# LAMINATED, BOLTED, AND SOLID KEELS FOR 50-FOOT NAVY MOTOR LAUNCH COMPARED FOR STRENGTH

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# LAMINATED, BOLTED, AND SOLID KEELS FOR 50-FOOT NAVY MOTOR LAUNCH COMPARED FOR STRENGTH

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## Summary

Single pieces of white oak timber are ordinarily used in making keels for the 50-foot motor launches built by the Navy. Oak timbers of suitable size and quality are difficult to obtain, and laminated keels have therefore been used to some extent in recent years.

At the request of the Bureau of Ships, relative strengths of laminated and solid white oak keels for a 50-foot motor launch were investigated by the Forest Products Laboratory.

The material for this study consisted largely of 7- by 10-inch by 42-foot and 5- by 7-inch by 36-foot timbers obtained from the Norfolk Navy Yard at Portsmouth, Virginia. The 7- by 10-inch timbers were used for keels of full cross section (approximately 6 by 6 inches), and the 5- by 7-inch timbers for keel sections of reduced cross section.

To conserve material and to obtain better matching between the various keel types, specimens were tested in short lengths (8 to 12 feet) rather than as full-length keels.

The tests included solid keel sections without joints, solid keel sections with a bolted plain scarf joint, laminated keel sections with plain scarf joints in individual laminations, and laminated keel sections with serrated scarf joints in individual laminations. All were tested in flexure under two-point loading with the loads at equal distances from the supports. The keel sections with bolted plain scarf joints were somewhat longer than others to permit the entire scarf joint to be between the load points.

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The moisture content of the timbers as received was from 40 to 50 percent. The solid keel sections were not dried, whereas all boards cut from the timbers for making laminated keels were kiln dried to about 10 percent moisture before they were glued. Prior to test, all were soaked in salt water for 3 months, which is assumed to be fully as long as any period in which a boat would be in the water continuously. Because they were soaked without first having been dried, the solid keel sections were well above the fiber-saturation point throughout the cross section at the time of test. The moisture content of the laminated keel sections, however, though high immediately adjacent to the surface, was only 13 percent at 1 inch from the surface. This difference in moisture content and its distribution undoubtedly affected the results.

The tests showed that a solid keel section with a bolted plain scarf joint is relatively weak, developing only about one-half the bending strength (modulus of rupture) of a solid keel section without joints. The laminated keel sections with plain scarf joints at a slope of 1 in 12 averaged 20 to 25 percent higher in maximum bending strength than the solid keel sections without joints. They usually failed first at the joint in the outer lamination on the tension side, which indicates a weakening influence, but the difference in moisture content between solid and laminated keel sections apparently more than compensated for this weakening influence.

The serrated scarf joints appeared to cause a greater reduction in strength than plain scarf joints, as the laminated keel sections with serrated joints had only about the same bending strength as solid keel sections without joints.

The laminated keel sections of reduced size sustained about the maximum loads expected.

It is obvious that the keels for a 50-foot motor launch will not always be at the moisture content at which these keel sections were tested. If the motor launches were on shipboard for extended periods following service in the water, the moisture contents would, of course, be lowered and the solid keel sections would approach the laminated sections in moisture content. Since the laminated keel sections were high in moisture only near the surface, the drying would not be likely to induce severe checks and an increase in strength would be expected. Solid oak pieces of the size of keel sections are likely to check severely in drying from a high to a low moisture content and the seasoning defects might largely offset the increase in strength normally resulting from drying. In other words, the comparison as given for laminated and solid keel sections would probably be equally favorable for laminated keels with additional drying.

## Introduction

Keels for 50-foot Navy motor launches are usually made from single pieces of white oak. Timbers of sufficient cross section and length and of suitable quality for such keels are becoming exceedingly scarce. To relieve this scarcity, some laminated keels have recently been used and are reported to be giving satisfactory service.

It is the purpose of this investigation to compare the strength properties of laminated, bolted, and solid keels.

## Description of Material

The white oak material used in this study consisted of eleven 7- by 10-inch by 42-foot pieces, stock No. 39-L-3215, and eleven 5- by 7-inch by 36-foot pieces, stock No. 39-L-3210. It was obtained from the Norfolk Navy Yard, Portsmouth, Virginia. The pieces were selected by representatives of the Bureau of Ships, and of the Forest Products Laboratory from white oak material conforming to class d (sawn timbers) of Bureau of Ships Ad Interim Specification 39-0-5 (INT) dated 15 December 1943.

Some 200 to 300 pieces were examined in making the selection. Those with the fewest knots and checks and the least amount of cross grain were taken. No consideration was given to the specific gravity of the timbers. The moisture content of the timbers as received at the Forest Products Laboratory was between 40 and 50 percent.

## Matching of Keel Sections

Each 42-foot timber furnished material for four end-matched keel sections of full cross section, as follows: (1) a solid keel section with a bolted scarf joint; (2) a solid keel section without joints; (3) a laminated keel section with plain scarf joints; (4) a laminated keel section with serrated scarf joints (fig. 1A). Each 36-foot timber furnished material for two end-matched laminated keel sections of reduced cross section, one with plain scarf joints and the other with serrated scarf joints (fig. 1B). Cross sections less than 6 by 6 inches are herein termed "reduced cross section." The placement of joints in the various laminated keel sections are shown in figures 2 and 3.

## Preparation of Keel Sections

Preliminary to the preparation of the keel sections each 7- by 10-inch by 42-foot timber was crosscut into four lengths, the minimum for each being as shown in A of figure 1. Since the total of the minimum lengths was less than the full 42-foot length of the timber, it was possible to crosscut so as to place large knots away from the central portion of the completed keel sections. The order of the sections within a 42-foot length was also varied from that shown in A of figure 1 when advantageous in obtaining the desired position of knots. These timbers frequently contained some spiral grain. Since the wide (10-inch) face was approximately plain-sawed, the slope of grain was decreased by ripping these 10-inch wide timbers approximately parallel to the grain, as indicated in figure 1A, when reducing them to the desired 6-1/2-inch widths.

Some of the timbers were rather deeply checked. This was reduced somewhat by always surfacing as much as possible from the face with the deepest checks.

## Solid Keel Sections without Joints

The solid keel sections of 6-inch width and 6-1/4-inch depth were surfaced and ripped as previously explained. These sections were 8 feet 9 inches long.

## Solid Keel Sections with Bolted Scarf Joints

Each blank for a solid keel section with bolted scarf joints was first cut to a 6-inch width and a 6-1/4-inch depth as already mentioned. A bolted scarf joint was then made in the central portion of the length in accordance with the details shown in figure 4. These joints were cut on a band saw. Copper rivets, 5/8 inch in diameter, with 1-1/4-inch head and copper washers with 5/8-inch inner and 1-1/8-inch outer diameters, were used in bolting the two halves together. The rivets and washers were furnished by the Norfolk Navy Yard. Each section was trimmed to a length of 11 feet 5 inches, and the bolted joint kept centrally located.

## Laminated Keel Sections with Plain Scarf Joints

One 9-1/2-foot section from each 7- by 10-inch by 42-foot timber was used for laminations for a keel section of full cross section. After ripping and surfacing these 9-1/2-foot sections in the manner already described to avoid as much checking and cross grain as possible, they were resawed into six 1-inch boards.

The laminations for the keel sections of reduced cross section were obtained from the 5- by 7-inch by 36-foot timbers. The smaller cross section of these timbers did not permit any choice in depth of surfacing or direction of rip as was done with the larger timbers. Fortunately, these smaller timbers were much freer of large knots, deep checks, and severe cross grain than the larger timbers. These smaller timbers were cross-cut into suitable lengths and ripped into four 1-inch boards. Some material was lost in ripping and surfacing laminations, and, hence, more laminations were needed. Since the full length of the 36-foot timbers was not required for the keel sections of reduced cross section, additional laminations were prepared from this extra material, as well as some from stock, and were placed near the center of the height of the keel sections where they would have little influence on strength.

All 1-inch boards were kiln-dried at the Forest Products Laboratory to approximately 10 percent equilibrium moisture content. Subsequent to drying, the boards were surfaced to 7/8-inch thickness. Plain scarf joints with a slope of 1 in 12 were made in various laminations. The faces of these joints were surfaced in a planer. The location of these joints in a finished keel section is shown in figure 2. The joints in any two adjacent laminations were separated by a distance equal to 24 times the thickness of a lamination (3/4 inch) measured from center to center of joint. These plain scarf joints were glued in accordance with Bureau of Ships Specification R39-0-7, using a low-temperature setting phenol-formaldehyde glue. Subsequent to gluing the joints, the boards were surfaced to 3/4-inch thickness. A few boards were surfaced to 3/8-inch thickness as indicated in figure 2 to obtain desired finished depth of keel section. Most of the two outside boards from the large 7- by 10-inch by 42-foot timbers were found to contain an excessive amount of large checks and were, therefore, discarded.

In assembling the keel sections, the laminations were arranged irrespective of their original position in the timbers so as to obtain outer laminations free of checks. The filler material was always placed in the central portion of the depth of the keel sections as described previously, and for any one keel section was selected to match the density of those laminations already assigned to the member. The laminations were glued into keel sections in accordance with Bureau of Ships Specification R39-0-7. On completion of the fabrication, the keel sections were dressed to the various widths and length as indicated in figure 2.

## Laminated Keel Sections with Serrated Scarf Joints

The preliminary steps in the fabrication of the laminated keel sections with serrated scarf joints were the same as for the laminated keel sections with plain scarf joints, with the exception that no filler material was selected from the white oak timbers furnished by the Bureau of Ships. After the 1- by 6-1/2-inch by about 9-1/2-foot boards had been conditioned in a kiln at the Forest Products Laboratory to 10 percent equilibrium moisture content and dressed to 7/8 inch thickness, the boards were shipped to Gamble Brothers, Louisville, Kentucky, for fabrication into laminated beams containing serrated scarf joints. The type of joint is shown in figure 5. The location of the joints is indicated in figure 3, wherein the joints are separated a distance equal to 24 times the thickness (3/4 inch) of a lamination as measured center to center of joint. Gamble Brothers furnished the white oak filler material using stock of about the same density as that in the remainder of the keel section. The outside laminations were previously arranged and marked at the Forest Products Laboratory to correspond with the order and matching of the outside lamination in the beams with the plain scarf joints. Gamble Brothers conformed to Bureau of Ships Specification R39-0-7 in the fabrication of the joints and keel sections. These sections were finished at the Forest Products Laboratory to the various widths and length as indicated in figure 3.

## Storage

All keel sections were submerged in a salt water solution (4 percent salt by weight) for a period of 3 months prior to test. Three months is assumed to be the longest period during which a 50-foot Navy boat would be in water for one continuous period.

Prior to being placed in the conditioning tanks, the members were end-coated to prevent the absorption of water through the ends. Three types of end coatings were used and all proved satisfactory. Following is a list of types of end coatings used on four different types of keels:

(1) Solid keel sections without joints: three coats of aluminum powder and phenolic-resin varnish.

(2) Solid keel sections with bolted scarf joints: three coats of filled hardened gloss oil.

(3) Laminated keel sections with plain scarf joints: three coats of filled hardened gloss oil.

(4) Laminated keel section with serrated scarf joints: 10 coats black asphaltum.

## Numbering System

The eleven 7- by 10-inch by 42-foot white oak timbers from which the solid keel sections and the laminated keel sections of full size (eight 3/4-inch laminations) were obtained, were numbered from 1 to 10, inclusive, and 10A. The eleven 5- by 7-inch by 36-foot white oak timbers from which the laminated keel section of reduced cross section were obtained were marked 11 to 20, inclusive, and 20A.

Letters were suffixed to these numbers to designate the type of keel section as follows:

| Letters | Designation |
|---|---|
| C | Solid control section (no joint) |
| SS | Solid section with bolted scarf joint |
| LP | Laminated section with plain scarf joint |
| LF | Laminated section with serrated scarf joint |
| K | Keel |
| KR | Keel of reduced size |

For example, the number 11LF-KR means that this keel section was obtained from the 5- by 7-inch by 36-foot timber No. 11 and was a laminated keel section of reduced cross section containing serrated scarf joints.

Gamble Brothers fabricated three extra laminated keel sections (eight 3/4-inch laminations) with serrated scarf joints from white oak material they had on hand. These were assigned numbers 10-B-LF-K, 10-C-LF-K, and 10-D-LF-K.

## Method of Tests

Static bending tests only were made on the keel sections. All tests were made with the tangential faces of the timbers horizontal so as to reduce any effect checks might have on the strength of the timbers.

All keel sections except those with bolted scarf joints were tested under third-point loading over a 7-foot span, (figs. 6, 7, and 8). This placed the loads 2 feet 4 inches from the supports. The solid keel sections with bolted joints were also tested with the load points 2 feet 4 inches from the supports, although the span was 10 feet 9 inches. The same bending moment was thus produced for the same load and for the two different spans and the loads were directly comparable for all static bending tests of keel sections. The plain scarf joints, serrated joints, and bolted joints all fell between the load points, and a uniform bending moment was thus produced throughout the critical section of every beam.

The load was transmitted to the beam through bearing blocks with a radius of curvature of 18 inches. The bearing blocks were allowed to pivot about knife edges rigidly attached to an auxiliary beam, which in turn was hinged by a knife edge attached to the head of the machine. Thin steel plates (1/8-inch thick) were placed between the loading blocks and the beams. Between one bearing block and the corresponding knife edge, a set of rollers was used. A steel plate was used over the other bearing block. The supports at the ends of the beams were of the half-rocker type, which allowed the ends to pivot and move horizontally as the load was applied.

Load was applied to the keel sections at the rate of 0.18 inch per minute when tested over a 7-foot span and 0.27 inch per minute when tested over a 10-foot 9-inch span. In all instances deflection of the centers with respect to the supports was read simultaneously with a reading of load until the load was well past the maximum (fig. 6). In tests of the solid sections without joints, deflections of the center with respect to the load points were also taken, and the movements of load points for use in computing work values were found by taking the difference between these deflection readings (fig. 7). In all other tests, movement of load points was found by direct measurement (fig. 8).

## Determination of Moisture Distribution

One-inch moisture sections were cut from each keel section subsequent to test, near the bending failure. The solid keel sections without joints were tested first, and the scheme of dividing the moisture sections from them for obtaining moisture distribution is shown in figure 9A. The revised scheme shown in figure 9B was used for dividing the other moisture sections. The thinner layers obtained by the revised method were desirable to show more accurately the moisture gradient in the laminated pieces.

## Discussion of Results

The results of the strength tests together with data on moisture distribution and a brief description of failures are shown in table 1. Table 2 is a summary of these data subdivided by type of section including: (1) solid with no joints, (2) solid with bolted scarf joint, (3) laminated with plain scarf joints, and (4) laminated with serrated scarf joints.

The comparisons that follow are based largely on values of maximum loads and modulus of rupture, since they gave the most consistent trends and are believed to reflect the relative merits of the various types of joints in keels as far as strength properties are concerned.

The solid sections with bolted scarf joints, as detailed in figure 4, developed a maximum stress in bending (modulus of rupture) of less than one-half that for solid sections without joints. It is apparent, therefore, that keels with bolted scarf joints are a poor substitute for keels without joints as regards strength. Failure of a keel with a bolted joint was usually by opening of the scarf and crushing and splitting of the wood at the bolts, as illustrated in figures 10 and 11.

A jointless solid keel section, illustrative of the typical failure which was by splintering tension, is shown in figure 12.

The laminated keel sections of 6- by 6-inch cross section with plain scarf joints at a slope of 1 in 12, located as shown in figure 2, developed an average modulus of rupture of 8,230 pounds per square inch; while for the jointless solid keel sections of similar cross section the average was 6,600 pounds per square inch. This indicates that as tested laminated keel sections with plain scarf joints were approximately 25 percent higher in modulus of rupture than jointless solid sections.

It is likely that the much lower moisture content in the interior portions of these laminated keel sections was an important factor in their higher strength in comparison with the jointless solid ones. The process of cutting a timber into laminations and then gluing these laminations together should not of itself increase the strength.

The moisture content of the timber from which keel sections were obtained varied from 40 to 50 percent when delivered at the Laboratory. The solid keel sections were not allowed to dry and after fabrication were soaked for 3 months in salt water. The moisture distribution at time of test is shown in the upper curve of figure 13. All portions of the keel are well above the fiber-saturation point (25 to 30 percent). On the other hand, the nominal 1-inch boards cut from the green oak timber for making laminated sections were dried to about 10 percent moisture prior to gluing. The laminated sections were also soaked in salt water for 3 months prior to testing. The moisture distribution in the laminated keel sections at time of test based on 11 sections is shown by the lower curve of figure 13. For the first 1/4 inch from the surface inward, the moisture contents of the solid and laminated keel sections were similar and relatively high. Beyond this point, the moisture in the laminated keel sections dropped much more rapidly than in the solid sections and at one-half inch inward was below the fiber-saturation point. At 1 inch inward, the moisture content was about 13 percent, then gradually decreased to about 11 percent at the center of the section.

In most laminated keel sections with plain scarf joints, the joint in the outer lamination on the tension side opened up, as shown in figures 14 and 15. This undoubtedly decreased the strength somewhat but the difference in moisture content between the solid and laminated keel sections apparently was a much more important factor in increasing the strength than the opening of the scarf joints was in decreasing it.

It is assumed that 3 months is as long a continuous period as a 50-foot motor launch will be in water, and, hence, the soaking to which these sections were subjected prior to test brought the moisture content as high as would ever be expected in service. It seems quite likely, however, that a motor launch may be on shipboard for long periods during which considerable drying of the keels would occur. Since the laminated keels are high in moisture only near the surface, they would probably dry without any serious checking or other seasoning defects, and the net result would be an increase in strength. The solid keel sections of 6- by 6-inch cross section would be expected to develop checks and other seasoning defects in drying. The reduction in moisture would have a tendency to increase the strength, but this is likely to be offset by seasoning checks particularly if cross grain, which is practically unavoidable, is present. After drying takes place, therefore, the solid keels would probably compare less favorably to laminated keels than is shown by the present tests.

The foregoing comparison between laminated keel sections with plain scarf joints and solid keel sections was based on tests of keel sections approximately 6 by 6 inches in cross section. In addition to these, other laminated keel sections of smaller cross section with either plain or serrated scarf joints in the laminations were tested. The results of these as well as of the other tests are shown in figure 16, wherein section modulus is plotted against maximum load. These graphs show, as would be expected, that the maximum loads for either of the two types of laminated sections are closely proportional to the section moduli. Departures from strict proportionality are no doubt due partly to inherent differences in the material. Also, the tendency for the smaller cross sections to be less strong (section modulus considered) suggests that, since the penetration of water in soaking was about the same in all instances, the soaking had relatively greater effect on the smaller sections. (The keels of reduced section were fabricated in a manner similar to those of full 6- by 6-inch section and soaked in salt water for the same period.)

A keel with plain scarf joints and 6.22 by 6.22 inches in cross section is shown by the curve in figure 16 to be about 20 percent stronger in bending than a jointless solid keel of the same size. Thus, a laminated keel with plain scarf joints as shown in figure 2 and of square section could sustain the same bending load or moment as a jointless solid keel if 94 percent as large. This comparison is based on strength values corresponding to moisture conditions induced by soaking for 3 months. After long continued drying subsequent to such soaking, the comparison would be expected to be as favorable to the laminated keel.

The laminated keel sections of full size with serrated scarf joints as shown in figure 5 developed an average modulus of rupture of 6,890 pounds per square inch compared to 6,600 pounds per square inch for solid keel sections, the difference being about 5 percent. When the comparison is based on the average curve for keels with serrated scarf joints as shown in figure 16, these keels show no superiority in strength compared to solid keel sections. No decrease in size would be suggested if laminated keels with such serrated joints were substituted for solid keel sections without joints. The effect of moisture content and opening of joints, as mentioned under laminated keels with plain scarf joints, also applies here. Figure 17 shows typical failure in keel sections containing serrated scarf joints.

Included in the laminated keel sections of full cross section and containing serrated scarf joints were three fabricated from laminating stock unrelated to that in other full-sized keel sections. These keel sections averaged somewhat higher in strength, but were also somewhat higher in specific gravity and lower in moisture content. These differences in specific gravity and moisture would account entirely for the difference in strength. Results from tests on these sections are shown in table 2 but are not included in figure 16.

Commercial laminating stock may not consistently be of better quality than solid stock, even though at times this may be true. A possibility of the laminating process, however, is that of selecting and combining wood of higher density than is available in the sizes otherwise required as well as that of positioning wood of high density where it is most effective and using wood of lower density in other parts of a member.

## Conclusions

(1) Solid keels with a bolted plain scarf joint of the design shown in figure 4 are about one-half as strong in bending as solid keels with no joints.

(2) Laminated keel sections with plain scarf joints of slope of 1 in 12 in each lamination located as shown in figure 2, sustained a maximum load in bending about 20 to 25 percent higher than solid keel sections without joints. Failure usually started at a scarf joint in the outer tension lamination, which would have a tendency to reduce the strength. The greater strength shown for the laminated keel is attributed largely to the difference between the effect of soaking on material that has been seasoned to a comparatively low moisture content and the effect when little or no seasoning has taken place. This same difference and similar results can presumably be expected to be realized in the construction and service of boats of the type considered.

(3) Laminated keel sections with serrated scarf joints of the dimensions shown in figure 5 and located as shown in figure 3 were approximately the same in bending strength as solid keel sections without joints. The moisture content and moisture distribution in these laminated sections was about the same as that of laminated keel sections with plain scarf joints and the less favorable comparison with solid keel sections is probably due to lesser efficiency of the serrated scarf joints.

It should be emphasized that it is the reported practice in the shops in which the serrated scarf joints were prepared to machine such joints very accurately after the lumber has been carefully seasoned and to assemble and glue promptly after machining in order to avoid changes of fit taking place with changes in moisture content. Preparation and gluing of such joints under other circumstances is likely to afford less favorable results.

The comparisons were based upon the results of tests of solid and laminated keels prepared from carefully matched stock. One possibility of the laminating process is that of selecting and combining wood of higher density and hence higher strength than can be readily obtained in the sizes otherwise required.

(4) Laminated keel sections of reduced cross section sustained loads in static bending about as would be expected from their cross sections and section moduli.

Table 1.--Results of static bending tests of white oak keel sections (two-point loading[1])

| Specimen No. | Number of 3/4-inch laminations | Cross section: Width | Cross section: Depth | Moisture content | Specific gravity[2] | Maximum load | Stress at proportional limit | Modulus of rupture | Modulus of elasticity | Work: Proportional limit | Work: Maximum load | Work: Total | Deflection at -: Proportional limit | Deflection at -: Maximum load | Moisture distribution: Piece No. 1 | Piece No. 2 | Piece No. 3 | Piece No. 4 | Piece No. 5 | Piece No. 6 | Piece No. 7 | Piece No. 8 | Piece No. 9 | 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) | (25) |
| | | In. | In. | Per-cent | | Lb. | 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. | In. | In. | Per-cent | Per-cent | Per-cent | Per-cent | Per-cent | Per-cent | Per-cent | Per-cent | Per-cent | |
| **Solid Section - No Joints** | | | | | | | | | | | | | | | (Pieces cut as shown in fig. 5A) | | | | | | | | | |
| 1 -O-K | ............ | 6.01 | 6.32 | 42.9 | 0.665 | 14,460 | 7,800 | 5,060 | 1,110 | 0.68 | 4.6 | 15.0 | 0.60 | 1.71 | 44.2 | 46.2 | 51.0 | 43.9 | 40.4 | 42.7 | 40.7 | 41.4 | 43.0 | Simple tension |
| 2 -O-K | ............ | 6.08 | 6.33 | 39.4 | .728 | 24,960 | 4,480 | 8,610 | 1,460 | 1.51 | 25.0 | 28.9 | .73 | 4.52 | 42.8 | 37.3 | 39.0 | 35.1 | 40.9 | 37.4 | 36.7 | 36.8 | 41.0 | Splintering tension |
| 3 -O-K | ............ | 6.02 | 6.27 | 49.7 | .620 | 14,000 | 3,190 | 4,970 | 1,100 | .89 | 3.4 | 4.4 | .70 | 1.37 | 53.7 | 48.0 | 57.1 | 57.3 | 45.6 | 44.6 | 45.3 | 51.5 | 48.9 | Simple tension |
| 4 -O-K | ............ | 6.06 | 6.29 | 48.1 | .618 | 19,360 | 2,800 | 5,380 | 960 | .77 | 8.6 | 16.1 | .70 | 2.73 | 55.0 | 46.3 | 53.3 | 60.8 | 42.9 | 42.2 | 43.8 | 49.5 | 46.1 | Splintering tension near knot outside load point |
| 5 -O-K | ............ | 6.08 | 6.28 | 49.2 | .607 | 17,010 | 3,330 | 5,960 | 1,020 | 1.12 | 11.0 | 18.0 | .78 | 3.20 | 59.1 | 55.6 | 55.8 | 53.9 | 45.0 | 44.2 | 48.2 | 48.4 | 48.6 | Simple to splintering tension |
| 6 -O-K | ............ | 6.04 | 6.31 | 58.2 | .612 | 15,890 | 2,790 | 5,550 | 940 | .77 | 10.2 | 12.0 | .70 | 3.18 | 55.6 | 52.6 | 59.2 | 56.4 | 44.1 | 45.0 | 52.2 | 59.6 | 51.7 | Splintering and very slight cross grain tension |
| 7 -O-K | ............ | 6.08 | 6.31 | 51.3 | .654 | 17,660 | 3,120 | 6,700 | 1,020 | .81 | 10.6 | 13.1 | .73 | 3.03 | 58.3 | 54.7 | 46.6 | 48.6 | 42.4 | 51.4 | 49.8 | 46.2 | 51.6 | Splintering tension |
| 8 -O-K | ............ | 6.09 | 6.31 | 39.3 | .756 | 26,560 | 5,200 | 9,930 | 1,600 | 1.58 | 29.5 | 31.8 | .77 | 4.72 | 45.4 | 40.3 | 40.1 | 34.0 | 38.4 | 38.7 | 38.7 | 37.6 | 38.8 | Splintering tension |
| 9 -O-K | ............ | 6.12 | 6.28 | 42.8 | .708 | 21,360 | 3,650 | 7,450 | 1,200 | 1.14 | 26.2 | 31.8 | .73 | 5.34 | 48.0 | 45.7 | 47.4 | 43.5 | 33.9 | 41.2 | 41.9 | 41.6 | 41.4 | Splintering tension |
| 10 -O-K | ............ | 6.07 | 6.31 | 42.2 | .685 | 19,140 | 2,950 | 6,650 | 1,350 | .63 | 19.2 | 22.8 | .59 | 2.73 | 46.5 | 47.2 | 51.3 | 40.2 | 37.5 | 40.2 | 36.4 | 36.9 | 42.0 | Splintering and simple tension |
| 10A-O-K | ............ | 6.33 | 6.03 | 48.8 | .683 | 18,800 | 4,010 | 6,860 | 1,240 | 1.29 | 13.1 | 23.1 | .80 | 3.55 | 51.3 | 52.4 | 51.7 | 48.0 | 46.1 | 46.9 | 43.8 | 47.0 | 49.6 | Splintering tension |
| Average | ............ | 6.09 | 6.28 | 46.0 | .664 | 18,860 | 3,480 | 6,600 | 1,190 | 1.00 | 13.9 | 19.7 | .70 | 3.26 | 50.9 | 47.8 | 50.2 | 48.0 | 42.1 | 43.8 | 42.7 | 45.2 | 45.7 | |
| **Solid Section - Bolted Plain Scarf Joint with a Slope of 1 in 18** | | | | | | | | | | | | | | | (Pieces cut as shown in fig. 5B) | | | | | | | | | |
| 1 -SH-K | ............ | 6.10 | 6.30 | 44.4 | .677 | 9,460 | 1,210 | 3,280 | 760 | .22 | 6.2 | 7.1 | .99 | 7.25 | 68.0 | 51.7 | 40.2 | 37.0 | 37.6 | 39.5 | 65.7 | 43.8 | 44.9 | Separation of scarf and crushing and splitting of wood at bolts near end of scarf on tension side |
| 2 -SH-K | ............ | 6.05 | 6.33 | 38.3 | .714 | 11,070 | 1,390 | 3,840 | 800 | .29 | 7.2 | 8.4 | 1.07 | 7.00 | 58.7 | 48.3 | 38.0 | 33.3 | 32.1 | 33.5 | 34.8 | 36.4 | 39.1 | Do. |
| 3 -SH-K | ............ | 6.04 | 6.30 | 49.7 | .667 | 7,970 | 1,310 | 2,790 | 640 | .31 | 3.5 | 5.6 | 1.27 | 5.00 | 57.0 | 62.1 | 47.7 | 43.2 | 42.8 | 45.2 | 45.2 | 46.9 | 48.5 | Do. |
| 4 -SH-K | ............ | 6.03 | 6.29 | 48.8 | .602 | 6,200 | 970 | 2,180 | 560 | .18 | 3.1 | 3.4 | 1.07 | 4.65 | 73.9 | 67.2 | 49.8 | 37.4 | 41.8 | 52.8 | 45.1 | 45.4 | 47.2 | Do. |
| 5 -SH-K | ............ | 6.05 | 6.28 | 47.7 | .608 | 6,750 | 1,060 | 2,380 | 600 | .20 | 2.0 | 4.1 | 1.10 | 3.77 | 79.4 | 59.1 | 46.7 | 41.2 | 39.5 | 42.7 | 45.5 | 46.0 | 47.4 | Do. |
| 6 -SH-K | ............ | 6.06 | 6.30 | 47.0 | .661 | 8,970 | 1,400 | 3,130 | 630 | .32 | 5.8 | 7.6 | 1.37 | 7.25 | 68.2 | 57.2 | 43.8 | 41.2 | 38.0 | 38.9 | 42.3 | 44.5 | 47.0 | Do. |
| 7 -SH-K | ............ | 6.06 | 6.30 | 48.0 | .652 | 8,020 | 1,050 | 2,800 | 590 | .21 | 5.1 | 6.0 | 1.10 | 7.00 | 72.2 | 68.0 | 47.7 | 40.2 | 40.6 | 40.9 | 43.3 | 47.4 | 48.9 | Do. |
| 8 -SS-K | ............ | 6.05 | 6.29 | 36.9 | .799 | 13,170 | 1,490 | 4,620 | 880 | .28 | 8.2 | 10.4 | 1.05 | 7.50 | 56.4 | 42.0 | 35.0 | 41.0 | 23.7 | 32.3 | 33.2 | 34.6 | 36.6 | Do. |
| 9 -SS-K | ............ | 6.08 | 6.31 | 39.5 | .738 | 8,770 | 1,390 | 3,050 | 670 | .31 | 5.7 | 7.6 | 1.29 | 6.92 | 66.1 | 54.0 | 40.6 | 35.7 | 35.2 | 35.6 | 36.1 | 37.6 | 39.1 | Do. |
| 10 -SS-K | ............ | 6.03 | 6.30 | 42.4 | .672 | 9,000 | 1,400 | 3,160 | 800 | .32 | 3.8 | 4.4 | 1.08 | 4.93 | 67.7 | 50.8 | 42.1 | 38.9 | 36.5 | 36.0 | 37.9 | 40.1 | 42.1 | Do. |
| 10A-SS-K | ............ | 6.06 | 6.30 | 47.5 | .649 | 8,420 | 960 | 2,940 | 630 | .17 | 4.7 | 5.5 | .94 | 6.25 | 70.9 | 56.3 | 43.5 | 40.9 | 41.1 | 42.8 | 44.6 | 46.9 | 48.2 | Do. |
| Average | ............ | 6.06 | 6.30 | 44.6 | .676 | 8,890 | 1,240 | 3,110 | 690 | .26 | 5.0 | 6.4 | 1.12 | 6.14 | 67.1 | 56.1 | 43.2 | 39.1 | 37.2 | 40.0 | 43.1 | 42.7 | 44.5 | |

(Sheet 1 of 3)

Table 1.--Results of static bending tests of white oak keel sections (two-point loading[1]) (continued)

| Specimen No. | Number of 3/4-inch laminations | Cross section: Width | Cross section: Depth | Moisture content test | Specific gravity[2] | Maximum load | Stress at proportional limit | Modulus of rupture | Modulus of elasticity | Work: Proportional limit | Work: Maximum load | Work: Total | Deflection at: Proportional limit | Deflection at: Maximum load | Moisture distribution: Piece No. 1 | Piece No. 2 | Piece No. 3 | Piece No. 4 | Piece No. 5 | Piece No. 6 | Piece No. 7 | Piece No. 8 | Piece No. 9 | 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) | (25) |
| | | In. | In. | Per-cent | | Lb. | 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. | In. | In. | Per-cent | Per-cent | Per-cent | Per-cent | Per-cent | Per-cent | Per-cent | Per-cent | Per-cent | |
| **Laminated Sections - Glued Plain Scarf Joints with a Slope of 1 in 12** | | | | | | | | | | | | | | | **[Pieces cut as shown in fig. 5B]** | | | | | | | | | |
| 1 -LP-K | 8 | 6.11 | 6.13 | 17.3 | .635 | 23,410 | 3,280 | 8,540 | 1,390 | .71 | 17.8 | 19.3 | .58 | 3.70 | 56.5 | 45.4 | 25.5 | 19.5 | 17.0 | 15.0 | 12.4 | 11.2 | 10.5 | Splintering tension and scarf joint failures in sixth and eighth laminations |
| 2 -LP-K | 8 | 6.12 | 6.14 | 18.9 | .732 | 29,650 | 4,360 | 10,790 | 2,000 | .93 | 20.1 | 20.1 | .53 | 3.24 | 64.5 | 44.2 | 28.6 | 20.9 | 18.6 | 16.2 | 12.9 | 11.0 | 9.7 | Slight cross grain and brash tension |
| 3 -LP-K | 8 | 6.18 | 6.08 | 24.4 | .637 | 18,140 | 2,780 | 6,720 | 1,340 | .58 | 6.9 | 7.1 | .51 | 2.04 | 78.0 | 62.3 | 43.2 | 33.2 | 28.4 | 23.9 | 14.4 | 12.2 | 11.0 | Simple tension with scarf joint failure in eighth lamination |
| 4 -LP-K | 8 | 6.11 | 6.08 | 21.2 | .655 | 22,310 | 2,970 | 8,280 | 1,360 | .61 | 13.7 | 15.4 | .54 | 3.09 | 75.4 | 63.7 | 42.1 | 25.4 | 20.3 | 17.8 | 13.1 | 11.5 | 11.0 | Simple and slight cross grain tension |
| 5 -LP-K | 8 | 6.13 | 6.07 | 20.8 | .648 | 22,560 | 2,790 | 8,390 | 1,370 | .55 | 19.2 | 20.1 | .50 | 4.00 | 75.6 | 54.3 | 34.0 | 24.0 | 20.1 | 17.1 | 14.2 | 12.3 | 10.9 | Simple to splintering tension and scarf joint failures in sixth and eighth laminations |
| 6 -LP-K | 8 | 6.09 | 6.05 | 22.8 | .619 | 20,310 | 2,630 | 7,640 | [illegible] | .51 | 8.1 | 8.9 | .50 | 2.23 | 75.3 | 62.3 | 42.6 | 31.5 | 24.2 | 18.7 | 13.5 | 12.2 | 11.4 | Simple tension |
| 7 -LP-K | 8 | 6.11 | 6.05 | 22.9 | .642 | 21,550 | 2,820 | 8,090 | [illegible] | .56 | 17.2 | 18.8 | .54 | 3.39 | 74.0 | 61.4 | 42.4 | 29.1 | 25.7 | 19.3 | 14.2 | 12.5 | 11.3 | Simple to splintering tension and slight scarf joint failure in eighth lamination |
| 8 -LP-K | 8 | 6.11 | 6.05 | 20.8 | .709 | 27,650 | 3,780 | 10,450 | [illegible] | .87 | 21.1 | 21.6 | .60 | 3.23 | 59.2 | 48.0 | 35.8 | 26.4 | 22.3 | 19.7 | 15.4 | 12.5 | 10.9 | Simple to splintering tension and scarf joint failure in eighth lamination |
| 9 -LP-K | 8 | 6.11 | 6.06 | 25.2 | .676 | 24,700 | 3,180 | 9,230 | [illegible] | .71 | 19.4 | 21.1 | .58 | 3.92 | 64.4 | 52.5 | 40.0 | 27.9 | 24.2 | ...... | 18.5 | 16.2 | 16.4 | Splintering tension and scarf joint failures in seventh and eighth laminations |
| 10 -LP-K | 8 | [illegible] | 6.05 | 18.9 | .690 | 16,000 | 2,700 | 6,180 | [illegible] | .46 | 4.6 | 5.3 | .47 | 1.60 | 72.6 | 56.6 | 36.2 | 23.8 | 20.3 | 17.2 | 13.4 | 12.2 | 10.8 | Severe cross grain tension at knot in eighth lamination, partial scarf joint failures in sixth and seventh laminations |
| 10A-LP-K | 8 | 6.13 | 6.08 | 20.6 | .648 | 16,710 | 2,970 | 6,230 | [illegible] | .61 | 4.3 | 5.0 | .58 | 1.59 | 75.2 | 52.6 | 30.5 | 21.2 | 18.4 | 15.6 | 13.0 | 11.6 | 10.2 | Severe cross grain tension at knot in eighth lamination, scarf joint failure in sixth lamination |
| Average | 8 | 6.10 | 6.08 | 21.3 | .667 | 22,100 | 3,120 | 8,230 | 1,430 | [illegible] | 13.9 | 14.8 | .54 | 2.91 | 70.2 | 54.8 | 36.4 | 25.7 | 21.8 | 17.3 | 14.0 | 12.3 | 11.3 | |
| 11 -LP-KR | 7-1/2 | 5.74 | 5.73 | 25.0 | 0.665 | 15,490 | 3,120 | 6,900 | 1,260 | 0.68 | 9.1 | 9.1 | 0.65 | 2.71 | 81.0 | 69.1 | 49.0 | 31.9 | 24.9 | 20.0 | 15.3 | 12.6 | 10.8 | Simple tension and scarf joint failure in seventh lamination |
| 12 -LP-KR | 7-1/2 | 5.71 | 5.75 | 21.8 | .667 | 16,180 | 2,450 | 7,200 | 1,230 | .44 | 12.2 | 12.6 | .52 | 3.43 | 64.0 | 56.7 | 32.0 | 22.8 | 21.5 | 16.8 | 13.2 | 9.8 | 10.5 | Simple tension and scarf joint failure in eighth lamination |
| Average | 7-1/2 | 5.72 | 5.74 | 23.4 | .666 | 15,840 | 2,780 | 7,050 | 1,240 | .56 | 10.6 | 10.8 | .58 | 3.07 | 72.5 | 62.9 | 40.5 | 27.4 | 21.7 | 18.4 | 14.2 | 11.2 | 10.6 | |
| 13 -LP-KR | 7 | 5.42 | 5.36 | 25.9 | .754 | 18,260 | 3,450 | 9,850 | 1,600 | .71 | 20.5 | 32.3 | .60 | 4.32 | 65.8 | 62.3 | 41.8 | 28.0 | 24.6 | 21.9 | 17.2 | 14.8 | 14.4 | Splintering tension and scarf joint failure in seventh lamination |
| 14 -LP-KR | 7 | 5.44 | 5.36 | 24.7 | .721 | 14,850 | 2,790 | 7,980 | 1,310 | .56 | 16.6 | 21.6 | .60 | 4.22 | 62.4 | 58.1 | 44.5 | 29.5 | 23.2 | 18.4 | 13.8 | 12.2 | 11.0 | Splintering and slight cross grain tension and partial scarf joint failures in fifth and sixth laminations |
| Average | 7 | 5.43 | 5.36 | 25.3 | .738 | 16,560 | 3,120 | 8,920 | 1,460 | .64 | 18.6 | 27.0 | .60 | 4.27 | 64.1 | 60.2 | 43.2 | 28.8 | 23.9 | 20.2 | 15.5 | 13.5 | 12.7 | |
| 15 -LP-KR | 6-1/2 | 5.03 | 5.00 | 23.8 | .746 | 14,270 | 4,010 | 9,530 | 630 | .86 | 15.9 | 20.5 | 1.74 | 3.75 | 62.0 | 58.3 | 41.8 | 26.0 | 19.7 | 15.3 | 11.8 | 10.9 | 9.7 | Splintering and slight cross grain tension and partial scarf joint failures in fifth, sixth, and seventh laminations |
| 16 -LP-KR | 6-1/2 | 5.00 | 4.97 | 26.7 | .609 | 9,100 | 2,180 | 6,190 | 1,190 | .41 | 9.1 | 9.3 | .58 | 3.37 | 81.7 | 67.2 | 40.3 | 23.9 | 20.1 | 17.1 | 13.4 | 12.0 | 11.6 | Simple tension and scarf joint failures in fourth and fifth laminations |
| 17 -LP-KR | 6-1/2 | 5.05 | 5.02 | 25.8 | .687 | 11,800 | 3,700 | 7,790 | 1,100 | 1.13 | 18.0 | 18.0 | 1.00 | 5.00 | 68.0 | 53.2 | 41.2 | 26.5 | 23.7 | 20.4 | 15.0 | 12.5 | 10.7 | Simple and splintering tension and partial scarf joint failures in sixth and seventh laminations |
| Average | 6-1/2 | 5.03 | 5.00 | 25.4 | .681 | 11,720 | 3,300 | 7,840 | 970 | .80 | 14.3 | 15.9 | 1.11 | 4.04 | 70.6 | 59.6 | 41.1 | 25.5 | 21.2 | 17.6 | 13.4 | 11.8 | 10.7 | |
| 18 -LP-KR | 6 | 4.60 | 4.63 | 28.6 | .675 | 9,070 | 3,070 | [illegible] | 1,460 | .68 | 23.8 | [illegible] | .73 | [illegible] | 78.4 | 58.2 | 47.4 | 29.4 | 25.9 | 24.0 | 17.8 | 12.7 | 11.0 | Splintering tension and partial scarf joint failures in fourth, fifth, and sixth laminations |
| 19 -LP-KR | 6 | 4.67 | 4.59 | 25.8 | .634 | 9,850 | 3,240 | [illegible] | [illegible] | .72 | 22.0 | 24.0 | .75 | 6.11 | 63.7 | 62.3 | 40.5 | 25.4 | 22.3 | 18.8 | 14.2 | 12.4 | 11.7 | Splintering tension and partial scarf joint failure in sixth lamination |
| Average | 6 | [illegible] | 4.61 | 27.2 | .654 | 9,460 | 3,160 | [illegible] | [illegible] | .70 | 22.9 | 23.9 | .74 | 6.31 | 71.0 | 60.2 | 44.0 | 27.4 | 24.1 | 21.4 | 16.0 | 12.6 | 11.4 | |
| 20 -LP-KR | 5-1/2 | [illegible] | [illegible] | 25.1 | [illegible] | [illegible] | [illegible] | 6,900 | 1,190 | .26 | 11.4 | 13.9 | [illegible] | 4.73 | 64.1 | 63.2 | 40.2 | 25.6 | 21.3 | 17.1 | 12.5 | 10.7 | 9.6 | Simple tension |
| 20A-LP-KR | 5-1/2 | [illegible] | [illegible] | 26.8 | [illegible] | [illegible] | [illegible] | 4,630 | 900 | .44 | 4.9 | 5.3 | [illegible] | 4.12 | 78.5 | 63.1 | 37.8 | 24.1 | 19.0 | 15.6 | 12.7 | 11.6 | 10.6 | Simple tension |
| Average | 5-1/2 | [illegible] | 4.22 | 26.0 | [illegible] | [illegible] | [illegible] | 5,760 | 1,040 | .35 | 8.2 | 9.6 | [illegible] | 4.42 | 71.3 | 63.2 | 39.0 | 24.8 | 20.2 | 16.4 | 12.6 | 11.2 | 10.1 | |

(Sheet 2 of 3)

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Table 1.—Results of static bending tests of white oak keel sections (two-point loading[1]) (continued)

| Specimen No. | Number of 3/4-inch laminations | Cross section: Width | Cross section: Depth | Moisture content | Specific gravity[2] | Maximum load | Stress at proportional limit | Modulus of rupture | Modulus of elasticity | Work: Proportional limit | Work: Maximum load | Work: Total | Deflection at: Proportional limit | Deflection at: Maximum load | Moisture distribution: Piece No. 1 | Piece No. 2 | Piece No. 3 | Piece No. 4 | Piece No. 5 | Piece No. 6 | Piece No. 7 | Piece No. 8 | Piece No. 9 | 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) | (25) |
| | | In. | In. | Percent | | Lb. | 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. | In. | In. | Percent | Percent | Percent | Percent | Percent | Percent | Percent | Percent | Percent | |
| **Laminated section - Glued Serrated Scarf Joints with a Slope of 1 in 5** | | | | | | | | | | | | | | | **(Pieces cut as shown in fig. 3)** | | | | | | | | | |
| 1 -LF-K | 8 | 6.09 | 6.05 | 18.8 | .680 | 19,030 | 2,860 | 7,170 | 1,320 | .56 | 6.3 | 13.0 | .54 | 1.90 | 57.7 | 46.7 | 30.8 | 22.2 | 18.9 | 15.4 | 13.2 | 12.2 | 12.0 | Scarf joint failures in seventh and eighth laminations and splitting within seventh and eighth laminations |
| 2 -LF-K | 8 | 6.13 | 6.08 | 18.4 | .741 | 19,350 | 2,970 | 7,170 | 1,660 | .50 | 5.0 | 9.9 | .44 | 1.53 | 57.4 | 49.2 | 31.0 | 22.6 | 18.8 | 14.9 | 11.5 | 10.8 | 10.4 | Scarf joint failure in eighth lamination and splitting within seventh and eighth laminations |
| 3 -LF-K | 8 | 6.09 | 6.06 | 20.2 | .632 | 14,210 | 2,550 | 5,340 | 1,130 | .54 | 3.4 | 3.6 | .56 | 1.44 | 66.2 | 55.0 | 38.6 | 26.8 | 21.0 | 16.1 | 11.2 | 10.0 | 8.6 | Scarf joint failure in eighth lamination and simple tension starting in seventh lamination |
| 4 -LF-K | 8 | 6.19 | 6.14 | 34.0 | .665 | 15,420 | 3,020 | 5,554 | 1,460 | .59 | 4.5 | 10.0 | .50 | 1.60 | 75.2 | 58.4 | 45.6 | 34.2 | 31.0 | 29.0 | 26.0 | 26.8 | 29.6 | Scarf joint failure in eighth lamination and splitting within seventh and eighth lamination |
| 5 -LF-K | 8 | 6.10 | 6.05 | 20.8 | .595 | 17,010 | 3,160 | 6,400 | 960 | .96 | 8.1 | 8.1 | .82 | 2.60 | 81.2 | 67.6 | 37.6 | 23.4 | 18.6 | 14.8 | 11.8 | 10.8 | 9.6 | Partial scarf joint failure in eighth lamination and simple tension starting in eighth lamination |
| 6 -LF-K | 8 | 6.07 | 6.06 | 19.0 | .589 | 16,670 | 2,860 | 6,280 | 1,010 | .77 | 6.0 | 7.0 | .70 | 2.10 | 76.0 | 58.2 | 34.6 | 21.8 | 18.0 | 15.0 | 11.2 | 10.6 | 9.2 | Simple tension |
| 7 -LF-K | 8 | 6.12 | 6.08 | 21.8 | .642 | 19,970 | 2,970 | 7,420 | 1,120 | .73 | 10.2 | 10.3 | .66 | 2.85 | 63.1 | 56.0 | 26.7 | 30.7 | 39.6 | 14.5 | 21.1 | 11.0 | 8.6 | Partial scarf joint failure in eighth lamination with splitting and simple tension in eighth lamination |
| 8 -LF-K | 8 | 6.14 | 6.08 | 22.2 | .747 | 23,000 | 3,400 | 8,520 | 1,900 | .56 | 5.9 | 8.4 | .44 | 1.52 | 61.4 | 49.0 | 35.5 | 28.0 | 25.9 | 21.2 | 16.2 | 13.2 | 10.6 | Scarf joint failure in eighth lamination and simple tension starting in seventh lamination |
| 9 -LF-K | 8 | 6.19 | 6.13 | 22.7 | .710 | 19,280 | 3,030 | 6,960 | 1,240 | .67 | 6.9 | ...... | .60 | 2.08 | 67.0 | 55.4 | 39.2 | 29.5 | 24.9 | 21.1 | 15.8 | 13.2 | 11.2 | Scarf joint failure in eighth lamination and splitting within seventh and between seventh and eighth lamination |
| 10 -LF-K | 8 | 6.08 | 6.04 | 20.0 | .688 | 20,080 | 2,730 | 7,600 | 1,480 | .47 | 6.5 | 15.0 | .46 | 1.86 | 63.8 | 49.6 | 34.5 | 25.0 | 21.2 | 17.6 | 13.8 | 11.4 | 9.7 | Scarf joint failure in eighth lamination and simple tension starting in seventh lamination |
| 10A-LF-K | 8 | 6.13 | 6.16 | 21.4 | .695 | 20,540 | 3,460 | 7,420 | 1,330 | .85 | 7.5 | 8.1 | .64 | 2.10 | 66.8 | 55.4 | 39.7 | 30.2 | 25.2 | 19.4 | 13.4 | 10.8 | 9.0 | Scarf joint failure in eighth lamination and simple tension starting in seventh lamination |
| Average | 8 | 6.12 | 6.08 | 21.8 | .671 | 18,600 | 3,000 | 6,890 | 1,330 | .66 | 6.4 | 9.3 | .58 | 1.96 | 66.9 | 54.6 | 35.7 | 26.8 | 23.9 | 18.1 | 15.0 | 12.8 | 11.7 | |
| 10B-LF-K[3] | 8 | 6.13 | 6.09 | 17.9 | .698 | 21,550 | 3,690 | 7,960 | 1,490 | .88 | 6.6 | 12.9 | .61 | 1.79 | 49.2 | 40.4 | 27.3 | 21.4 | 18.4 | 15.8 | 13.4 | 11.2 | 9.6 | Scarf joint failure in eighth lamination and splitting within seventh and eighth laminations |
| 10C-LF-K[3] | 8 | 6.10 | 6.07 | 17.8 | .648 | 18,620 | 2,840 | 6,960 | 1,420 | .53 | 5.2 | ....... | .50 | 1.66 | 55.0 | 45.5 | 30.3 | 21.6 | 18.7 | 15.8 | 12.4 | 10.8 | 10.0 | Scarf joint failure in eighth lamination and simple tension starting in seventh lamination |
| 10D-LF-K[3] | 8 | 6.18 | 6.08 | 19.4 | .735 | 20,190 | 3,680 | 7,420 | 1,460 | .86 | 5.4 | 15.9 | .62 | 1.66 | 56.5 | 47.6 | 34.8 | 26.1 | 21.6 | 17.4 | 12.4 | 10.6 | 10.0 | Partial scarf joint failures in seventh and eighth laminations and simple tension starting in eighth lamination |
| Average | 8 | 6.14 | 6.08 | 18.4 | .694 | 20,120 | 3,400 | 7,450 | 1,460 | .76 | 5.7 | 14.4 | .58 | 1.70 | 53.6 | 44.5 | 30.8 | 23.0 | 19.6 | 16.3 | 12.7 | 10.9 | 9.9 | |
| 11 -LF-KR | 7-1/2 | 5.69 | 5.81 | 35.8 | .660 | 12,800 | 2,800 | 5,600 | 1,320 | .56 | 3.1 | 4.3 | .55 | 1.34 | 82.3 | 73.2 | 55.3 | 24.6 | 33.6 | 41.0 | 27.4 | 26.2 | 23.5 | Severe cross grain tension failure in seventh and eighth laminations |
| 12 -LF-KR | 7-1/2 | 5.66 | 5.70 | 18.2 | .656 | 14,340 | 2,010 | 6,540 | 1,220 | .32 | 7.0 | 7.3 | .44 | 2.42 | 66.4 | 57.8 | 29.2 | 21.4 | 18.0 | 13.9 | 11.5 | 10.2 | 8.9 | Simple tension |
| 13 -LF-KR | 7-1/2 | 5.75 | 5.73 | 19.0 | .732 | 17,460 | 3,200 | 7,770 | 1,750 | .56 | 6.7 | 8.9 | .48 | 1.90 | 64.2 | 47.4 | 30.6 | 22.8 | 19.2 | 14.8 | 11.6 | 10.0 | 9.4 | Scarf joint failures in seventh and eighth laminations and splitting within sixth and seventh laminations |
| Average | 7-1/2 | 5.70 | 5.75 | 24.3 | .683 | 14,830 | 2,670 | 6,640 | 1,430 | .48 | 5.6 | 6.8 | .49 | 1.89 | 71.0 | 59.5 | 38.4 | 22.9 | 23.6 | 23.2 | 16.8 | 15.5 | 13.9 | |
| 14 -LF-KR | 7 | 5.47 | 5.37 | 26.4 | .720 | 13,380 | 3,190 | 7,090 | 1,530 | .60 | 4.8 | 7.2 | .58 | 1.72 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | Scarf joint failures in sixth and seventh laminations and splitting between sixth and seventh laminations |
| 15 -LF-KR | 7 | 5.49 | 5.36 | 26.2 | .720 | 13,750 | 3,620 | 7,380 | 1,750 | .69 | 5.9 | 6.7 | .58 | 1.83 | 62.0 | 55.0 | 40.8 | 29.0 | 24.2 | 20.6 | 18.6 | 17.6 | 15.0 | Scarf joint failure in seventh lamination and splitting within sixth and seventh laminations |
| 16 -LF-KR | 7 | 5.58 | 5.34 | 22.0 | .625 | 9,870 | 2,600 | 5,400 | 1,120 | .55 | 4.0 | 4.2 | .66 | 1.85 | 71.0 | 54.0 | 31.4 | 23.8 | 20.0 | 15.4 | 12.2 | 10.2 | 8.5 | Partial scarf joint failure in seventh lamination and simple tension starting in seventh lamination |
| Average | 7 | 5.49 | 5.36 | 24.9 | .688 | 12,310 | 3,140 | 6,990 | 1,470 | .61 | 4.9 | 6.0 | .61 | 1.80 | 66.5 | 54.5 | 36.1 | 26.4 | 22.1 | 18.0 | 15.4 | 13.9 | 11.4 | |
| 17 -LF-KR | 6-1/2 | 5.04 | 4.97 | 23.6 | .680 | 9,270 | 2,190 | 6,260 | 1,410 | .35 | 6.0 | 6.0 | .47 | 2.38 | 66.6 | 58.5 | 39.7 | 26.8 | 22.6 | 19.1 | 14.3 | 12.0 | 10.2 | Scarf joint failure in seventh lamination and severe cross grain tension starting in sixth lamination |
| 18 -LF-KR | 6-1/2 | 5.02 | 4.98 | 22.6 | .708 | 9,650 | 3,540 | 6,510 | 1,570 | .75 | 3.9 | 4.1 | .68 | 1.65 | 66.8 | 54.6 | 37.2 | 25.6 | 21.0 | 17.2 | 9.2 | 11.2 | 10.4 | Scarf joint failure in seventh lamination and splitting within sixth and seventh laminations |
| 19 -LF-KR | 6-1/2 | 5.03 | 4.97 | 21.5 | .732 | 10,860 | 3,040 | 7,340 | 1,600 | .55 | 5.6 | ...... | .58 | 2.06 | 62.0 | 48.8 | 33.8 | 24.0 | 21.0 | 17.9 | 13.0 | 11.2 | 9.4 | Scarf joint failure in seventh lamination and splitting between sixth and seventh laminations |
| Average | 6-1/2 | 5.03 | 4.97 | 22.6 | .707 | 9,930 | 2,920 | 6,700 | 1,530 | .55 | 5.2 | 5.0 | .58 | 2.03 | 65.1 | 54.0 | 36.9 | 25.5 | 21.5 | 18.1 | 12.2 | 11.5 | 10.0 | |
| 20 -LF-KR | 6 | 4.56 | 4.63 | 25.8 | .666 | 6,300 | 2,790 | 5,410 | 1,070 | .46 | 6.0 | ...... | .68 | 2.95 | 67.7 | 56.5 | 39.0 | 29.9 | 23.9 | 18.2 | 24.0 | 19.8 | 11.4 | Tension failure at joint and simple tension away from joint in sixth lamination |
| 20A-LF-KR | 6 | 4.58 | 4.58 | 22.4 | .673 | 4,720 | 1,400 | 4,130 | 1,050 | .17 | 2.7 | 2.8 | .44 | 1.98 | 68.6 | 50.4 | 34.4 | 25.6 | 20.6 | 15.2 | 12.0 | 10.5 | 10.2 | Simple tension starting at joint in sixth lamination |
| Average | 6 | 4.57 | 4.60 | 24.1 | .644 | 5,510 | 1,820 | 4,770 | 1,060 | .32 | 4.4 | 2.8 | .56 | 2.42 | 68.2 | 53.4 | 36.7 | 27.2 | 22.2 | 16.7 | 18.0 | 15.2 | 10.8 | |

[1]For solid specimens with bolted joints, span was 129 inches with loads placed 28 inches from supports; for all other keel sections, the span was 84 inches and the loads were placed 28 inches from supports.

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

[3]Laminated keel sections 10B-LF-K, 10C-LF-K, and 10D-LF-K were fabricated from white oak lumber unrelated to the material in other keel sections.

(Sheet 3 of 3)

Z M 67016 F

Table 2.--Summary of results of static bending tests on white oak keel sections - (two-point loading[1])

| Number of specimens | Number of 3/4-inch laminations | Gross section: Width | Gross section: Depth | Moisture content | Specific gravity[2] | Maximum load | Stress at proportional limit | Modulus of rupture | Modulus of elasticity | Work: Proportional limit | Work: Maximum load | Work: Total | Deflection: Proportional limit | Deflection: Maximum load | Moisture distribution, Piece No.: 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (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. | In. | Percent | | Lb. | 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. | In. | In. | Percent | Percent | Percent | Percent | Percent | Percent | Percent | Percent | Percent |
| Solid Section - No Joints | | | | | | | | | | | | | | | (Pieces cut as shown in fig. 4A) | | | | | | | | |
| 11 | .............. | 6.09 | 6.28 | 46.0 | 0.668 | 18,860 | 3,480 | 6,600 | 1,180 | 1.00 | 13.9 | 19.7 | 0.70 | 3.26 | 50.9 | 47.8 | 50.2 | 48.0 | 42.1 | 43.8 | 42.7 | 45.2 | 45.7 |
| Solid Section - Bolted Plain Scarf Joint with a Slope of 1 in 18 | | | | | | | | | | | | | | | (Pieces cut as shown in fig. 4B) | | | | | | | | |
| 11 | .............. | 6.06 | 6.30 | 44.6 | .676 | 8,890 | 1,240 | 3,110 | 690 | .26 | 5.0 | 6.4 | 1.12 | 6.14 | 67.1 | 56.1 | 43.2 | 39.1 | 37.2 | 40.0 | 43.1 | 42.7 | 44.5 |
| Laminated Section - Glued Plain Scarf Joints with a Slope of 1 in 12 | | | | | | | | | | | | | | | | | | | | | | | |
| 11 | 8 | 6.10 | 6.08 | 21.3 | .667 | 22,100 | 3,120 | 8,230 | 1,430 | .65 | 13.9 | 14.8 | .54 | 2.91 | 70.2 | 54.8 | 36.4 | 25.7 | 21.8 | 17.3 | 14.0 | 12.3 | 11.3 |
| 2 | 7-1/2 | 5.72 | 5.74 | 23.4 | .666 | 15,840 | 2,780 | 7,050 | 1,240 | .56 | 10.6 | 10.8 | .58 | 3.07 | 72.5 | 62.9 | 40.5 | 27.4 | 23.2 | 18.4 | 14.2 | 11.2 | 10.6 |
| 2 | 7 | 5.43 | 5.36 | 25.3 | .738 | 16,560 | 3,120 | 8,920 | 1,460 | .64 | 18.6 | 27.0 | .60 | 4.27 | 64.1 | 60.2 | 43.2 | 28.8 | 23.9 | 20.2 | 15.5 | 13.5 | 12.7 |
| 3 | 6-1/2 | 5.03 | 5.00 | 25.4 | .681 | 11,720 | 3,300 | 7,840 | 970 | .80 | 14.3 | 15.9 | 1.11 | 4.04 | 70.6 | 59.6 | 41.1 | 25.5 | 21.2 | 17.6 | 13.4 | 11.8 | 10.7 |
| 2 | 6 | 4.64 | 4.61 | 27.2 | .654 | 9,460 | 3,160 | 8,070 | 1,380 | .70 | 22.9 | 23.9 | .74 | 6.34 | 71.0 | 60.2 | 44.0 | 27.4 | 24.1 | 21.4 | 16.0 | 12.6 | 11.4 |
| 2 | 5-1/2 | 4.19 | 4.22 | 26.0 | .690 | 5,130 | 2,000 | 5,760 | 1,040 | .35 | 8.2 | 9.6 | .70 | 4.42 | 71.3 | 63.2 | 39.0 | 24.8 | 20.2 | 16.4 | 12.6 | 11.2 | 10.1 |
| Laminated Section - Glued Serrated Scarf Joints with a Slope of 1 in 3 | | | | | | | | | | | | | | | | | | | | | | | |
| 11 | 8 | 6.12 | 6.08 | 21.8 | .671 | 18,600 | 3,000 | 6,890 | 1,330 | .66 | 6.4 | 9.3 | .58 | 1.96 | 66.9 | 54.6 | 35.7 | 26.8 | 23.9 | 18.1 | 15.0 | 12.8 | 11.7 |
| [3]3 | 8 | 6.14 | 6.08 | 18.4 | .694 | 20,120 | 3,400 | 7,450 | 1,460 | .76 | 5.7 | 14.4 | .58 | 1.70 | 53.6 | 44.5 | 30.8 | 23.0 | 19.6 | 16.3 | 12.7 | 10.9 | 9.9 |
| 3 | 7-1/2 | 5.70 | 5.75 | 24.3 | .683 | 14,870 | 2,670 | 6,640 | 1,430 | .48 | 5.6 | 6.8 | .49 | 1.89 | 71.0 | 59.5 | 38.4 | 22.9 | 23.6 | 23.2 | 16.8 | 15.5 | 13.9 |
| 3 | 7 | 5.43 | 5.36 | 24.9 | .688 | 12,310 | 3,140 | 6,620 | 1,470 | .61 | 4.9 | 6.0 | .61 | 1.80 | 66.5 | 54.5 | 36.1 | 26.4 | 22.1 | 18.0 | 15.4 | 13.9 | 11.8 |
| 3 | 6-1/2 | 5.03 | 4.97 | 22.6 | .707 | 9,930 | 2,920 | 6,700 | 1,530 | .55 | 5.2 | 5.0 | .58 | 2.03 | 65.1 | 54.0 | 36.9 | 25.5 | 21.5 | 18.1 | 12.2 | 11.5 | 10.0 |
| 2 | 6 | 4.57 | 4.60 | 24.1 | .644 | 5,510 | 1,820 | 4,770 | 1,060 | .32 | 4.4 | 2.8 | .56 | 2.42 | 68.2 | 53.4 | 36.7 | 27.8 | 22.2 | 16.7 | 18.0 | 15.2 | 10.8 |

[1] For solid specimens with bolted joints, span was 129 inches with loads placed 28 inches from supports; for all other keel sections, the span was 84 inches and the loads were placed 28 inches from supports.

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

[3] These three laminated keel sections were fabricated from white oak lumber unrelated to the material in other keel sections.

Z M 67017 F

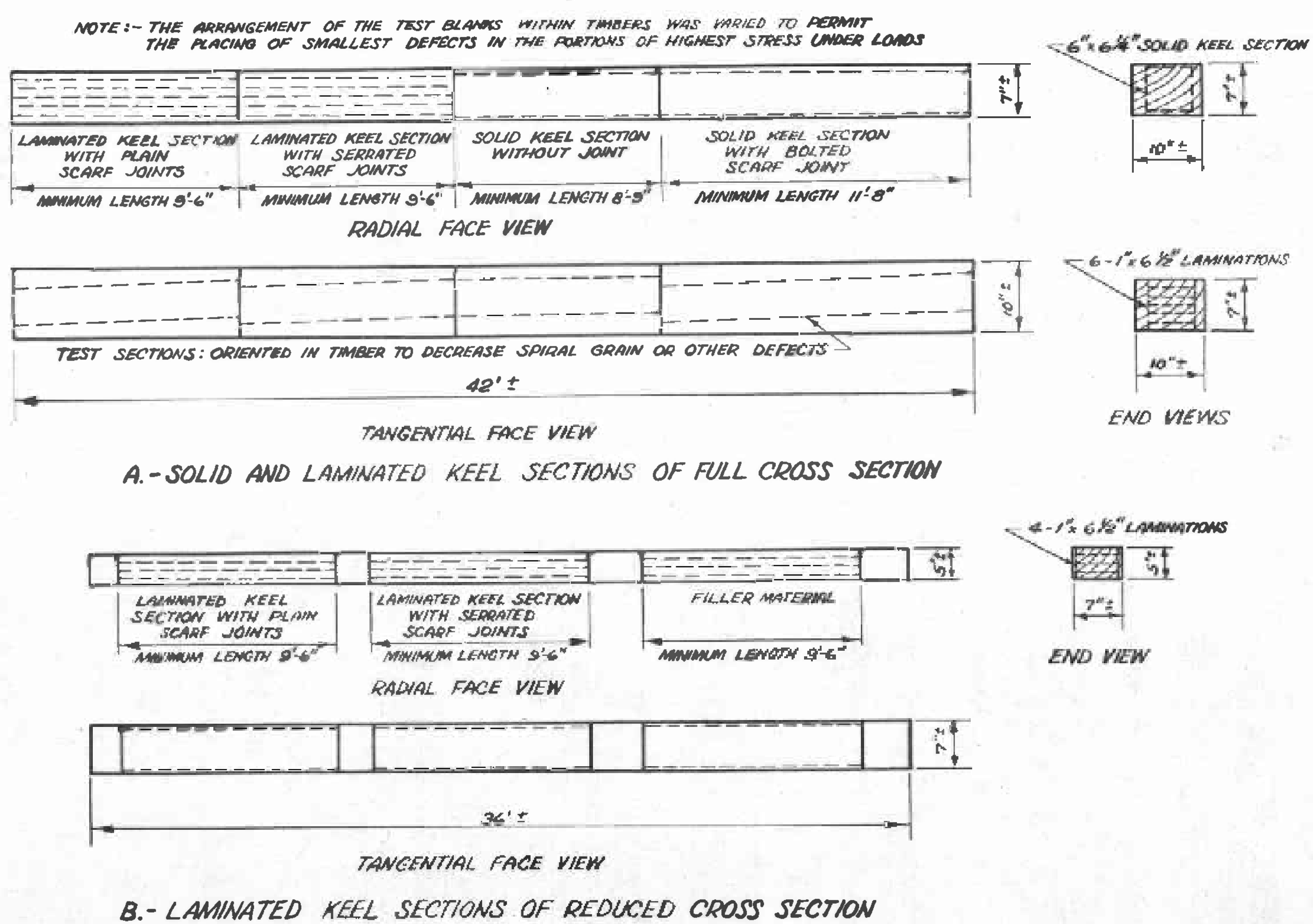
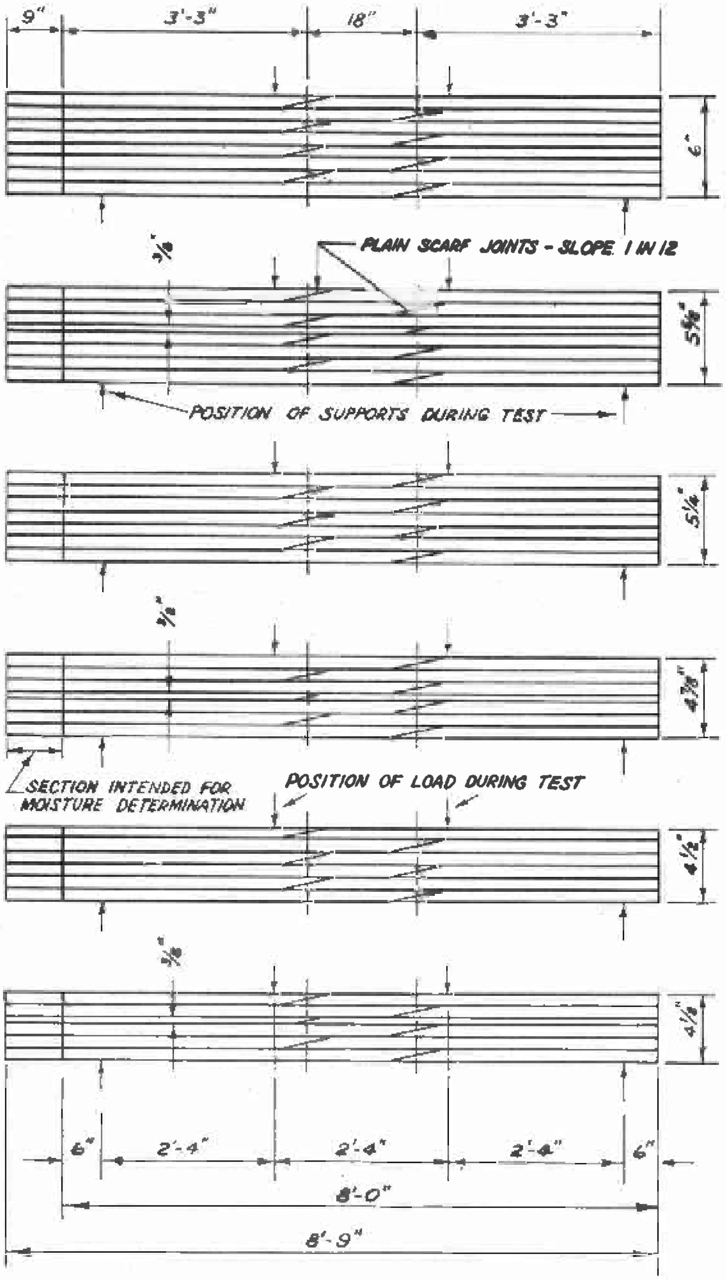



Figure 1.--Method of matching.

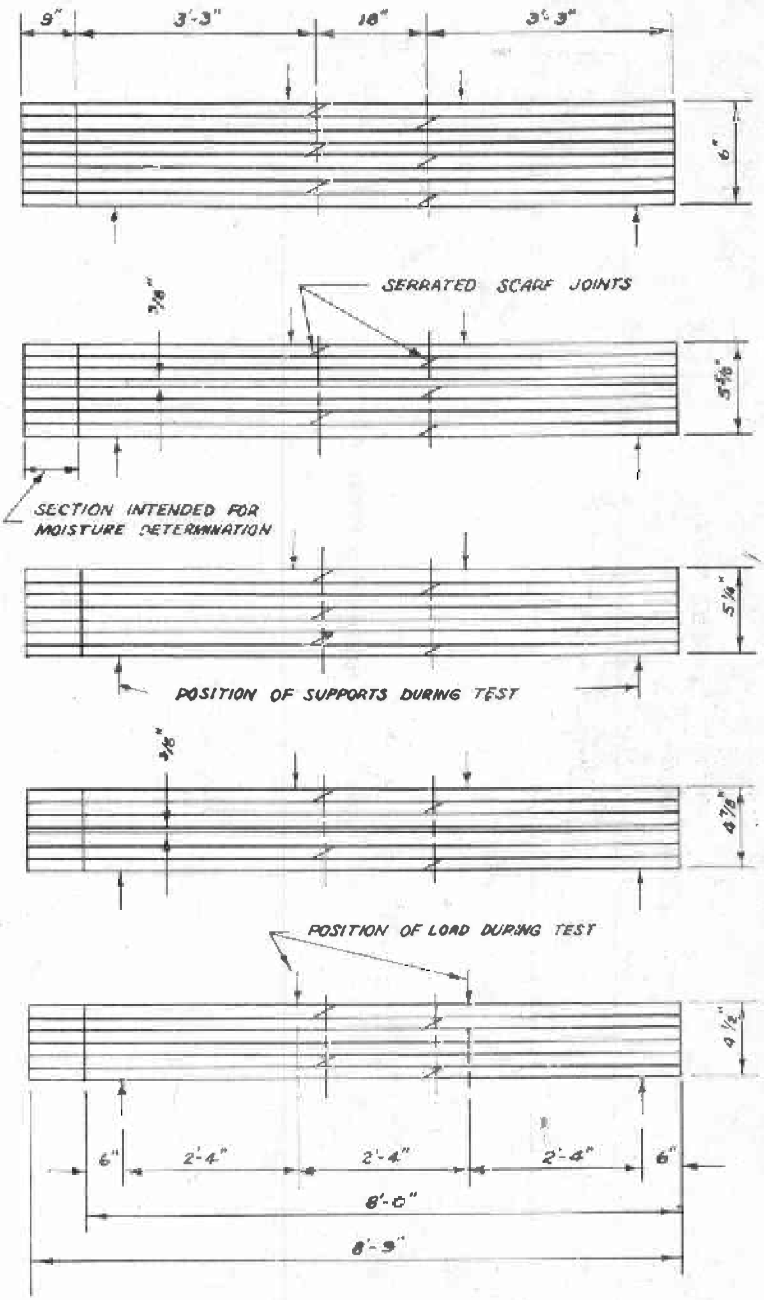
Z4 71849 F




| NUMBER OF TESTS | SPECIMAN NUMBERS | NUMBER OF 3/4" THICK LAMINATIONS PER KEEL SECTION | WIDTH OF KEEL SECTION — INCHES |
|---|---|---|---|
| 11 | 1LP-K TO 10LP-K & 10-A-LP-K | 8 | 6 |
| 2 | 11LP-KR & 12LP-KR | 7½ | 5⅝ |
| 2 | 13LP-KR & 14LP-KR | 7 | 5¼ |
| 3 | 15LP-KR TO 17LP-KR | 6½ | 4⅞ |
| 2 | 18LP-KR & 19LP-KR | 6 | 4½ |
| 2 | 20LP-KR & 20-A-LP-KR | 5½ | 4⅛ |

Figure 2.--Details of laminated keel sections with plain scarf joints.

Z M 71850 F




| NUMBER OF TESTS | SPECIMEN NUMBERS | NUMBER OF 3/4" THICK LAMINATIONS PER KEEL SECTION | WIDTH OF KEEL SECTION — INCHES |
|---|---|---|---|
| 14 | 1LF-K TO 10LF-K & 10-A-LF-K 10B-LF-K 10C-LF-K 10D-LF-K | 8 | 6 |
| 3 | 11LF-KR TO 13LF-KR | 7 1/2 | 5 5/8 |
| 3 | 14LF-KR TO 16LF-KR | 7 | 5 1/4 |
| 3 | 17LF-KR TO 19LF-KR | 6 1/2 | 4 7/8 |
| 2 | 20LF-KR & 20A-LF-KR | 6 | 4 1/2 |

Figure 3.--Details of laminated keel sections with serrated scarf joints.

Z M 71851 F

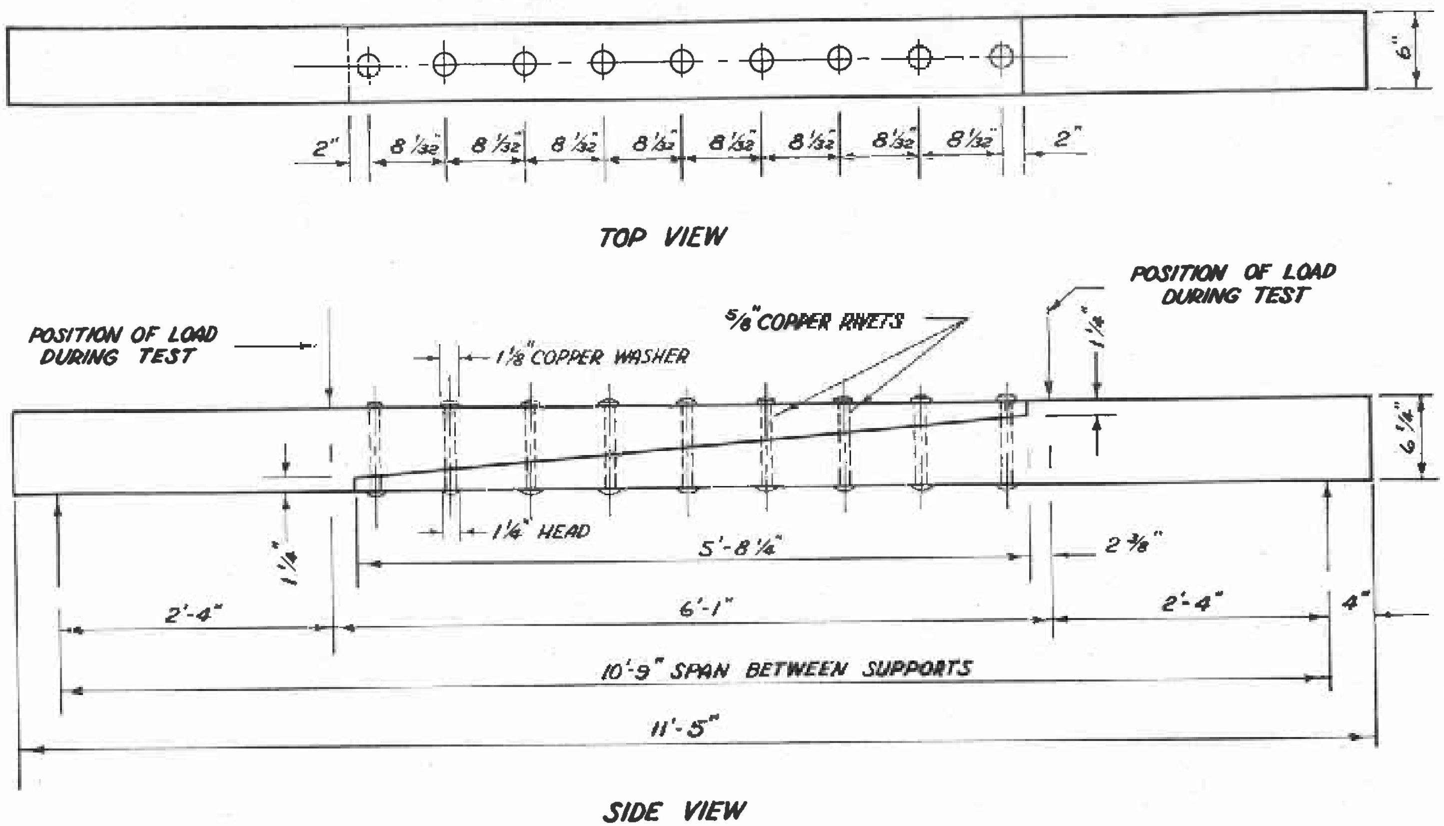



Figure 4.--Details of solid keel section with bolted scarf joint.

Z M 71852 F

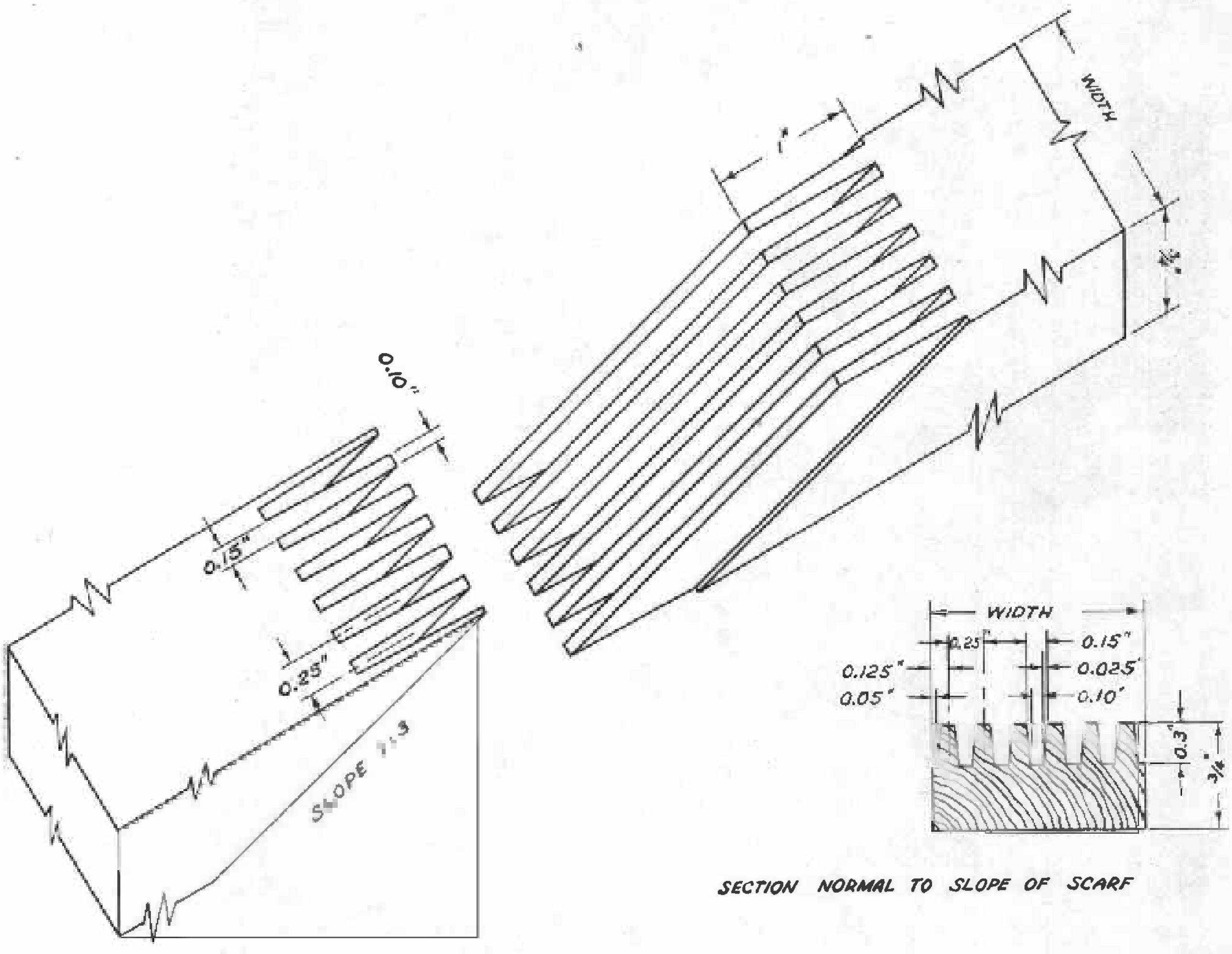



Figure 5.--Sketch showing details of serrated scarf joint.

Z M 71653 F

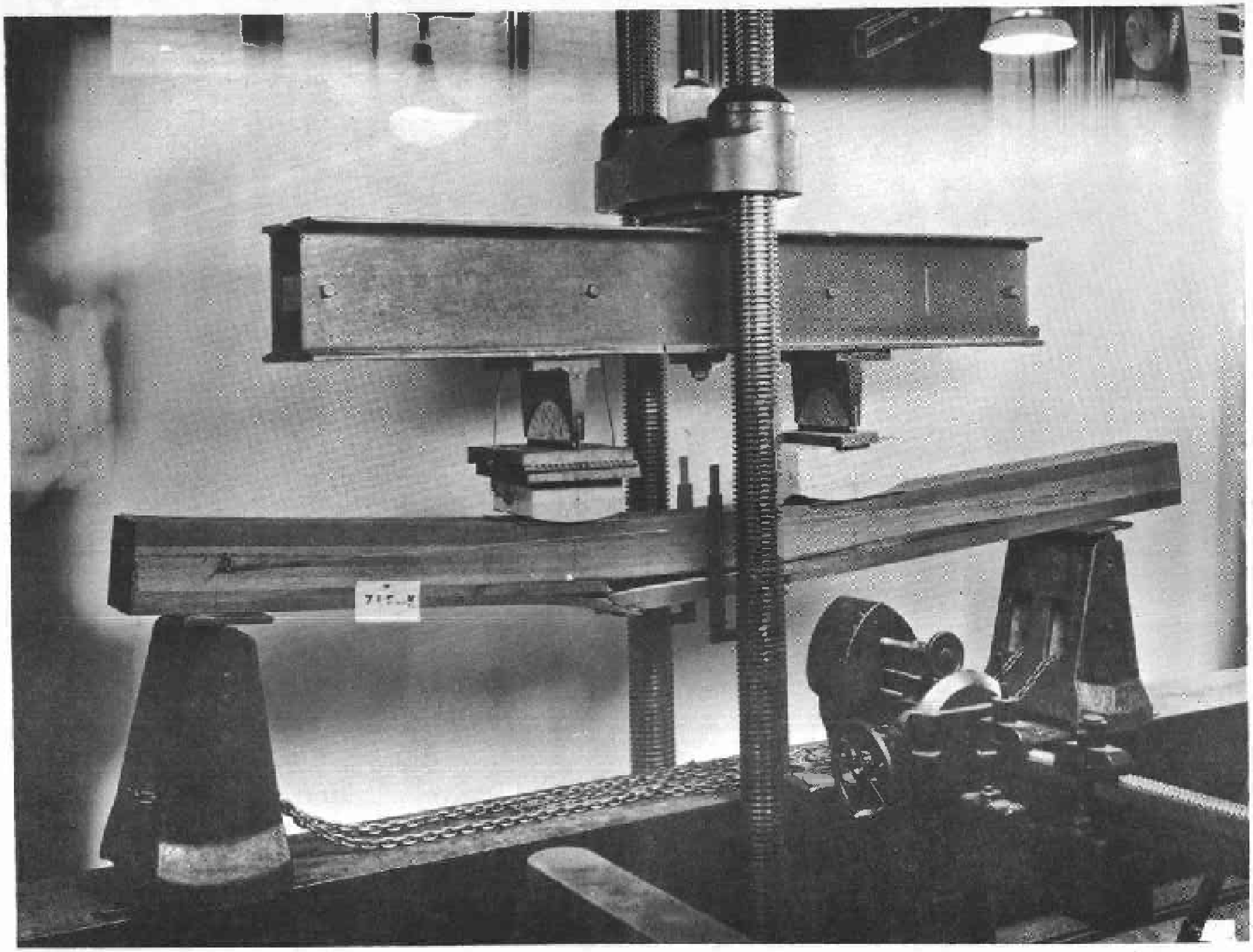


Figure 6.--Oak keel section in testing machine used to determine static bending strength. Figure shows string extending from support to support and scale attached to timber at center of span for measuring total deflection. Span was 7 feet and load was applied 2 feet 4 inches (one-third span) from supports.

Z M 71654 F

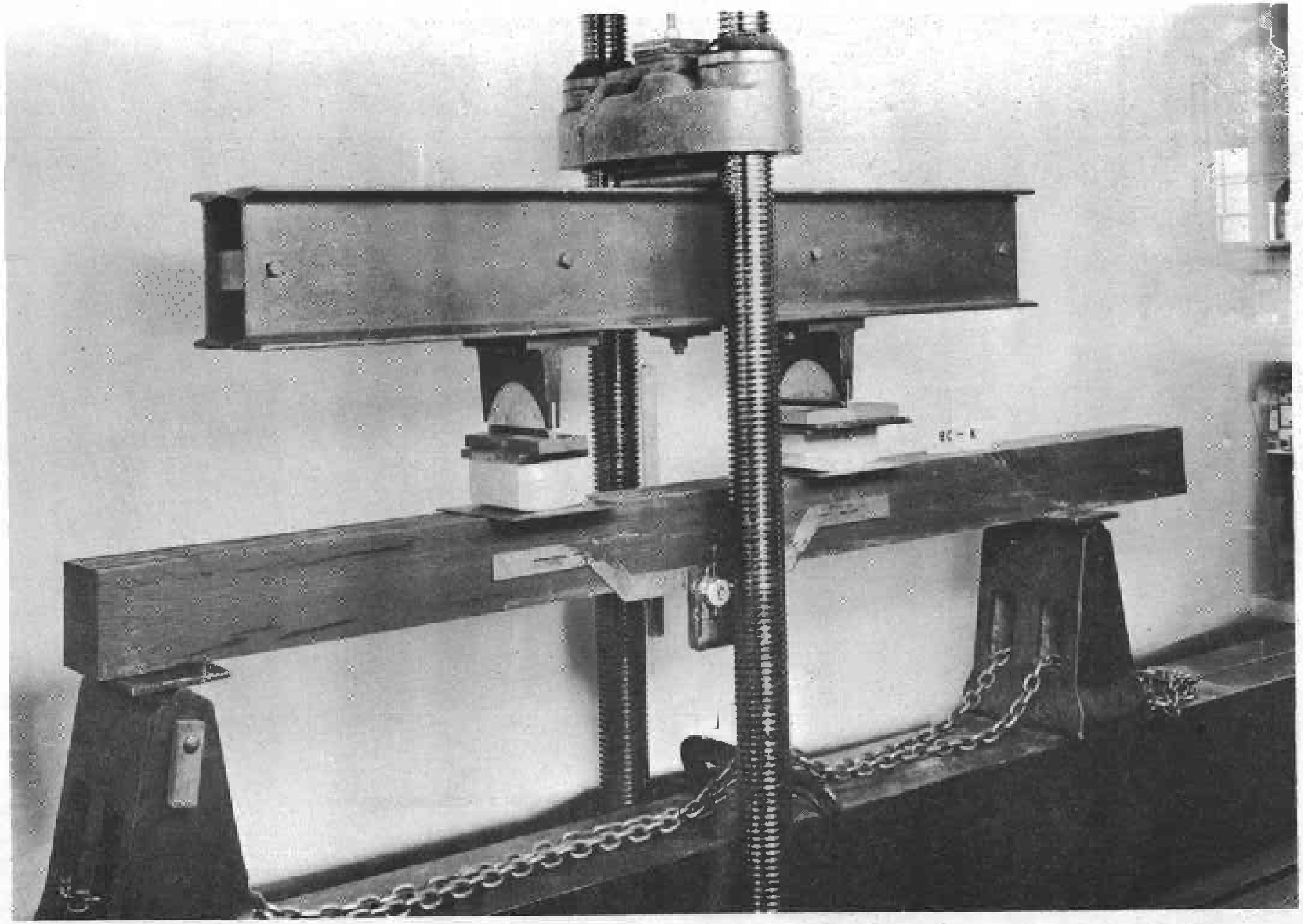


Figure 7.--Oak keel section in testing machine. Figure shows yoke and dial for measuring deflection between load points.

Z M 71855 F

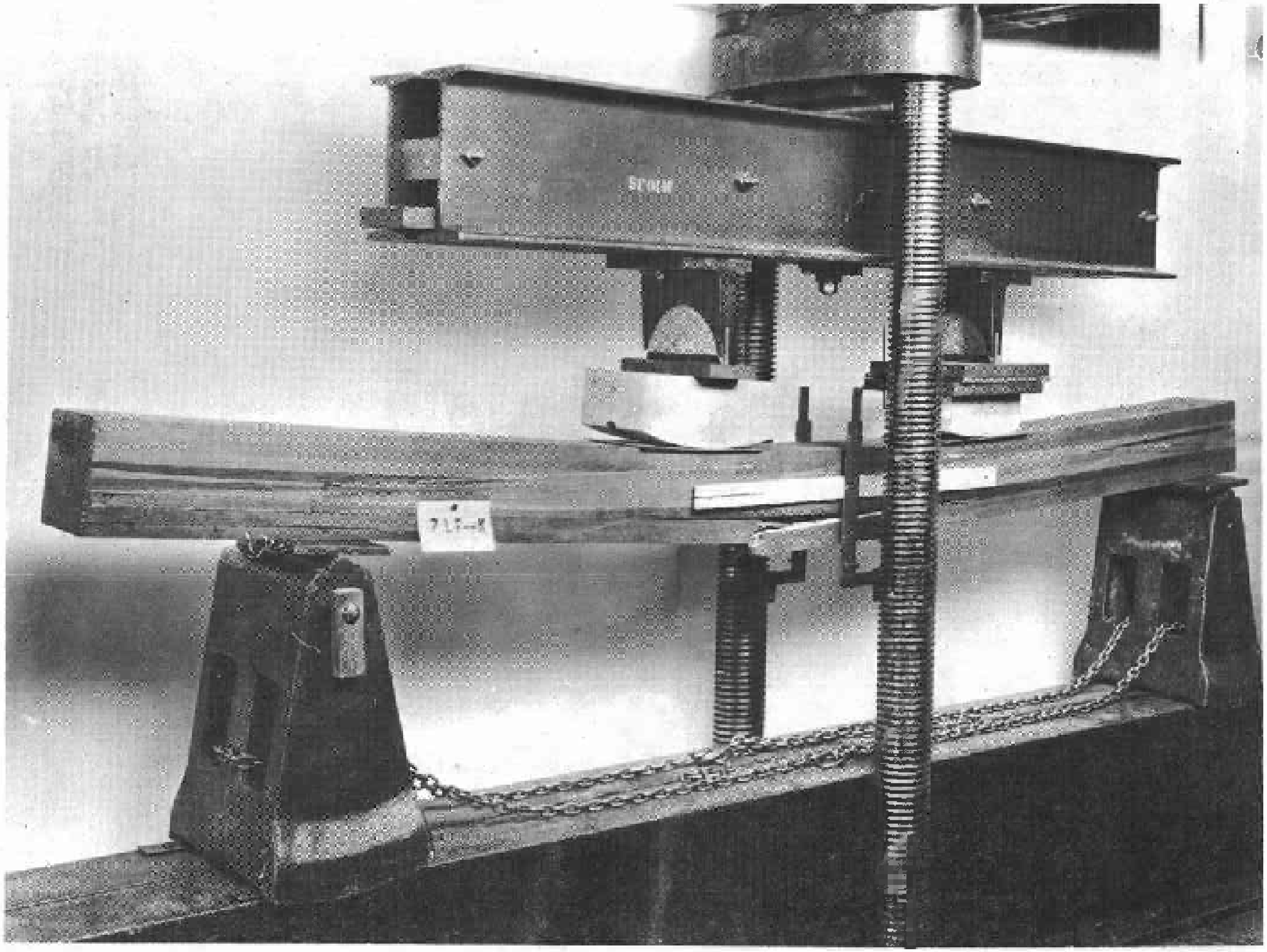


Figure 8.--Oak keel section in testing machines. Figure shows scale attached to board supported by nails under load points and string extending from support to support for measuring average deflection under load points.

Z M 71856 F

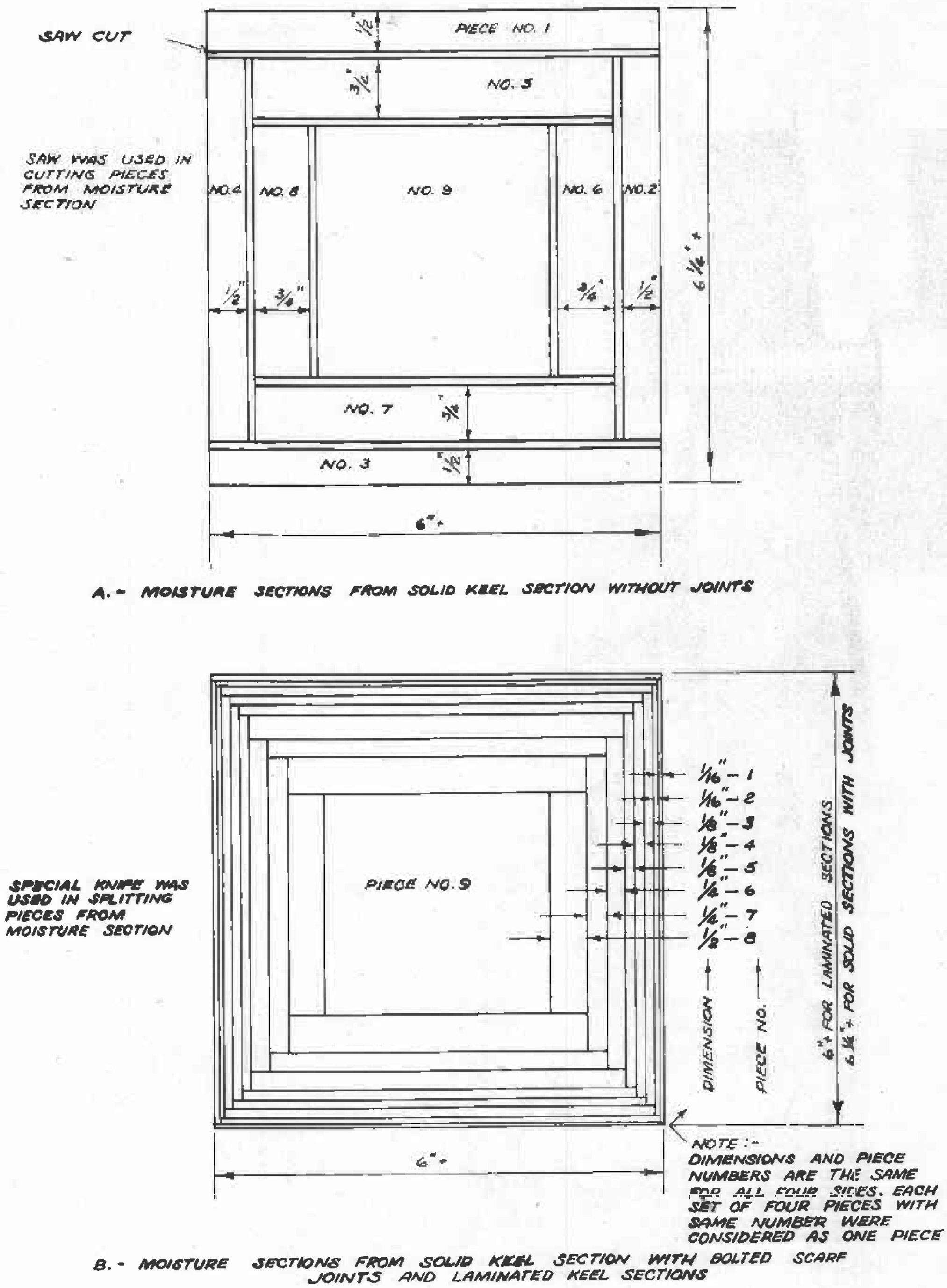



Figure 9.--Details for cutting pieces from 1-inch moisture sections.

Z M 71857 F

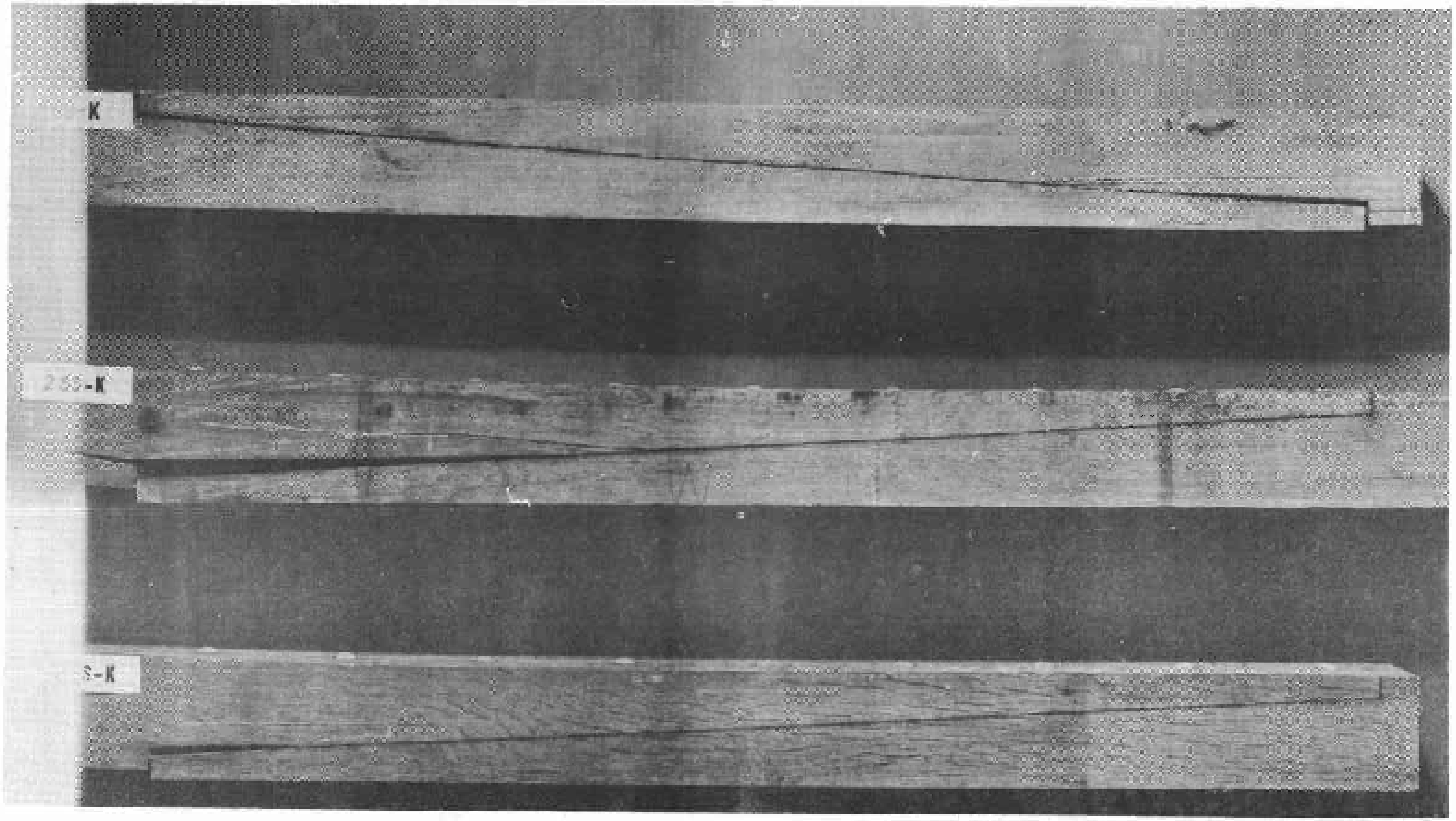


Figure 10.--Side view of solid keel sections with bolted plain scarf joints of slope of 1 in 18 after test, showing opening of the scarf joint, which was typical of these failures.

Z M 71858 F

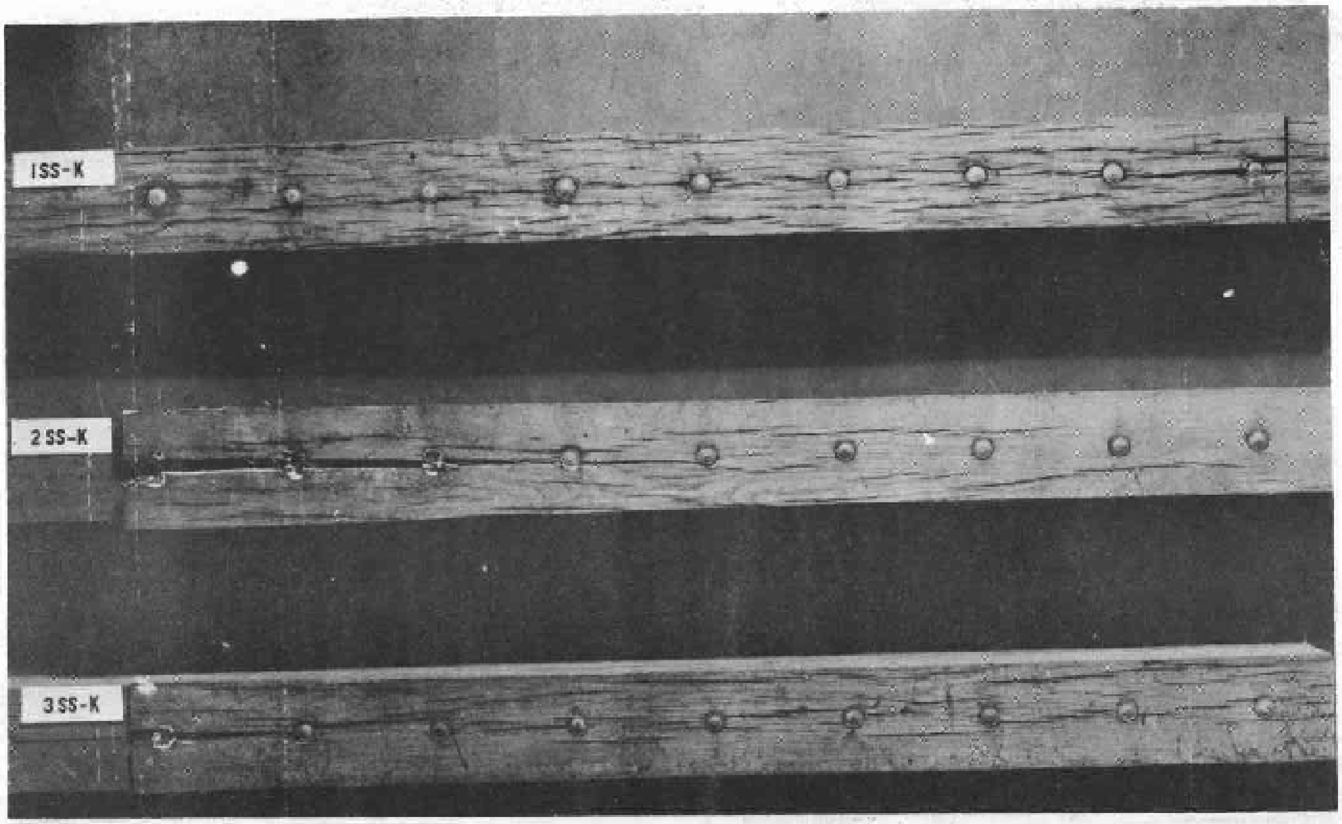



Figure 11.--Bottom view of solid keel sections with bolted plain scarf joints after test, showing the crushing and splitting of the wood at the bolts near the end of the joint on the tension side.

Z M 71859 F

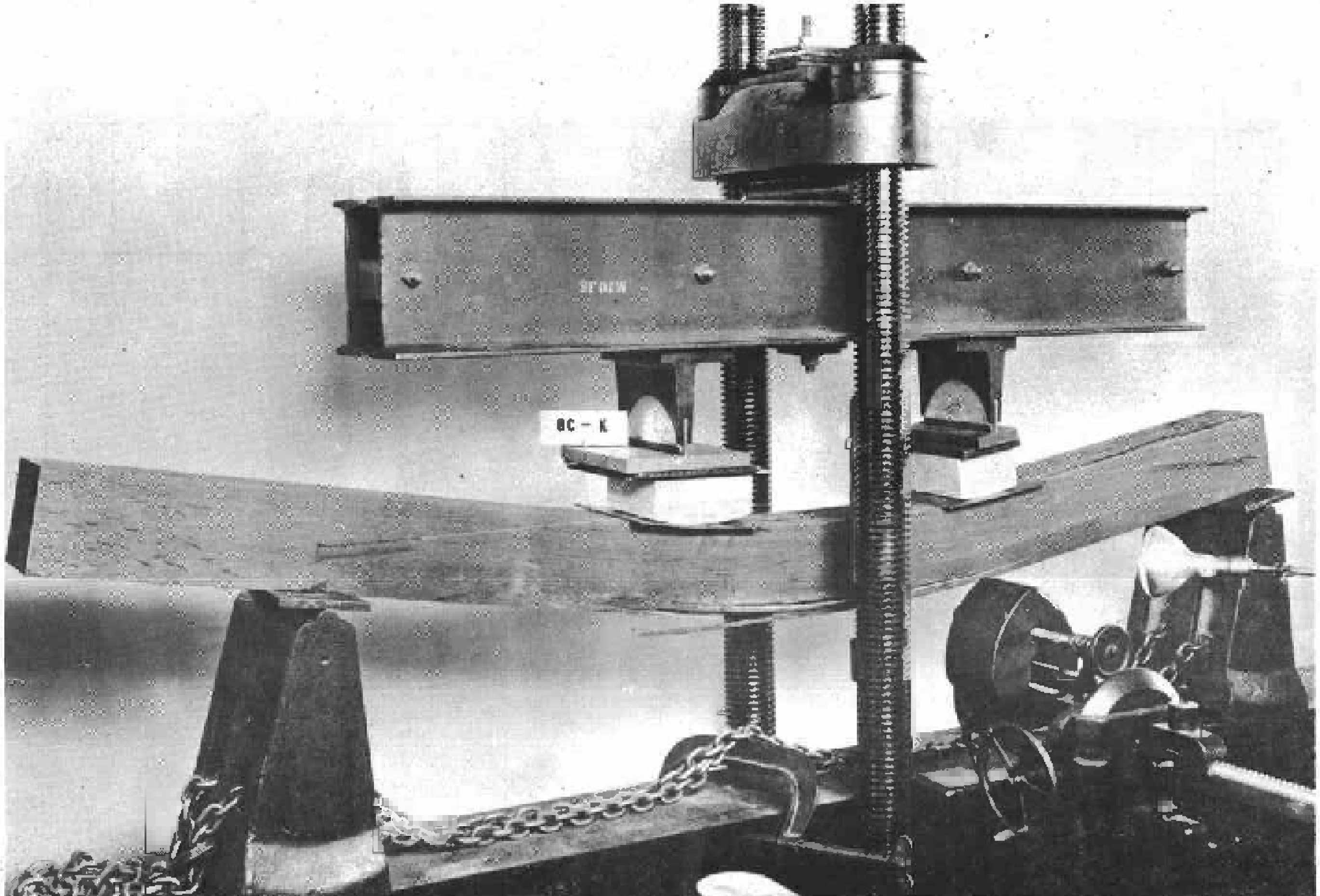



Figure 12.--Typical splintering tension failure of a solid keel section without joints. Most beams failed in this manner; a few failed by simple tension.

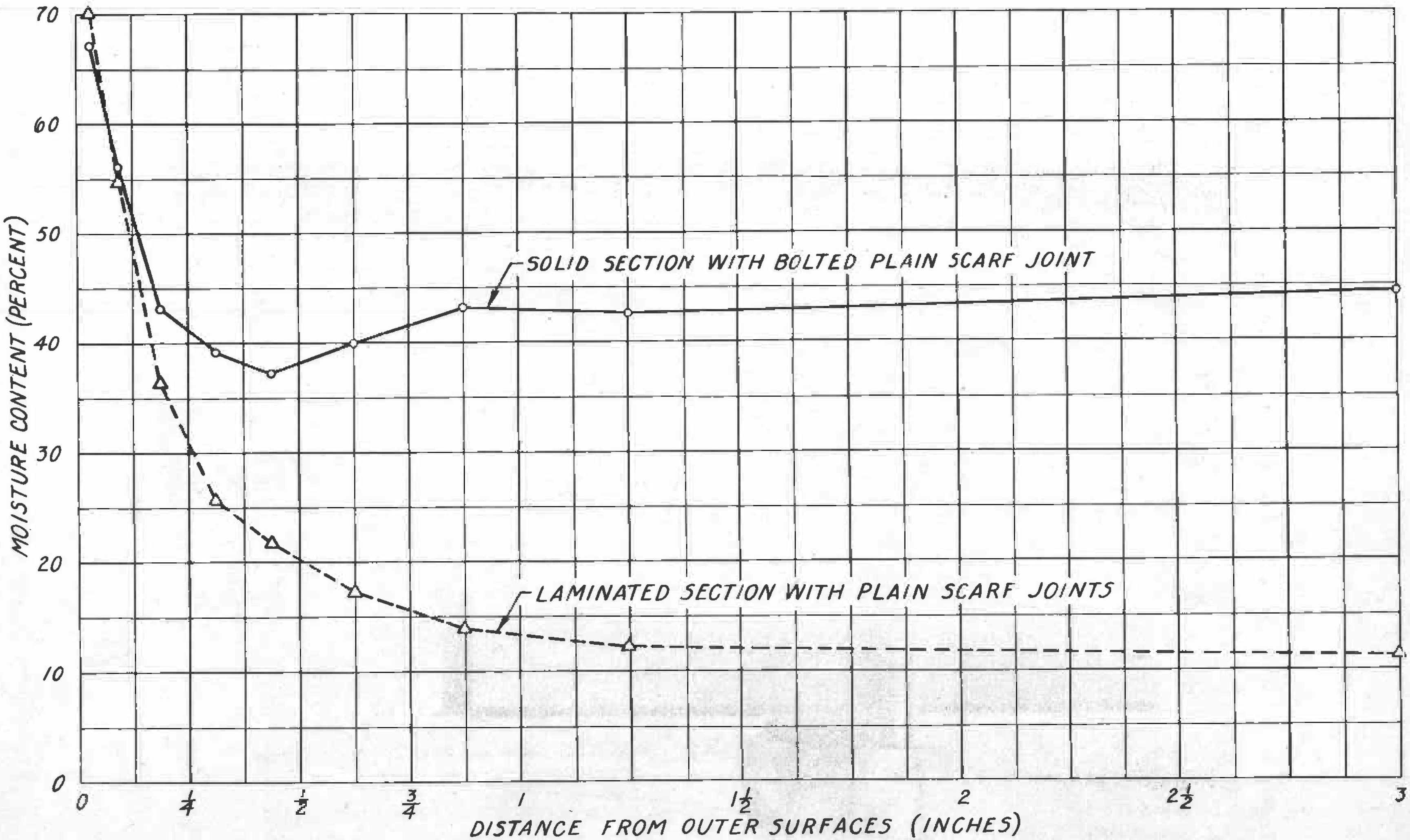



Figure 13.--Moisture distribution in 6 by 6 inch keel sections.

Z M 66723 F

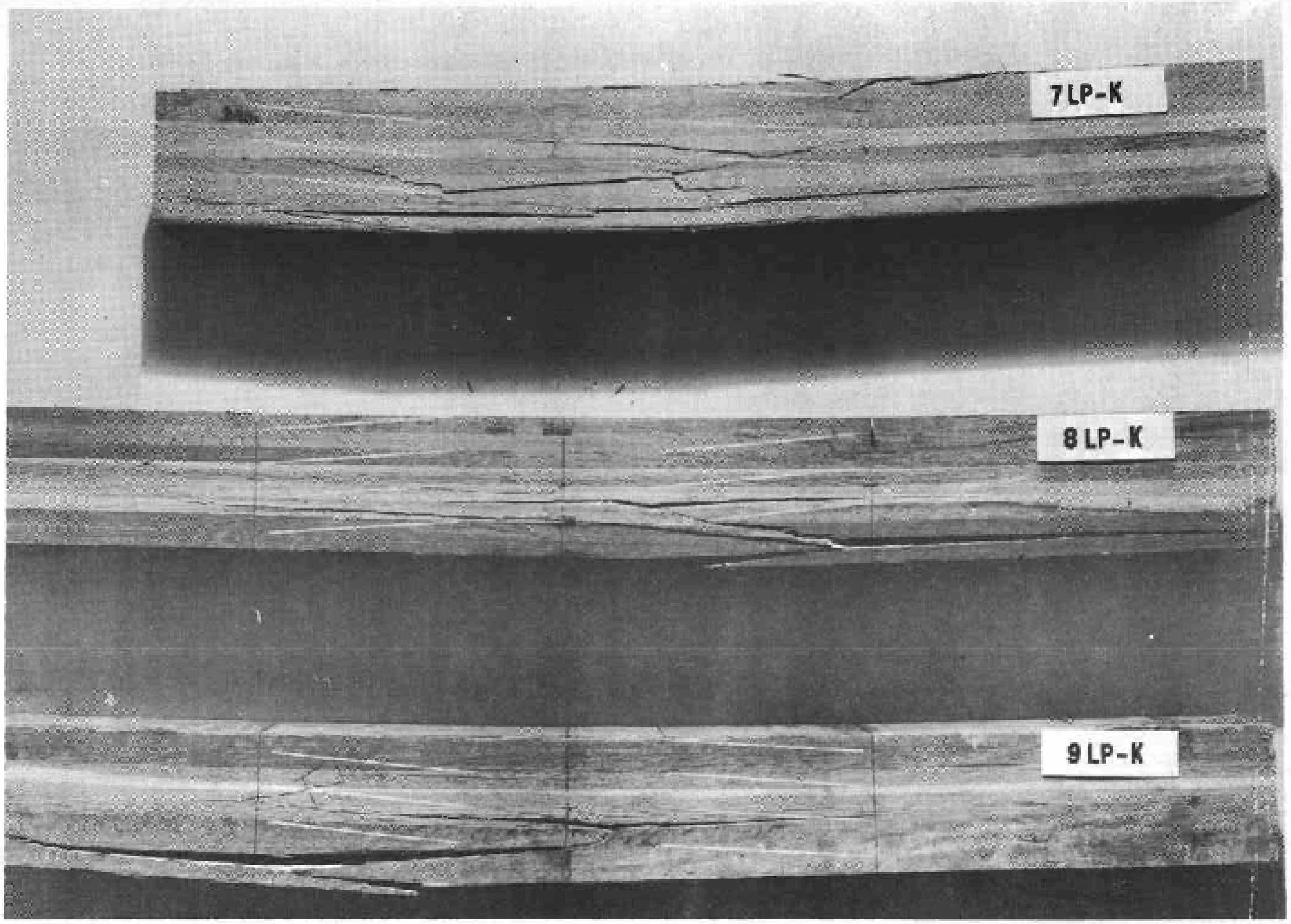



Figure 14.--Side view of failed laminated keel sections with plain scarf joints of slope 1 in 12. Typical failure is a simple-to-splintering tension and some opening of scarf joint usually in outer lamination on tension side.

Z M 71861 F

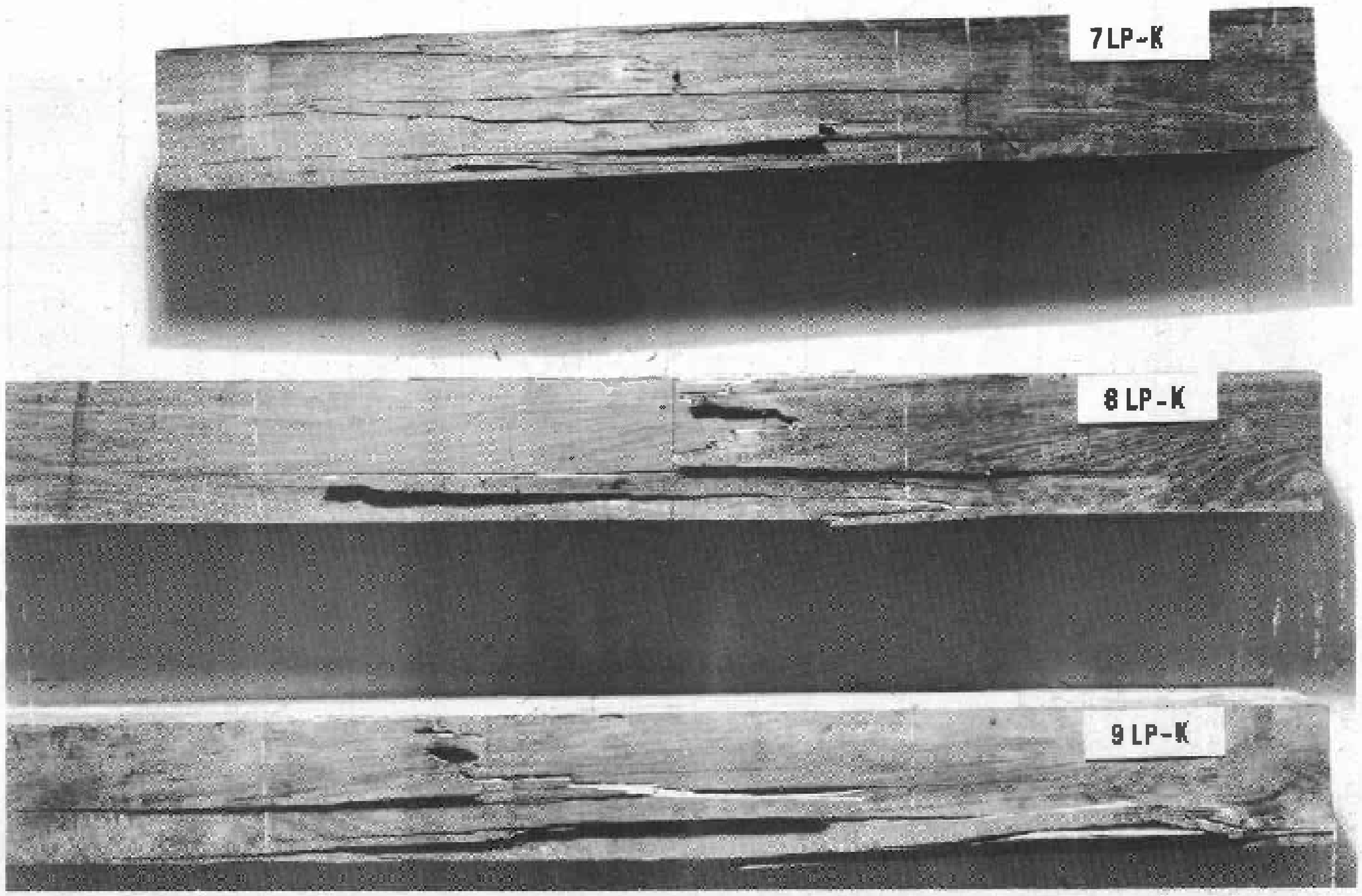



Figure 15.--Bottom view of typical failures of laminated keel sections with plain scarf joints of slope of 1 in 12.

Z M 71862 F.

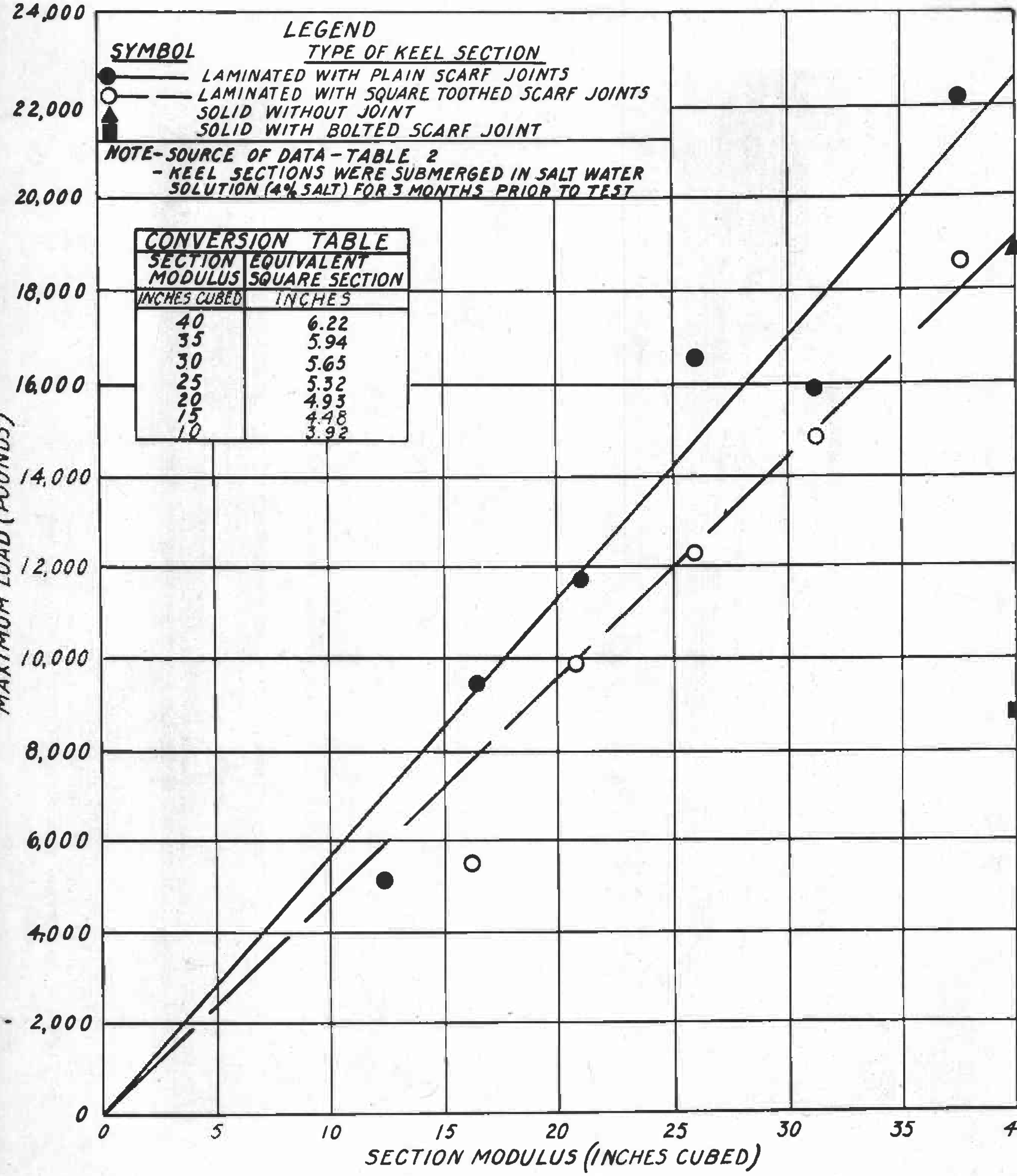



Figure 16.--Relation of maximum load to section modulus for white oak keel sections.

Z M 66724 F

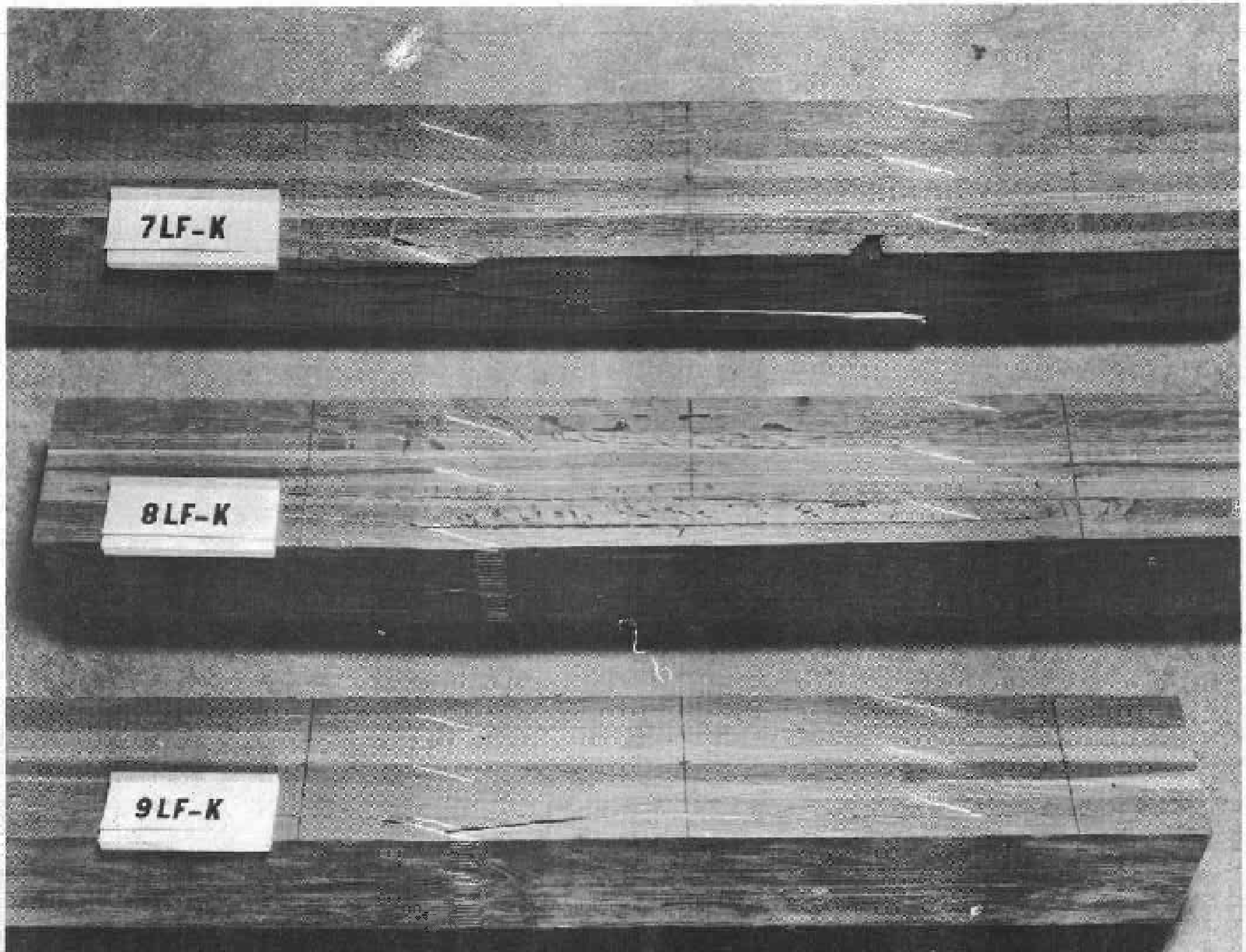



Figure 17.--Failure of laminated keel section with serrated scarf joint of slope of 1 in 3. Typical failure is an opening of the joint in outer lamination on tension side followed by simple or splintering tension.

Z M 71863 F