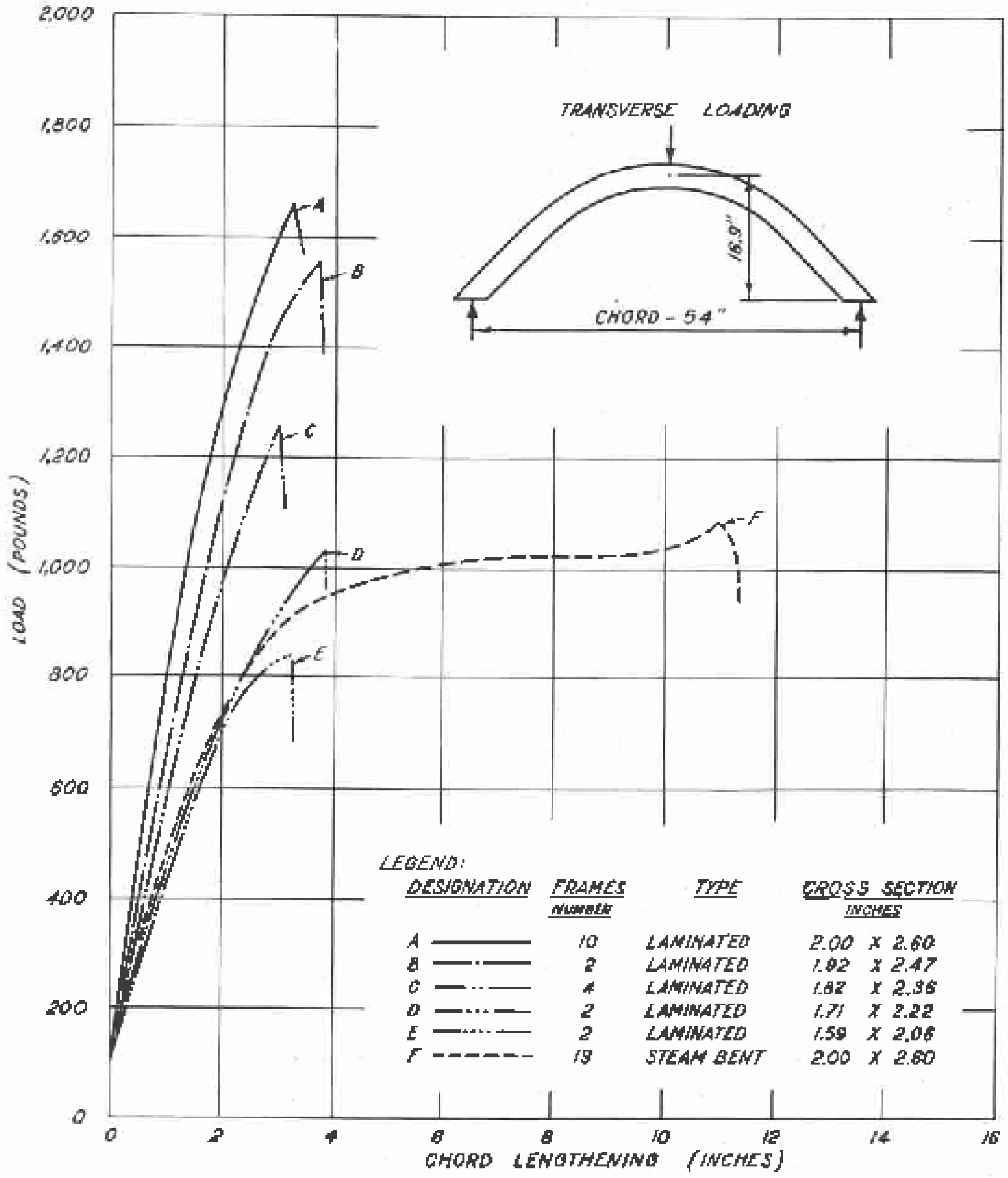


Figure 21.--Composite load-chord lengthening curves for white oak laminated bent and solid steam bent frames.

Z M 63604 F

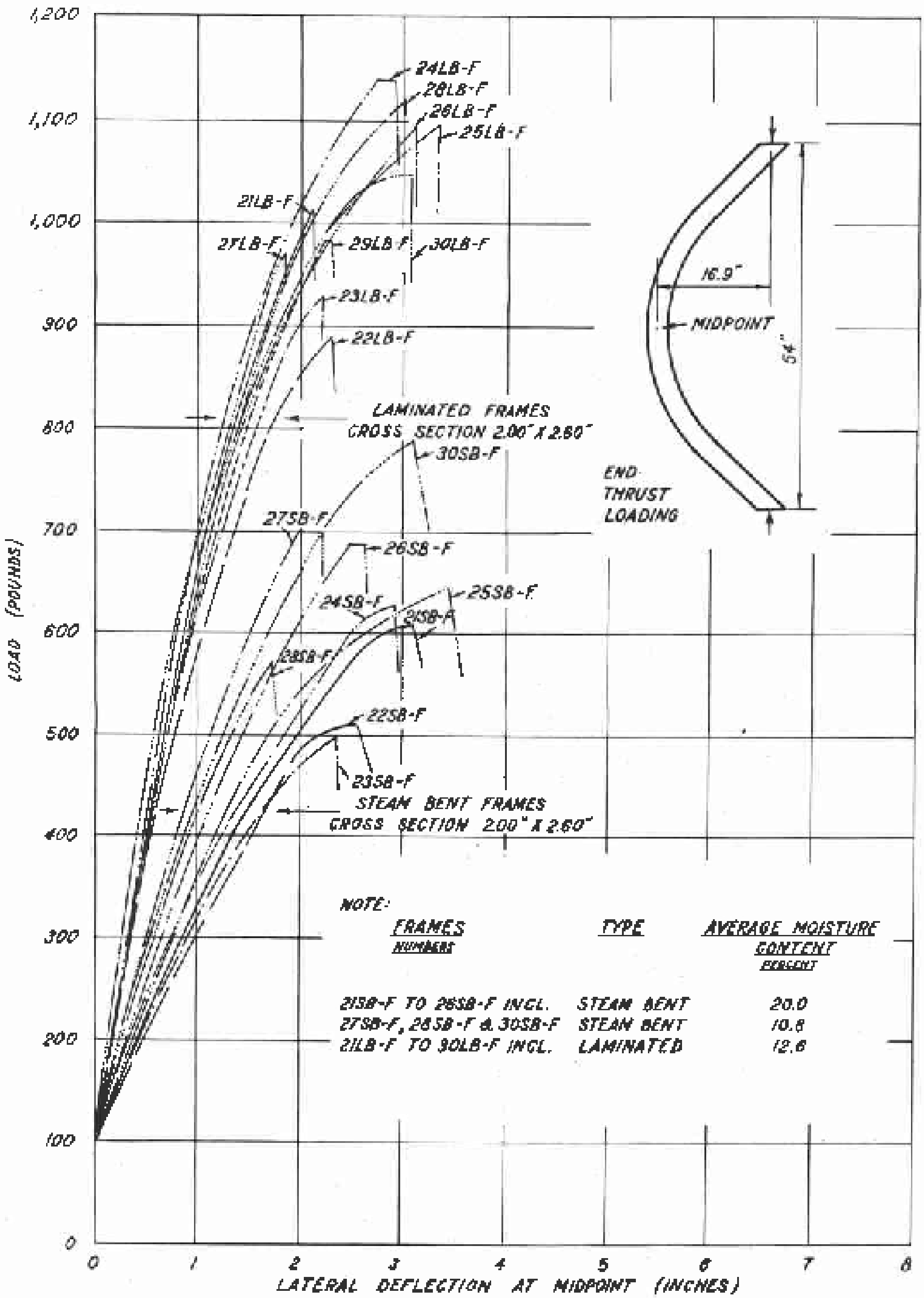


Figure 22.--Load-deflection curves for white oak laminated bent and solid steam bent frames.

Z M 63605 F

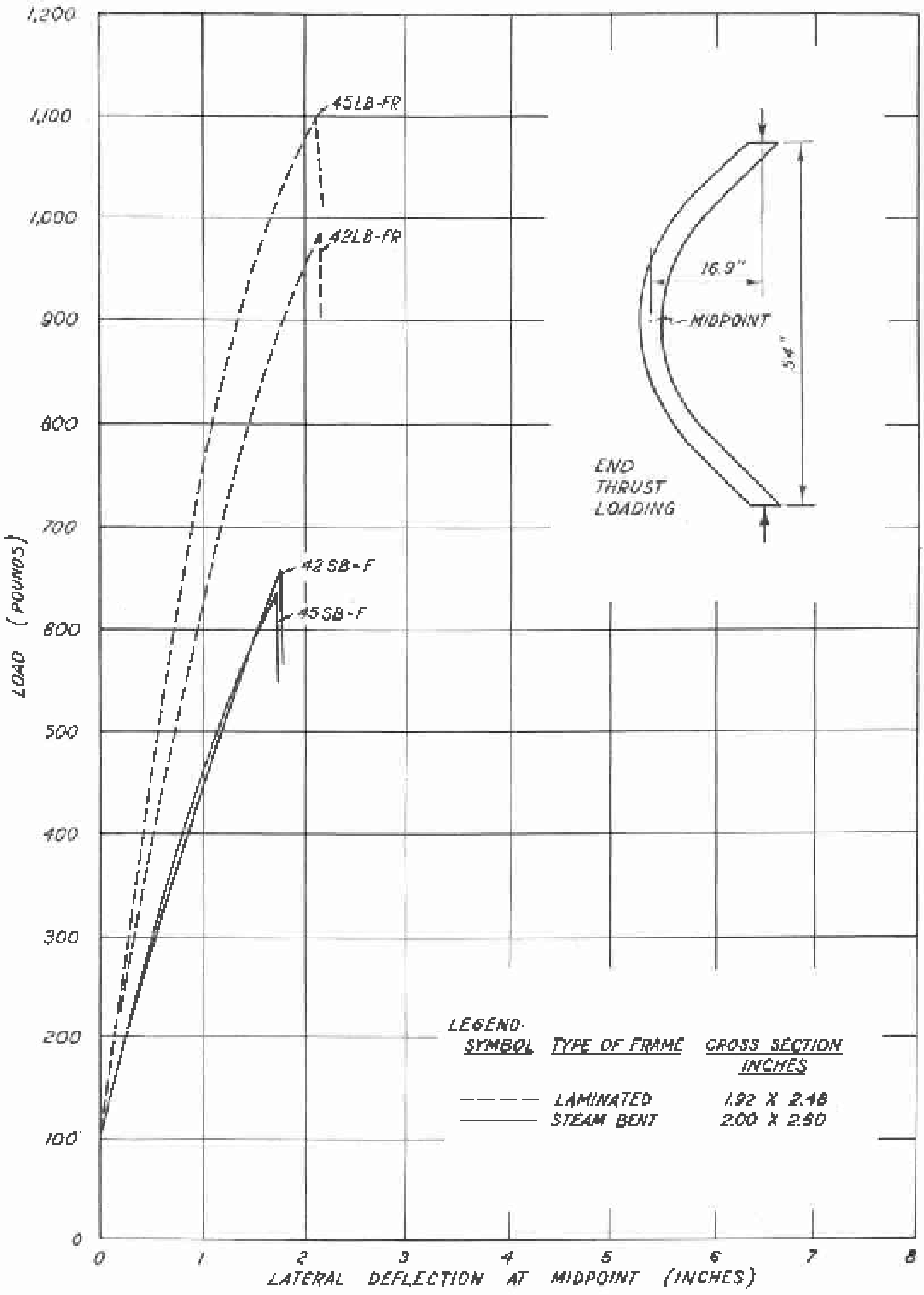


Figure 23.--Load-deflection curves for white oak laminated bent frames of reduced cross section and solid steam bent frames of full cross section.

Z M 63606 F

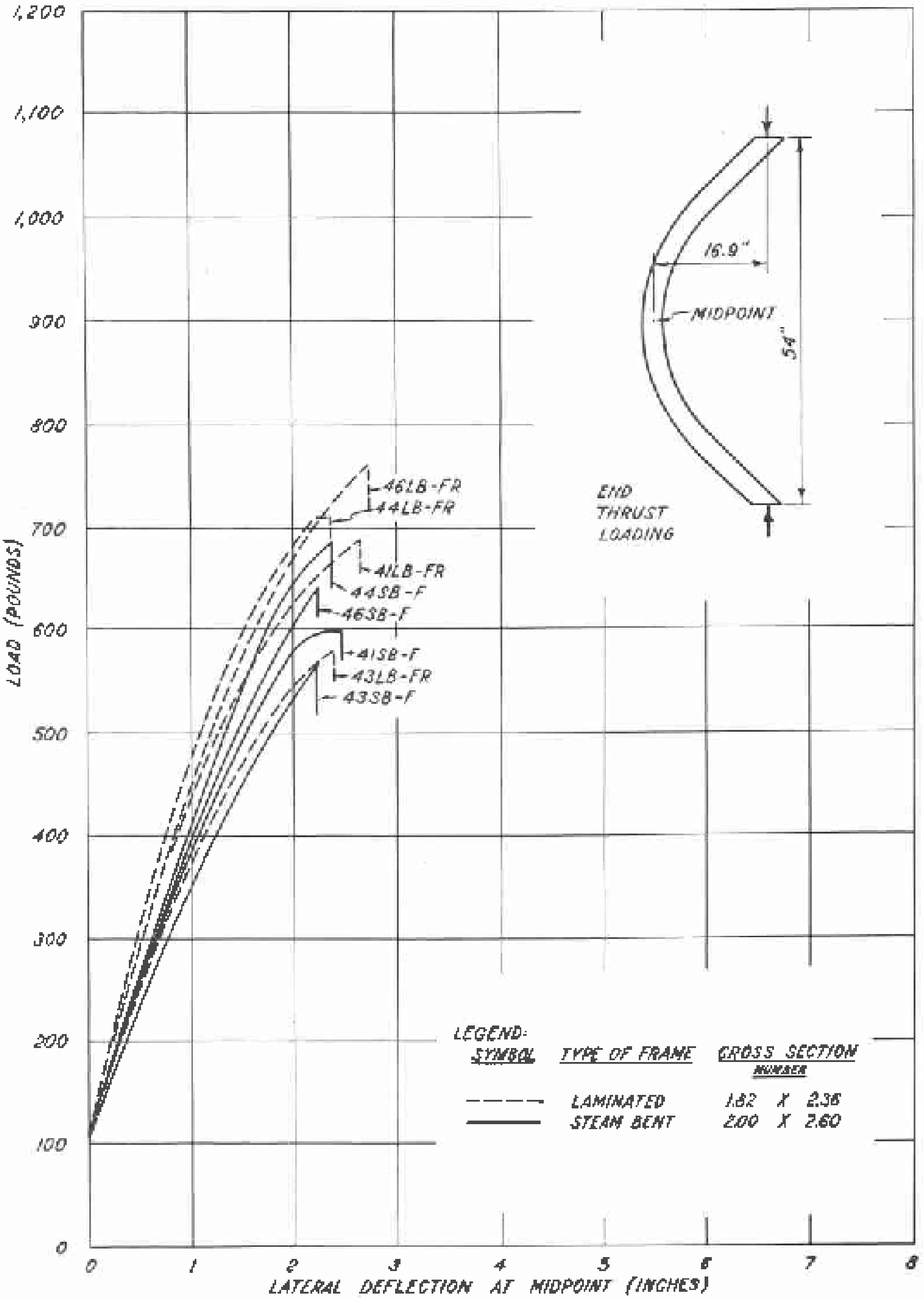


Figure 24.--Load-deflection curves for white oak laminated bent frames of reduced cross section and solid steam bent frames of full cross section.

Z M 63607 F

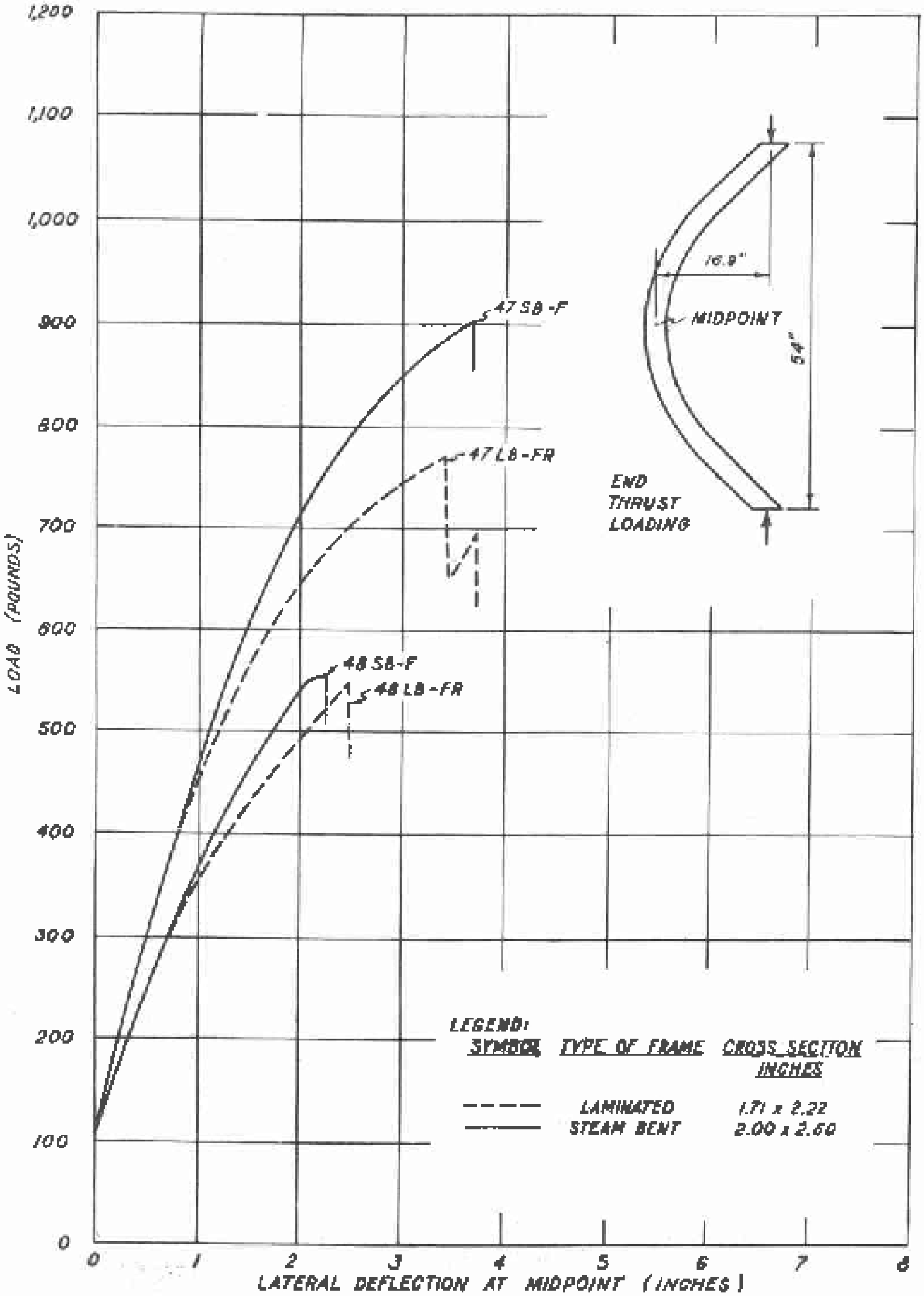


Figure 25.--Load-deflection curves for white oak laminated bent frames of reduced cross section and solid steam bent frames of full cross section.

Z M 63608

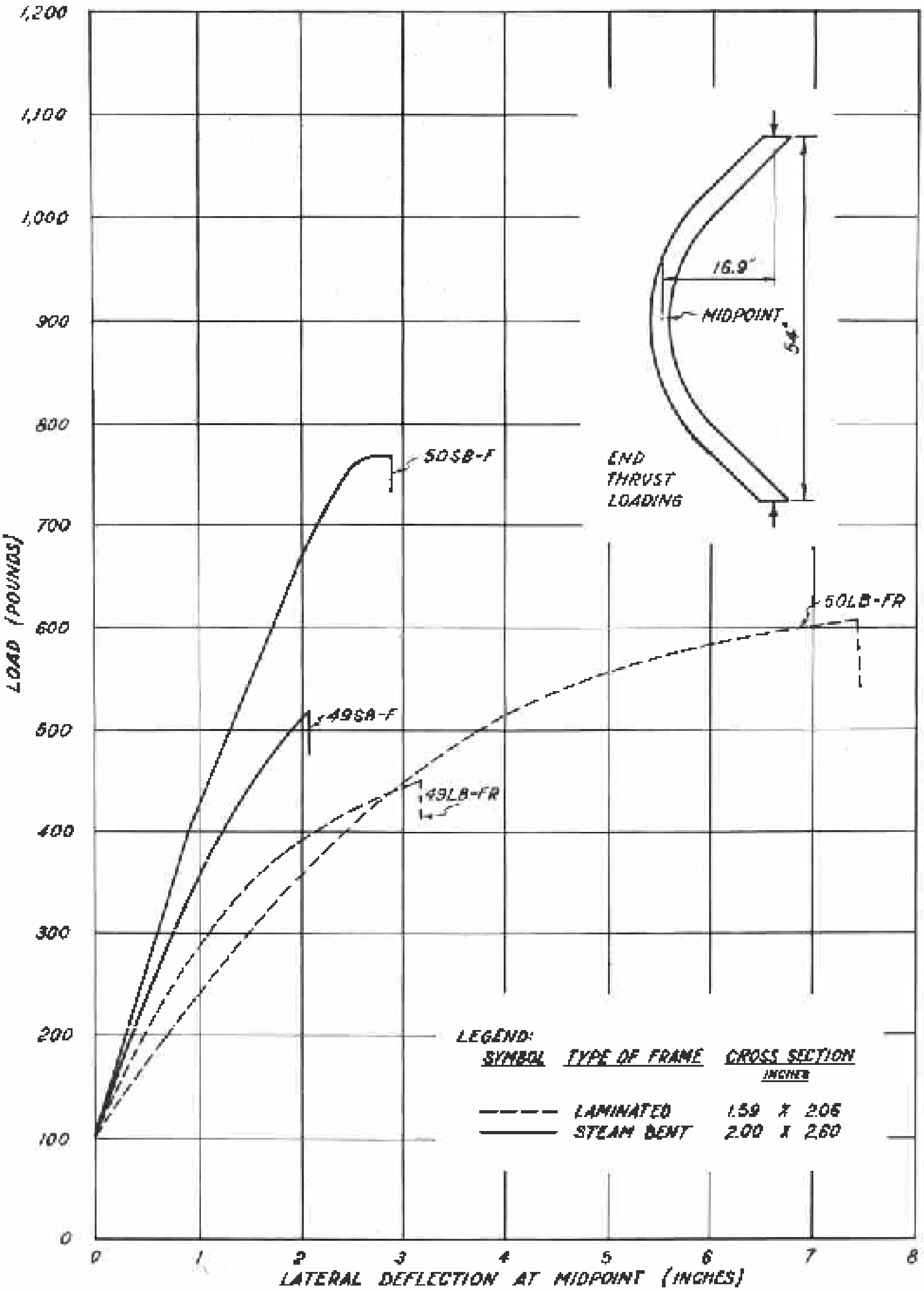


Figure 26.--Load-deflection curves for white oak laminated bent frames of reduced cross section and solid steam bent frames of full cross section.

Z M 63609 F

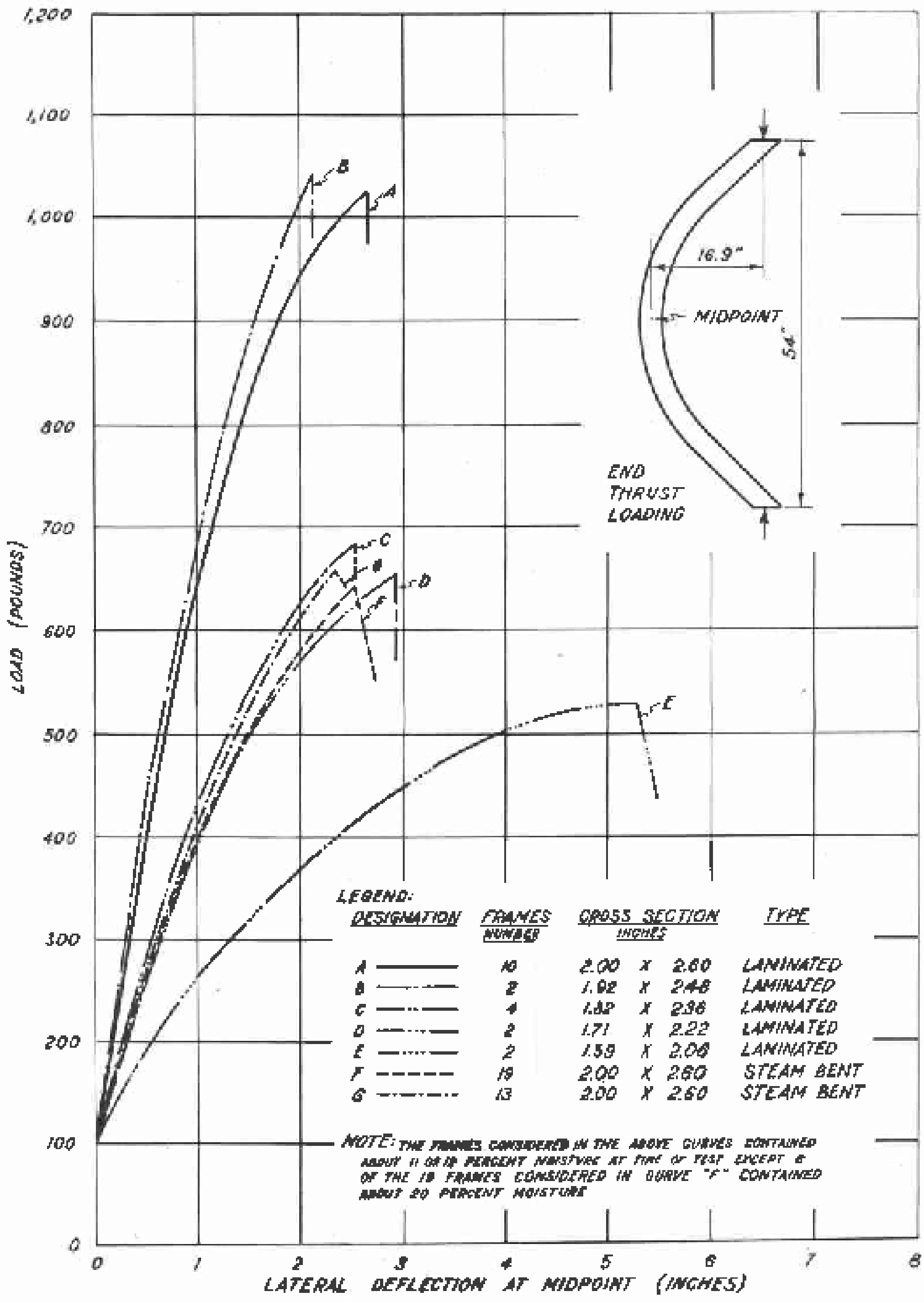


Figure 27.--Composite load-deflection curves for white oak laminated bent and solid steam bent frames.

Z M 63610 F

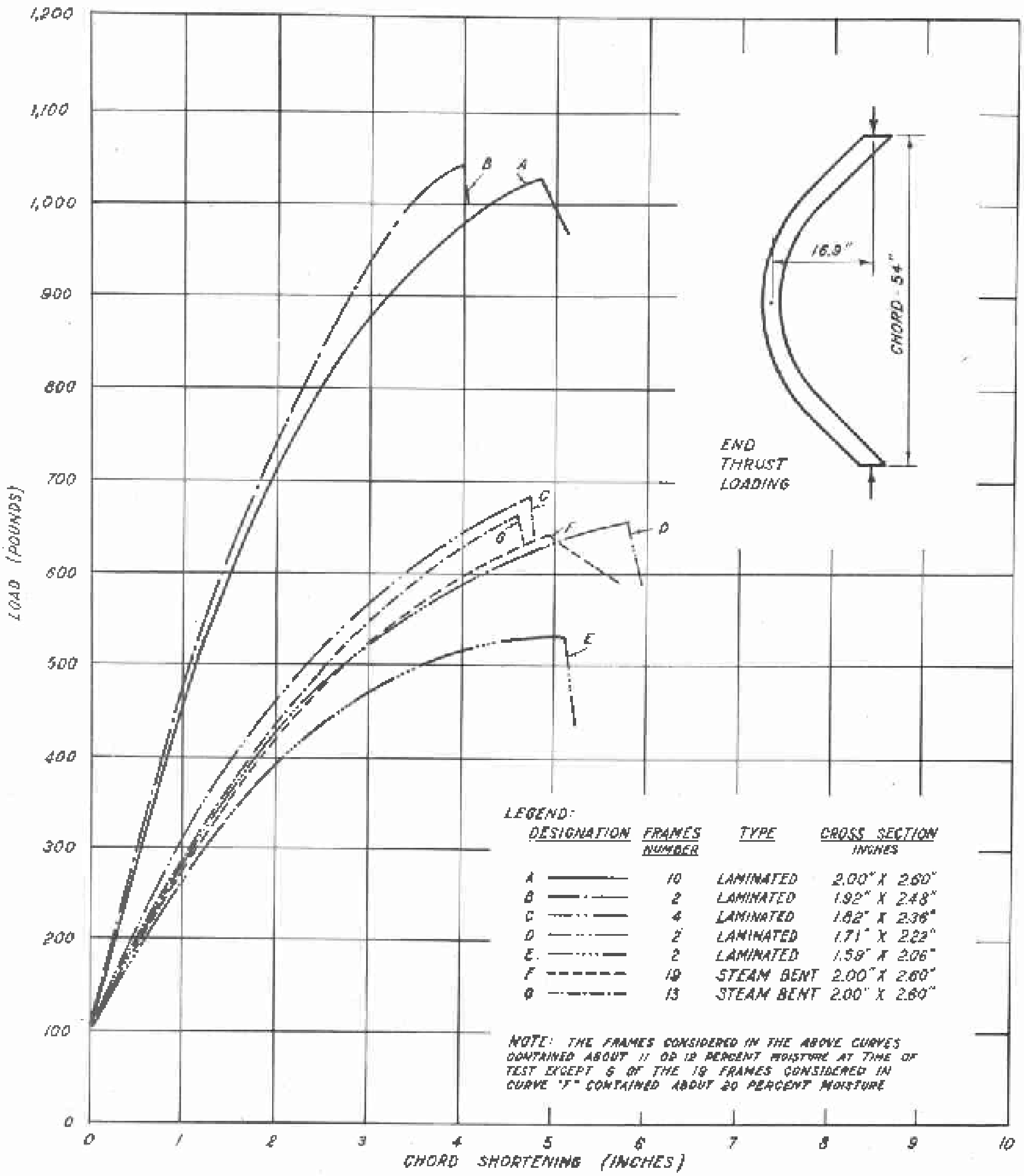


Figure 28.--Composite load-chord shortening curves for white oak laminated bent and solid steam bent frames.

Z M 63611 F

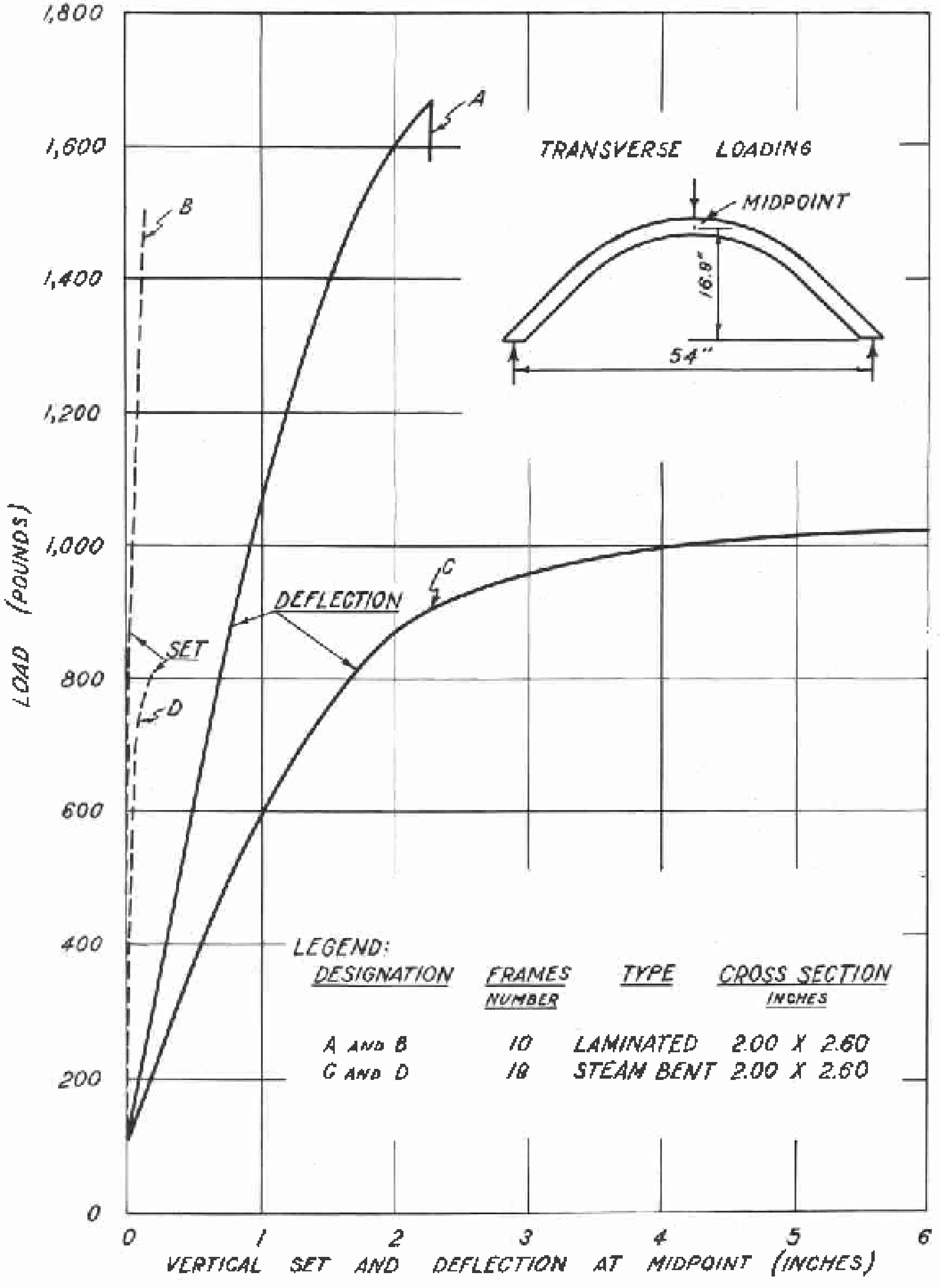


Figure 29.--Composite load-set and load-deflection curves for white oak laminated bent and solid steam bent frames.

ZM 63612 F

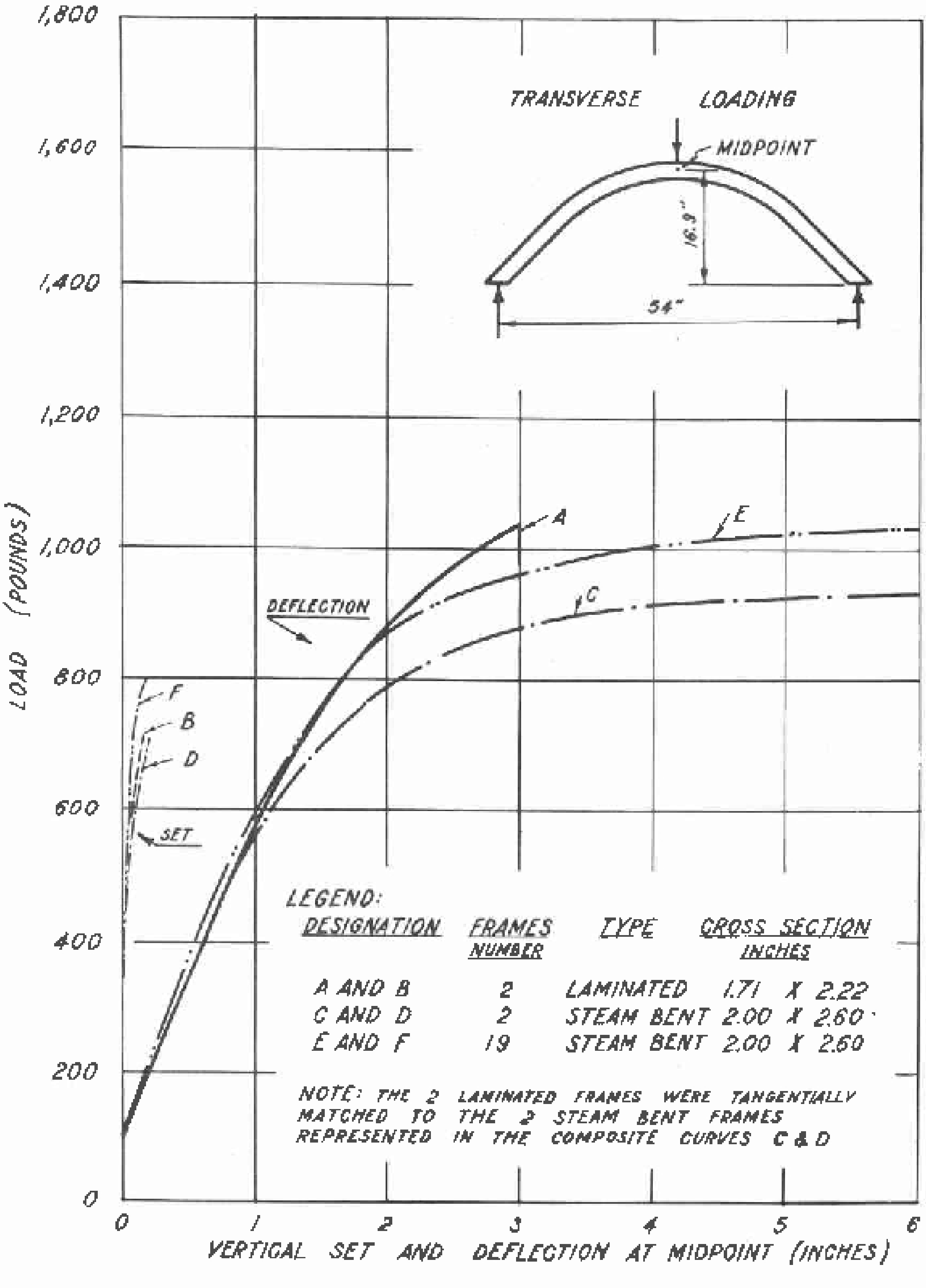


Figure 30.--Composite load-set and load-deflection curves for white oak laminated bent and solid steam bent frames.

Z M 63613 F

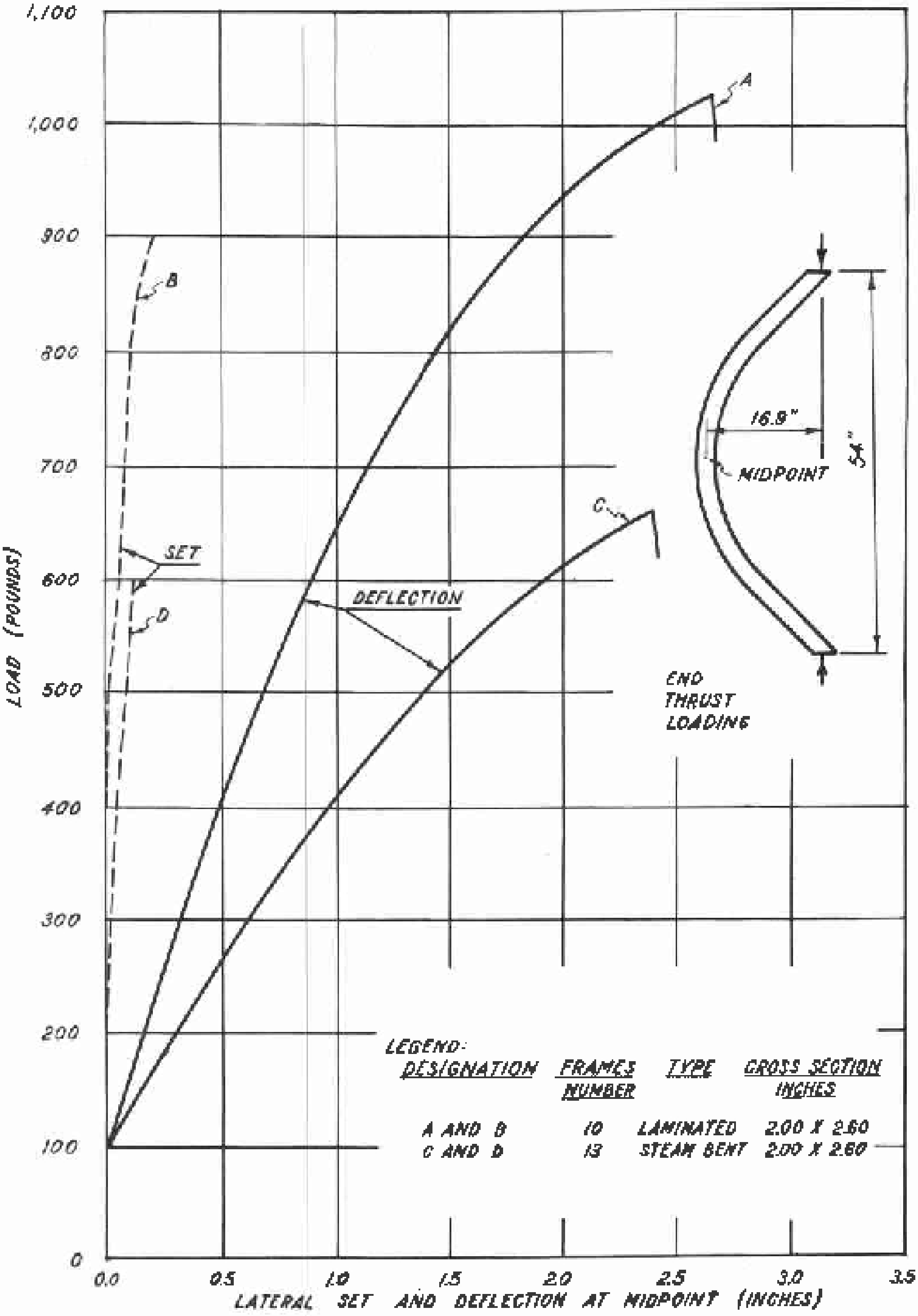


Figure 31.--Composite load-set and load-deflection curves for white oak laminated bent and solid steam bent frames.

Z M 6°614 F

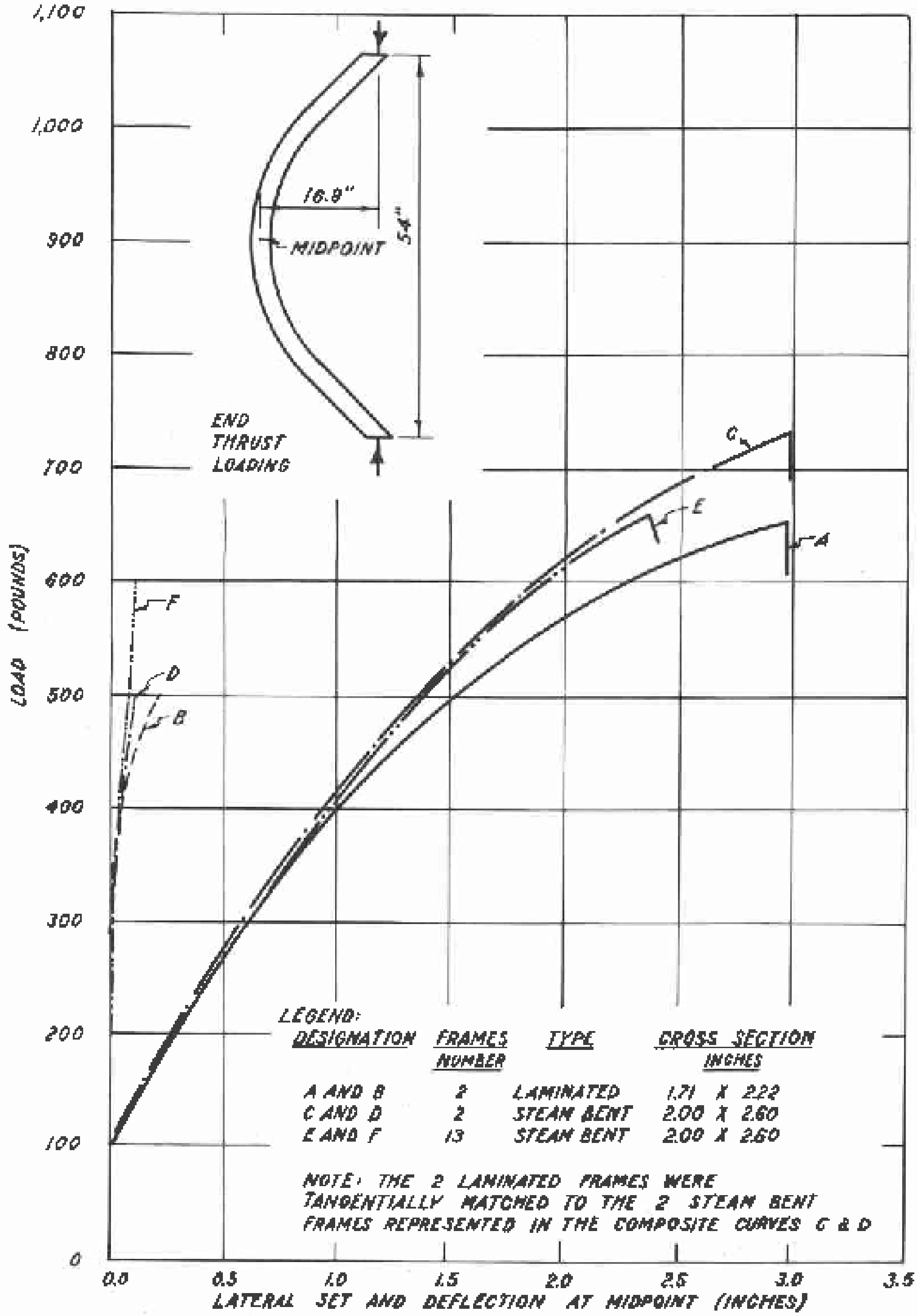


Figure 32.--Composite load-set and load-deflection curves for white oak laminated bent and solid steam bent frames.

2 M 63015 F

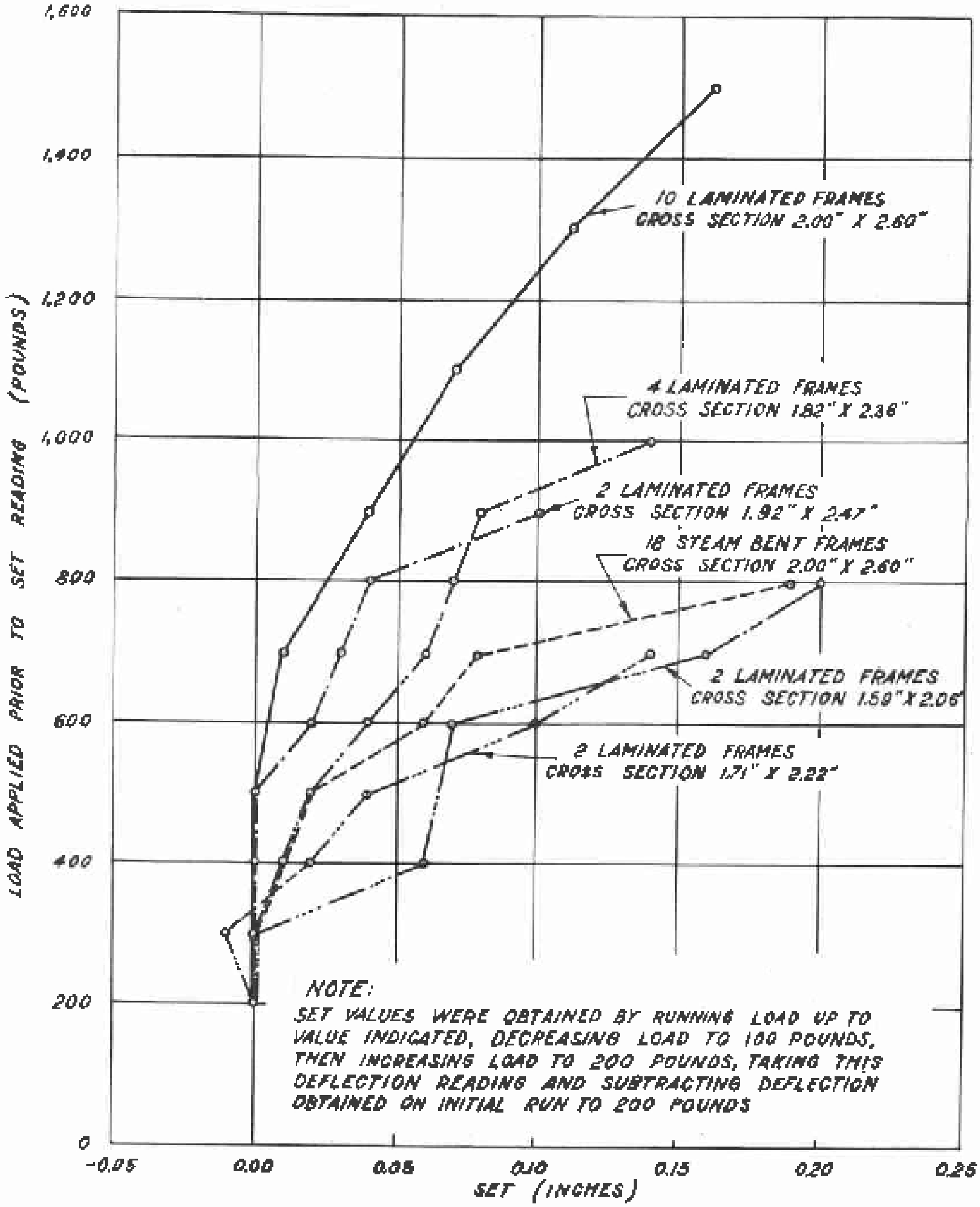


Figure 33.--Load-set curves for white oak laminated bent and solid steam bent frames, transverse loading.

2 M 63616 F

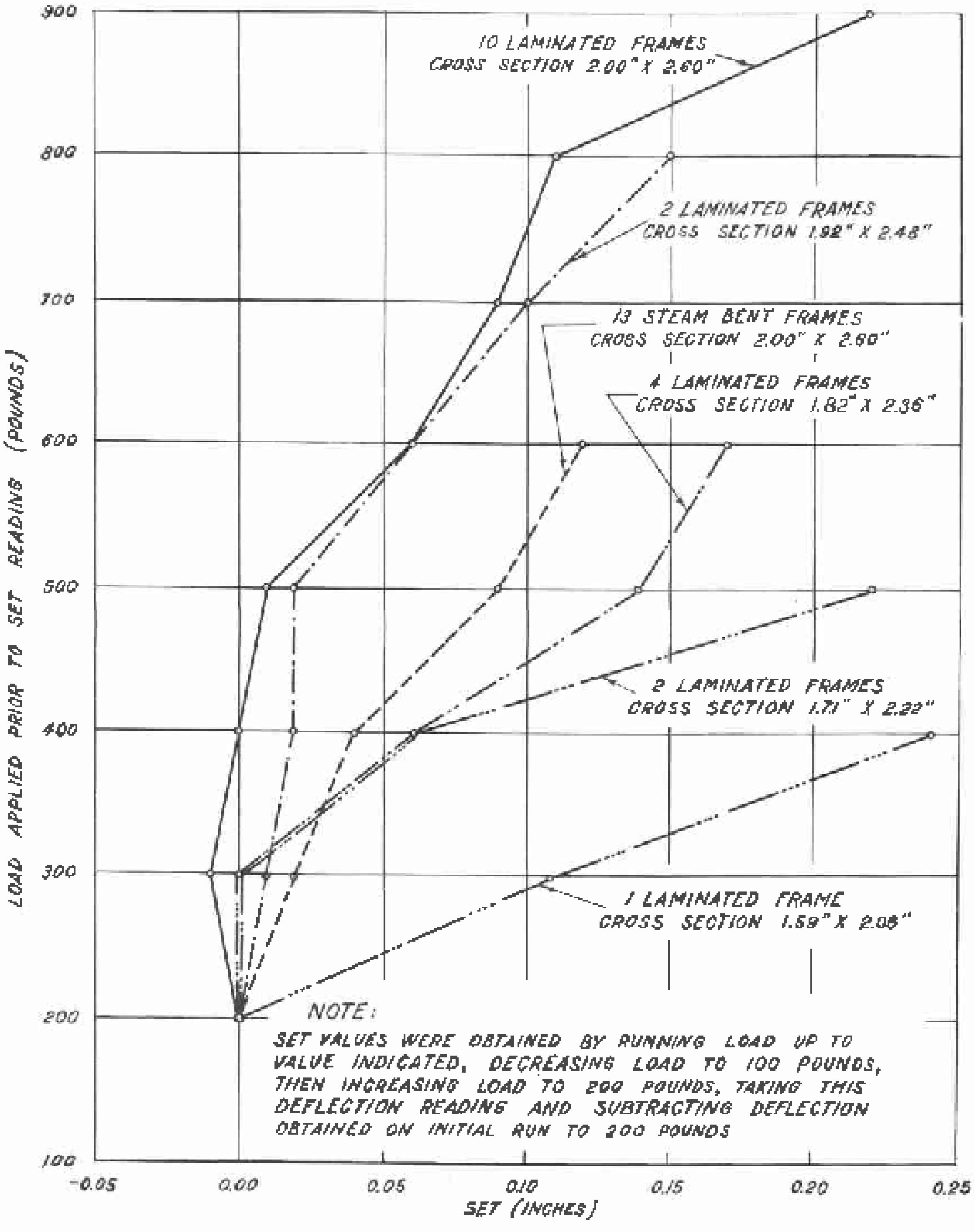


Figure 31.--Load-set curves for white oak laminated bent and solid steam bent frames, end thrust loading.

Z M 63617 F

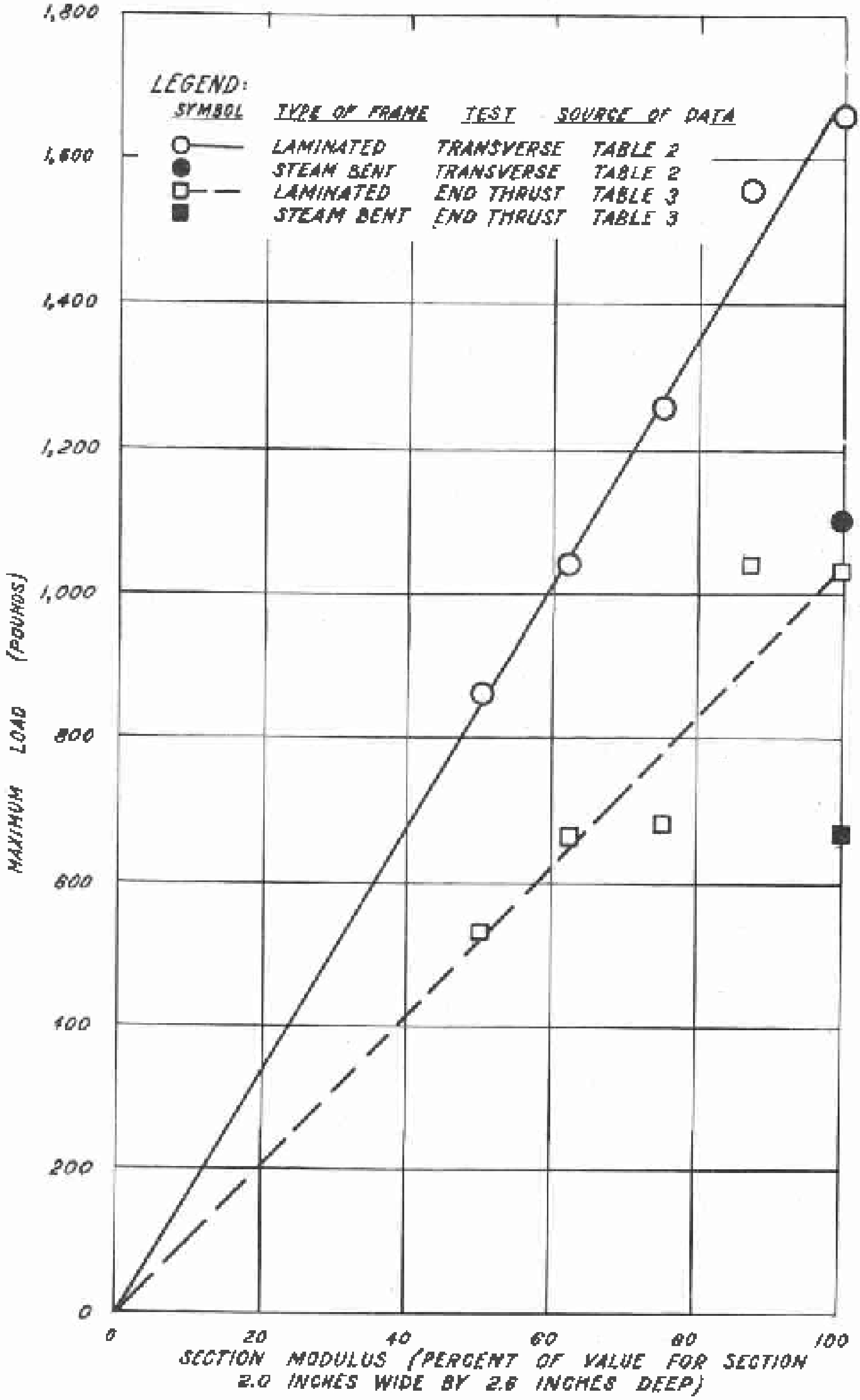


Figure 35.--Relation of maximum load to section modulus.

Z M 65101 F

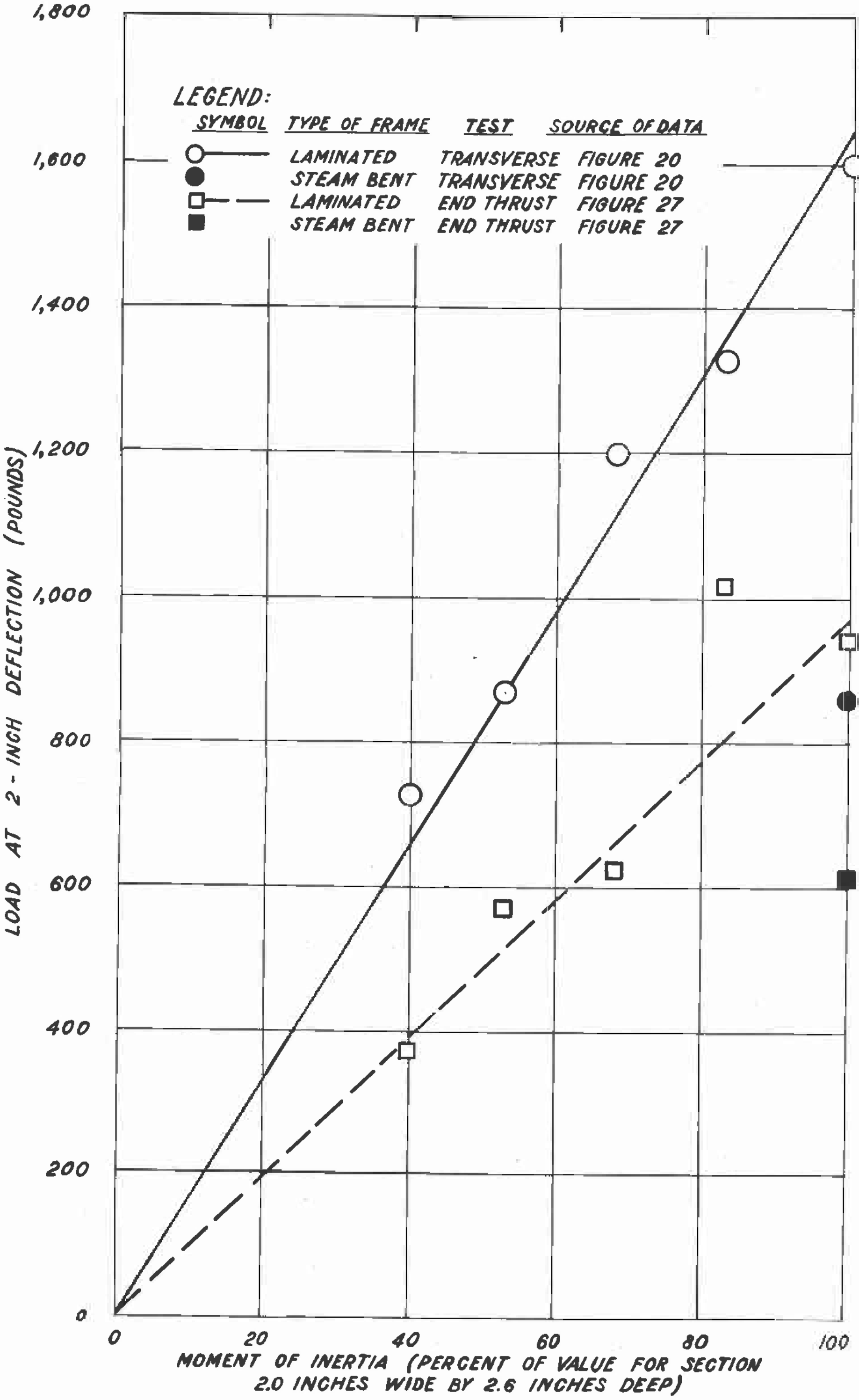


Figure 36.--Relation of load at 2-inch deflection to moment of inertia.

Z M 65102 F