STUDIES OF COMPRESSION FAILURES AND THEIR DETECTION IN LADDER RAILS

February 1949

(Report) No. D1733

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
Madison 5, Wisconsin
In Cooperation with the University of Wisconsin

STUDIES OF COMPRESSION FAILURES AND THEIR DETECTION IN LADDER RAILS

By MAXON Y. PILLOW, Wood Technologist

Forest Products Laboratory,[1] Forest Service
U. S. Department of Agriculture

Some Characteristics of Compression Failures

Compression failures are minute fractures or short, locally deformed areas along the cell walls of fibers that result when excessive endwise-compression forces are applied to wood. Occasionally, well-defined buckling can be seen without magnification; but, more frequently, compression failures are so small that a high-power microscope is necessary to detect them. Readily visible ones are shown in figure 1, as well as some that are barely visible, even at slight magnification, when photographed under optimum conditions of lighting. These localized areas of damaged fibers, each of which extends across at least several annual rings, constitute one important cause of the condition in wood commonly known as brashness, which permits pieces of lumber to break suddenly and completely at relatively small loads and deflections and with an abrupt fracture across the grain.

Cause of Ladder-rail Breakage

Requests for diagnosis of causes of unexpected breakage of ladder rails during service are frequently received by the Forest Products Laboratory. These requests come from ladder manufacturers and users, as well as from insurance companies and others concerned with ladder failures. Examinations at the Laboratory of many broken ladder rails showed that the fractures had occurred at compression failures that were present before the rails ultimately broke in what was frequently reported to have been ordinary use.

Ladder materials are specified as to kind, size, and quality in safety codes of "American Engineering and Industrial Standards" and by the National Safety Council for the purpose of providing equipment that is as safe as possible. Such codes for ladder rails are based on available information regarding defects and on characteristics of the wood that are known to affect adversely the strength properties of wood in service. Previous studies of

---

[1] Maintained at Madison 5, Wis., in cooperation with the University of Wisconsin.

causes of brashness in wood showed that compression failures seriously reduce bending-strength properties, particularly when loads are applied suddenly.[2] For this reason, the safety codes require that side rails shall be free from compression failures.

Need for Information

The objective of studies covered by this report was to provide information essential to manufacturers and users of ladders on effects and detection of compression failures in ladder-rail material, both during manufacture and service of the finished products. Studies of broken parts of ladders have demonstrated the need of understanding the nature of compression failures and of adopting practical methods by which to exclude them from equipment on which safety of life and property depends. Investigations of and experience with the specifications and selection of material for aircraft during the war resulted in the improvement of inspection methods adequate for the detection of compression failures.[3]

Accordingly, the work at the Laboratory covered by this report included examinations of broken ladder rails and of material during manufacturing, determination of pertinent strength properties of the material with respect to the presence of compression failures, further development of practical inspection methods, and assembly of explanatory material to aid and guide inspectors in detection of obscure compression failures. This work was facilitated by cooperation of ladder manufacturers from whom experimental material was obtained, and at whose plants practical inspection techniques were explored.

Examinations of Broken Ladder Rails

Ladder rails that failed in service usually had abrupt breaks across the grain rather than splintering breaks. Microscopic examinations under polarized light on thin sections of wood, which included the ultimate abrupt breaks, showed that the fractures across the grain had occurred at compression failures. These observations conformed to those of previous work on causes of brashness that showed positive relationships between the presence of compression failures and abrupt breaks across the grain.[2]

Two breaks due to compression failures occurred about 1 foot apart in one ladder rail (fig. 2), while in another ladder both rails had broken simultaneously at the same rung insertion because of compression failures in both rails. In the rails of both of these ladders, the compression failures were too small to be detected by ordinary visual inspection of the sides and

---

[2] Cause of Brashness in Wood, by Arthur Koehler. USDA Tech. Bull. 342, 1933, Washington, D. C.

[3] Detection of Compression Failures in Wood, by Eric A. Anderson. Report No. 1588, June 1944, Forest Products Laboratory, Madison 5, Wis.

edges of the rails. Their presence, nevertheless, was indicated by areas of broken fibers that extended across several annual rings on end-grain surfaces (fig. 3) that were cut from near the failures of each of the rails.[3] Thus, the abrupt fractures across the grain of the rails were found to occur at compression failures already present in the wood, and the presence of these defects was indicated in nearby parts of the rail by fiber breakage in end-grain surfaces, although they were not detected by ordinary visual inspection of other surfaces.

Studies of Ladder-rail Material

The numerous requests for information regarding causes of, and subsequent determination of effects of, compression failures in relation to ladder-rail breakage during service indicated a need by ladder manufacturers for information on practical inspection methods by which to detect compression failures. In order to satisfy such a requirement, additional investigation of occurrence of compression failures in ladder-rail material and of their effect on strength properties of the wood was considered necessary.

Material Examined

This study was made on ladder-rail material in the process of manufacture so that observations and results would directly apply to the particular needs of ladder producers for information on compression failures. Visual examinations of the end-grain surfaces showed fiber breakage that indicated the presence of compression failures in an appreciable percentage of a large number of ladder rails in storage. Such fiber breakage had occasionally occurred on only one end of some rails, but more frequently it was observed at both ends of the rails. This observation indicated that compression failures were distributed throughout the lengths of most of the rails showing such fiber breakage.

Many of the compression failures were undoubtedly small and, therefore, potentially hazardous, since they could not be readily seen and might remain undetected until after the ladders were placed in service.

Occasionally, compression failures were also visible on surfaces of ladder rails, but the ones observed were generally very small. They were most easily detected in rails to which a clear lacquer had been applied. Such a finish acts as a clearing agent by reducing the refraction of light from very small surface irregularities, such as small compression failures, so that their characteristics are somewhat more readily identified.[4]

---

[4]Compression Failures in Wood Detected by the Application of Carbon Tetrachloride to the Surface, by John P. Limbach. Report No. 1591, March 1945, Forest Products Laboratory, Madison 5, Wis.

Selection of Test Material

Some of the ladder rails examined for fiber breakage on end-grain surfaces were selected for study by means of a toughness test to determine their strength properties and manner of failure. Seven ladder rails that showed fiber breakage at one or both ends, were available for this work in comparison to six other rails on which no fiber breakage was observed. The ladder rails had been shaped to their final cross-sectional size and were either 14 or 16 feet in length, and their surfaces had been sanded.

One sample about 2 feet along the grain was cut from an end selected at random from each of six rails on which no fiber breakage was observed on end-grain surfaces. From each of the seven other rails that showed some fiber breakage, one or more samples, 2 feet long, were cut from each end. Usually, three or four consecutive samples from one end and one sample from the opposite end were cut from the latter rails. In addition, consecutive samples also were cut from the complete lengths of two of these rails.

Each of the samples provided material for determination of properties of the wood that were considered important for studying the effects of compression failures in material for ladder rails.

Properties Studied

Previous work had shown that when compression failures were present, they seriously affected strength, particularly that of specimens subjected to impact loads.[2] Such test specimens break suddenly and completely and with abrupt fractures across the grain; while specimens not having compression failures usually splinter, and the parts on each side of the break often hang together tenaciously. Toughness-test values, as determined by a machine developed at the Forest Products Laboratory, have been shown to be suitable for detecting brashness in wood, particularly when this condition has been caused by compression failures that were present prior to the testing.[2] Therefore toughness-test values were determined on three specimens cut from each of the samples obtained from the ladder rails.

Specific-gravity determinations were made on each of the toughness-test specimens, since it is known that wood with appreciably lower density than the average for a species is one of the causes of brashness in wood.[2] The moisture content of the material was relatively uniform as a result of conditioning the specimens under controlled conditions of temperature and relative humidity. These values were mostly between 12 and 13 percent of the oven-dry weight.

---

[2] Strength and Related Properties of Wood Grown in the United States, by L. J. Markwardt and T. R. C. Wilson. USDA Tech. Bull. 479, 1935. Washington, D. C.

End-grain and Surface Examinations

End-grain surfaces of the samples were examined for the presence or absence of fiber breakage. Pieces about three-fourths inch along the grain were sawed from one end of each sample in order to standardize the examination of the ladder-rail material. While previous observations indicated that the relative coarseness or sharpness of a cut-off saw did not seriously hamper such an examination, it was found to be facilitated by using a reasonably sharp saw pulled through the piece at a moderate rate of speed. Some observations have indicated that coarse and dull saws tend to cause rougher surfaces, particularly when the saws are pulled rapidly through the piece, so that fiber breakage will be partially obscured by the roughness of the surface. A 16-inch novelty cut-off saw, with four teeth and one raker to each set, that was driven at about 1,800 revolutions per minute, was used. Thus, end-grain surfaces were obtained by conditions that were considered to be as favorable as possible for practical means of detection of fiber breakage. Comparisons of the original ends of the ladder rails to those obtained subsequently in the Laboratory also showed that some suspected fiber breakage was an artifact due principally to roughened surfaces produced by a coarse and probably somewhat dull cut-off saw.

The samples were classified with respect to the presence or absence of fiber breakage after examination under uniform conditions (table 1). This classification, in general, conformed to the previous observation in which fiber breakage had been suspected on one or both ends of the ladder rails originally examined. Samples from other rails showed no indications of fiber breakage either in the original examination at the manufacturing plant or in that at the Laboratory under more favorable conditions (fig. 4).

Examinations at low magnification (20X) of end-grain surfaces with fiber breakage showed that cells of the wood had been broken off cleanly rather than having been cut and pushed to one side by the saw teeth (fig. 5). This breakage occurred in radially oriented areas that frequently extended across both springwood and summerwood of two or more annual rings. The saw cut obviously must be made close to compression failures to cause such fiber breakage. The occurrence of fiber breakage at both ends of the ladder rails and at frequent distances along their lengths indicated that compression failures were closely spaced and uniformly distributed throughout some of the ladder rails being studied (fig. 6).

The fiber breakage showed considerable variation with respect to the size of the areas in which the cells had been broken rather than having been normally cut by the saw teeth, and also to the frequency of occurrence of broken-fiber areas on the end-grain surface (fig. 7). The occurrence of any fiber breakage is considered evidence of the presence of compression failures. Examinations of broken ladder rails under a high-power microscope and polarized light, both in this study and in previous ones, showed that numerous compression failures of microscopic size were present in the vicinity of fiber breakage on end-grain surfaces of the wood.

The surfaces and edges of the ladder-rail samples also were examined for compression failures large enough to be detected visually by only very low magnification. Previous studies had shown that some compression failures could be seen when incident light struck the surface of the piece from one side at an angle of about 20° and when the point of view was between 45° and vertical to the surface[2] (fig. 8). A 3-inch reading glass with about 2X magnification was also used.

Of the 34 samples of ladder rails showing fiber breakage, small, but nevertheless visible, compression failures were observed in 13 samples. These visible failures were distributed so as to include all but one of the seven rails in which fiber breakage was found on the end-grain surfaces (table 1). Most of these compression failures, however, were so small that they were detected only by means of careful visual examination under optimum lighting conditions and low-power magnification after their presence was indicated by fiber breakage on end-grain surfaces. Thus it appears that, for purposes of practical methods for detecting compression failures in ladder rails, careful examinations of the ends for fiber breakage affords the greatest possibility of identifying pieces in which this defect is present. Certainly, any rails with visible compression failures on either edges or surfaces also should be excluded from the finished ladders, since it is possible that they are so localized that they did not cause fiber breakage on end-grain surfaces of the rails. Excessive endwise compression due to rough handling, such as by dropping lumber across other material or otherwise bending it, sometimes causes such localized compression failures. These frequently are so large, however, that they are readily detected by ordinary visual examination of smoothly planed and finished surfaces when suitable lighting is used.

Results of Determinations

Specific gravity.--The average specific-gravity value of the specimens from each of the samples having fiber breakage on end-grain surfaces was only very slightly lower than that of specimens from the samples without this characteristic, namely, 0.422 and 0.431, respectively (table 1). Thus, exceptionally low specific-gravity values for the species were not found to be a cause of brashness in either of these groups of specimens.

Toughness.--Toughness-test values were determined for three specimens from each of the samples obtained from the ladder rails available for this study. The average value for all of the specimens from samples having fiber breakage was less than one-half of that of specimens from the samples without this characteristic, namely, 53.7 and 117.4 inch-pounds per specimen, respectively (table 1). The ranges of these values overlapped slightly; but, nevertheless, they differed significantly (fig. 9). This overlapping of the ranges resulted because the low specific gravity of three specimens from one sample without fiber breakage caused moderately low toughness values and several specimens with relatively high specific gravity caused about the same toughness values, even though fiber breakage and compression failures were present in the samples. The average toughness value of three specimens from each sample having fiber breakage was considerably lower in relation to average specific gravity of the specimens than that of the other specimens from samples without fiber breakage (fig. 10). Thus, for wood of the same density, fiber breakage on end-grain surfaces is identified with seriously lower toughness-test values than is wood without this characteristic, which is caused by the presence of compression failures.

Types of failure.--Toughness specimens of this study, and also of previous studies of causes of brashness,[2] have shown that abrupt or brittle breaks across the grain are very frequently caused by compression failures present before the ultimate fractures occurred. Examination of such brittle fractures by high-power magnification has shown that many occurred at compression failures (fig. 11). The specimens from samples having fiber breakage on end-grain surfaces had characteristically brittle failures in contrast to the splintering failures of specimens from samples without fiber breakage (figs. 12, 13, and table 1).

Abrupt breaks due to compression failures in the specimens occurred almost directly across many fibers and sometimes across parts of several annual rings. Examinations by low magnification of specimens with brittle fractures due to compression failures showed that they had characteristically steplike contours (fig. 14). This type of failure in wood bent as a beam results when the ultimate fracture occurs along several closely adjacent compression failures. Such steplike breaks serve as a means of identification of ultimate failures through previously existing compression failures. They were found to be present, wholly or in part, in all of the specimens from samples showing fiber breakage on the end grain, but not in those from samples that did not show this characteristic (table 1).

Thus these data, in combination, showed that brittle failures and low toughness values were caused by compression failures and were related to the occurrence of fiber breakage on end-grain and, occasionally, to visible compression failures on side surfaces. Specimens with splintering failures and relatively higher toughness values were obtained only from samples of ladder rails on which no evidence of compression failures was observed by visual examinations of ends and sides of the samples.

Distribution of Compression Failures

This study showed that compression failures were abundantly distributed along the length of the 2-foot samples having fiber breakage on their end-grain surfaces. The fiber breakage was at least 6 inches and was sometimes more than 1 foot from the brittle failures of specimens also having low toughness values caused by compression failures. Thus the several samples that were obtained from a single ladder rail had fiber breakage, brittle fractures, and low toughness values that demonstrated an abundant occurrence of compression failures distributed at very short intervals along the length of the rail. Many of these were of microscopic size, since the only visible compression failures that were found in these rails were widely scattered and relatively few in number. In fact, they were detected only after careful examination under highly favorable conditions.

Occasional pieces of lumber have been found to have visible compression failures that were restricted to a narrow zone across the piece. Such pieces did not show fiber breakage except close to the obviously damaged zone. It is believed that such compression failures are due to rough handling of the lumber, such as by dropping it across obstacles, that causes buckling of the wood in localized areas. Many compression failures, however, are believed to result from more widely distributed and possibly less severe stress, so that microscopic buckling of the fibers occurs abundantly along the length of a piece of lumber. Stresses in standing trees resulting from violent winds are believed to contribute to wide distributions of compression failures such as were observed in this study.

Recommendations for Inspection Practices

The study of ladder rails and previous ones on causes of brashness of wood have shown that compression failures are a serious hazard to strength properties of materials on which safety of life and property depends. These studies also have shown that the presence of compression failures can be detected by practical inspection methods by which unsuitable pieces can be excluded from critical equipment. Observations made under manufacturing conditions and on samples submitted to the Forest Products Laboratory have demonstrated that compression failures of microscopic size are exceedingly numerous in some pieces of material, while those large enough to be visible without high-power magnification are rare. It has usually been the effects of compression failures on strength properties and on types of failures that have been observed.

Inspection of End-grain

Observations at plants manufacturing ladder rails showed that careful inspection of end-grain surfaces for fiber breakage is a practical means of detecting compression failures. Such inspections can be made on sawed lumber in large sizes intended for resawing to ladder-rail dimensions, provided that the ends are sawed with reasonable smoothness. Exclusion of pieces showing fiber breakage in rough-lumber sizes will result in some saving in manufacturing costs (fig. 15, A). Lumber having that characteristic confined to only part of the cross section sometimes can be resawed so as to salvage the remainder that is suitable for ladder-rail material (fig. 15, B).

Ends of ladder rails, when trimmed to final length, should be cut with a saw that will produce a surface having smoothness suitable for detecting fiber breakage due to compression failures. A coarse, dull saw has been found to obscure fiber breakage, while a very fine, sharp saw is inclined to produce somewhat glossy surfaces having a similar effect on identifying fiber breakage. Inspection of ladder-rail ends should be made directly after the ends are trimmed, or when they are piled in storage if ladder assembly is not to be completed immediately. Ladder rails piled on a push truck with the ends exposed to moderately bright light coming from one side is a condition recommended for a rigid inspection by which to identify fiber breakage caused by the presence of compression failures. Diffused light, regardless of its brightness, and coming from all sides so as to dissipate shadows, is not satisfactory.

The inspection for fiber breakage should be rigid, and both ends of each rail piled on a truck or in a storage pile should be inspected. Any rail having fiber breakage on both ends should be excluded from assembly into a ladder. Rails showing fiber breakage on only one end can be shortened at about 2-foot intervals. If the fiber breakage on one end of such a rail completely disappears within a relatively short length, for example, 2 to 6 feet, then it is believed that the remaining length can be used with reasonable safety, provided there are no other visible compression failures on the sides or edges.

The known information on occurrence and effects of compression failures demonstrates that a ladder rail having fiber breakage on one or both ends is likely to be hazardous to safety of life and property. Therefore, ladder rails having fiber breakage at either end, such as is shown in figures 3, 6, and 7, are not considered safe.

Inspection of Sides

Sides and edges of all ladder rails should also be inspected for identification of any visible compression failures that may be present. These may be obscured by unevenness of sawed or even of planed surfaces. Compression failures are made more readily visible, however, after clear lacquer, shellac, or varnish has been added to the surfaces. Application of a nonswelling liquid, such as carbon tetrachloride, also makes small, but not microscopic, compression failures more readily visible.

Careful inspection of sides and edges of ladder rails after they have been lacquered or varnished, is considered a practical means of detecting visible compression failures that may have resulted from localized endwise compression stresses that resulted in forming compression failures only in narrow zones across the width of the rails. Incident light from a reflector spot bulb, for example, focused at an angle of about 20° to the surface being examined, has been found to facilitate identification of visible compression failures. These are most readily seen when viewed from a position between 45° and 90° with respect to the surface and from the same side from the vertical as the source of light (fig. 8).

Arrangement of Lights

Figure 16 shows a convenient arrangement of lighting from a reflector spotlight for identifying visible compression failures on the side grain and from a conventional incandescent 60-watt bulb in a desk lamp for examining end-grain surfaces for fiber breakage. The latter bulb should be shielded so that the light does not shine directly in the inspector's eyes. Studies of these methods to identify visible compression failures and fiber breakage have shown that inspections can be carefully and rapidly made on ladder rails on a table of convenient height for the work. A cleat about 3/4 inch thick and 1-1/2 inches wide nailed to the table top was found to facilitate turning the pieces during examination of all four sides.

In general, it is recommended that the actual inspections of end-grain and side surfaces be made by inspectors who are qualified by understanding and practical knowledge of the appearance, characteristics, and effects of compression failures on the strength properties of wood. Thus responsibility for inspection can be assigned to qualified supervisory or experienced personnel having other duties, and thereby interference with production can be minimized. Workers making the final assembly of the ladders, however, always should be alert to detect any visible compression failures that may appear as lines of buckled fibers across the grain of ladder rails. Compression failures have been observed in ladders being assembled, although it was not known whether they might have been detected earlier by adequate inspection or were only made visible by the stresses applied during assembly.

Table 1.--Occurrence of fiber breakage on end-grain and readily visible compression failures on side surfaces of ladder rail samples, average specific gravity and toughness test values, and descriptions of the types of test failures of three specimens from each sample.

Designation: Rail-end No.	Designation: Sample No.	Occurrence of: Fiber breakage	Occurrence of: Visible compression failures	Average specific gravity	Toughness value: Average	Toughness value: Minimum	Toughness value: Maximum	Types of failure of test specimens: Splinting	Types of failure of test specimens: Brittle	Types of failure of test specimens: Intermediate	Types of failure of test specimens: Step-like
					In. lb./spec.	In. lb./spec.	In. lb./spec.	No.	No.	No.	No.
1	0	0	0	0.418	110.1	100.0	117.5	3	0	0	0
6	0	0	0	.362	80.2	74.5	87.3	0	0	3	0
12	0	0	0	.444	110.0	99.0	128.8	3	0	0	0
19	0	0	0	.428	128.6	121.2	134.5	3	0	0	0
20	0	0	0	.416	144.5	97.0	200.8	3	0	0	0
21	0	0	0	.517	130.8	115.7	141.6	3	0	0	0
Average				.431	117.4						
2	0	+	+	.460	60.0	46.2	77.4	0	3	0	3
2	1	+	0	.469	78.8	77.4	81.6	0	3	0	3
2	2	+	0	.510	81.0	68.5	91.5	0	3	0	3
3	0	+	0	.531	69.0	64.0	75.2	0	3	0	3
4	0	+	+	.412	42.5	36.5	48.6	0	3	0	3
	1	+	0	.415	38.4	30.8	44.6	0	3	0	3
	2	+	0	.406	45.6	41.4	51.7	0	3	0	3
5	0	+	+	.399	55.6	51.7	59.5	0	3	0	3
7	0	+	0	.382	58.6	50.1	66.3	0	0	3	3
	1	+	0	.383	55.5	53.3	58.7	0	3	0	3
	2	+	0	.386	63.7	56.4	72.3	0	3	0	3
8	0	+	0	.376	57.2	54.1	61.0	0	3	0	3
9	0	+	+	.501	69.3	64.8	73.0	0	3	0	3
10	0	+	+	.549	74.6	66.3	83.1	0	3	0	3
13	0	+	+	.406	38.7	36.5	42.2	0	3	0	3
	1	+	0	.407	55.4	53.3	58.7	0	3	0	3
	2	+	0	.396	45.4	39.0	55.7	0	3	0	3
	3	+	0	.391	37.8	29.2	53.3	0	3	0	3
14	0	+	0	.435	61.7	57.2	67.0	0	3	0	3
15	0	+	0	.417	54.5	47.0	63.3	0	3	0	3
	1	+	0	.423	63.5	61.0	67.0	0	3	0	3
16	0	+	0	.424	51.4	43.8	62.5	0	3	0	3
	1	+	0	.416	44.0	36.5	47.8	0	3	0	3
	2	+	+	.407	34.0	22.5	45.4	0	3	0	3
	3	+	0	.382	45.7	43.0	47.0	0	3	0	3
	4	+	+	.383	47.8	34.1	67.0	0	3	0	3
17	0	+	+	.415	51.4	44.6	63.3	0	3	0	3
18	0	+	+	.415	39.6	26.6	54.1	0	3	0	3
	1	+	+	.405	55.5	49.3	64.0	0	3	0	3
	2	+	+	.403	53.5	47.8	62.5	0	3	0	3
	3	+	0	.403	48.5	43.8	56.4	0	3	0	3
	4	+	0	.413	43.5	33.3	56.4	0	3	0	3
	5	+	+	.419	50.6	43.8	59.5	0	3	0	3
	6	+	0	.407	52.2	43.8	56.4	0	3	0	3
Average				.422	53.7						

Z M 78974 F

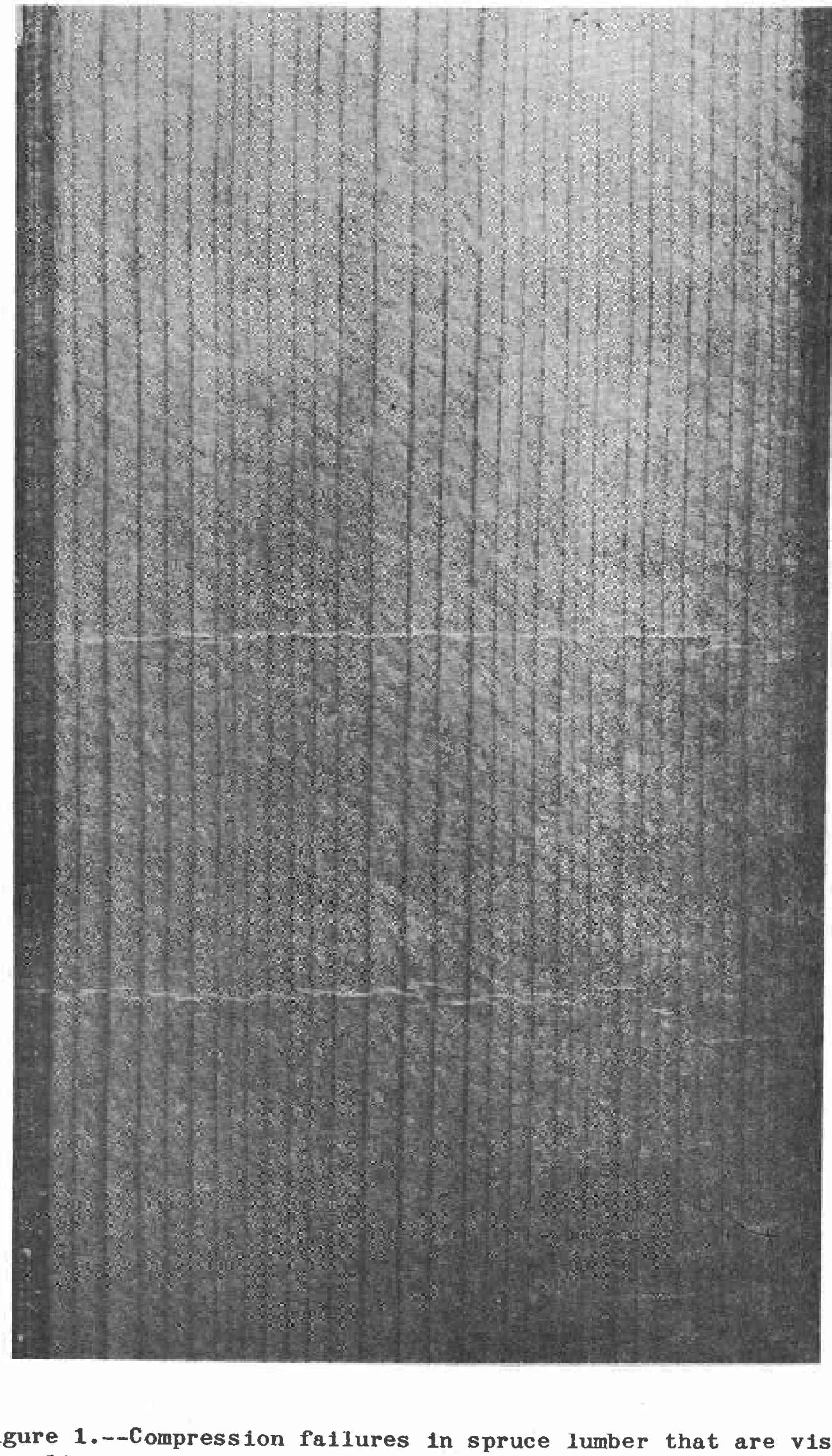

Figure 1.--Compression failures in spruce lumber that are visible as lines across the grain. Slightly magnified.

Z M 80312 F

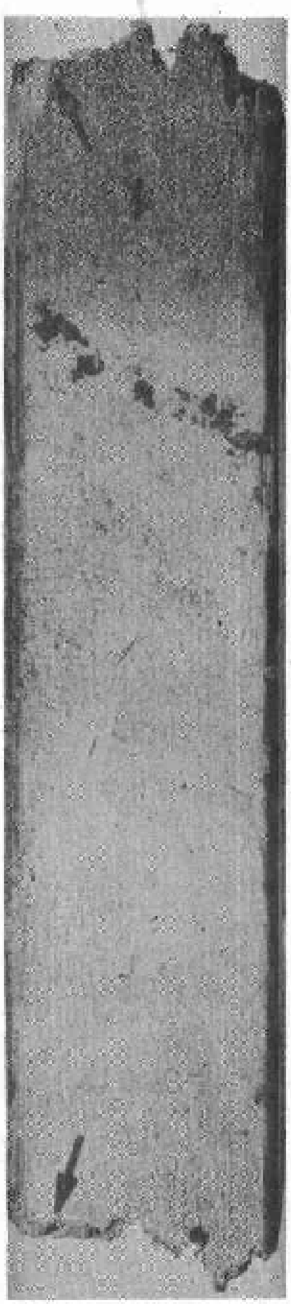

Figure 2.--Side view of a ladder rail that failed in two places at approximately the same time because compression failures were present prior to the ultimate breaks in tension, which are indicated by arrows.

Z M 80313 F

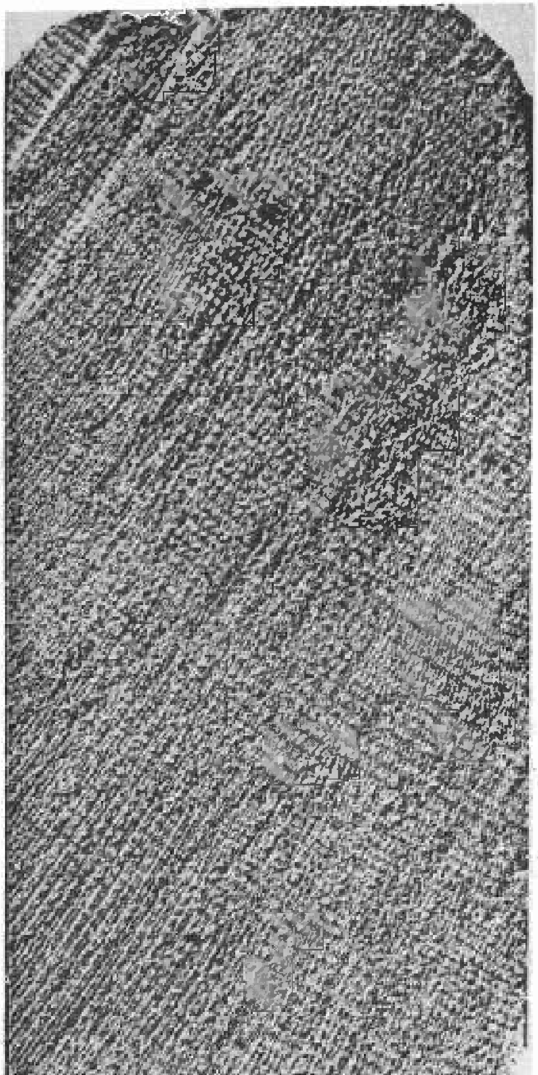

Figure 3.--Cross section of a ladder rail showing fiber breakage that indicates the presence of compression failures.
Z M 80314 F

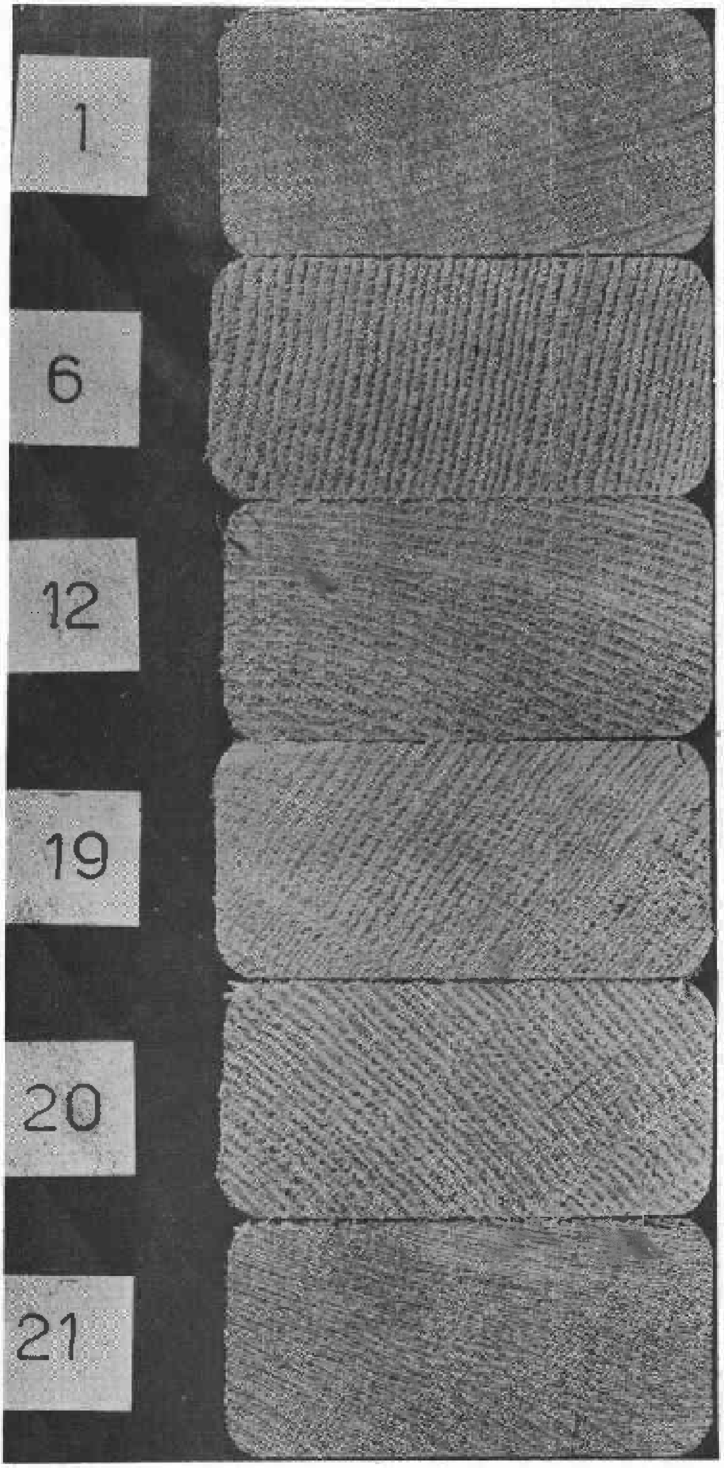

Figure 4.--Cross sections of ladder-rail samples that showed no fiber breakage.
Z M 80315 F

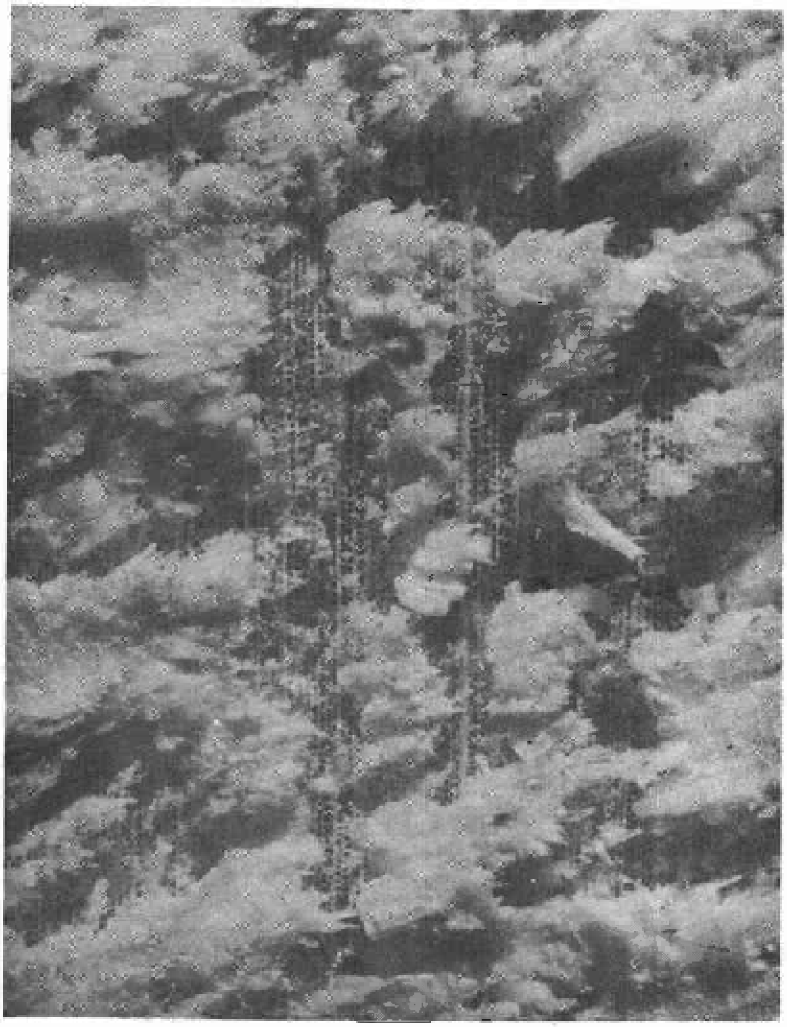

Figure 5.--Photomicrograph of fiber breakage due to compression failures, showing areas of cleanly broken fibers interspersed by groups of other fibers cut by the saw teeth and pulled to one side. X20.

Z M 80316 F

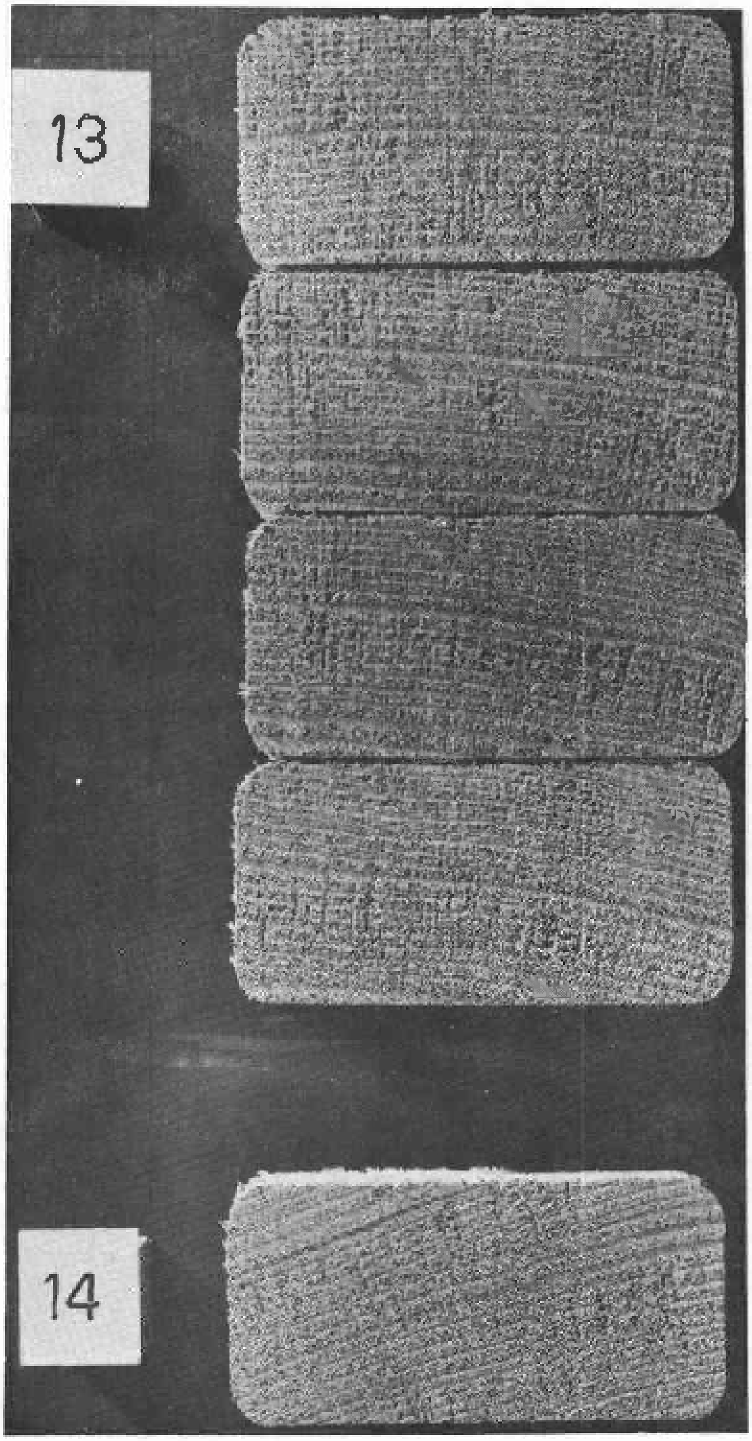

Figure 6.--Four cross sections cut at about 2-foot intervals from one end (13) and one from the opposite end (14) of a 16-foot ladder rail, all showing fiber breakage caused by the presence of compression failures.

Z M 80317 F

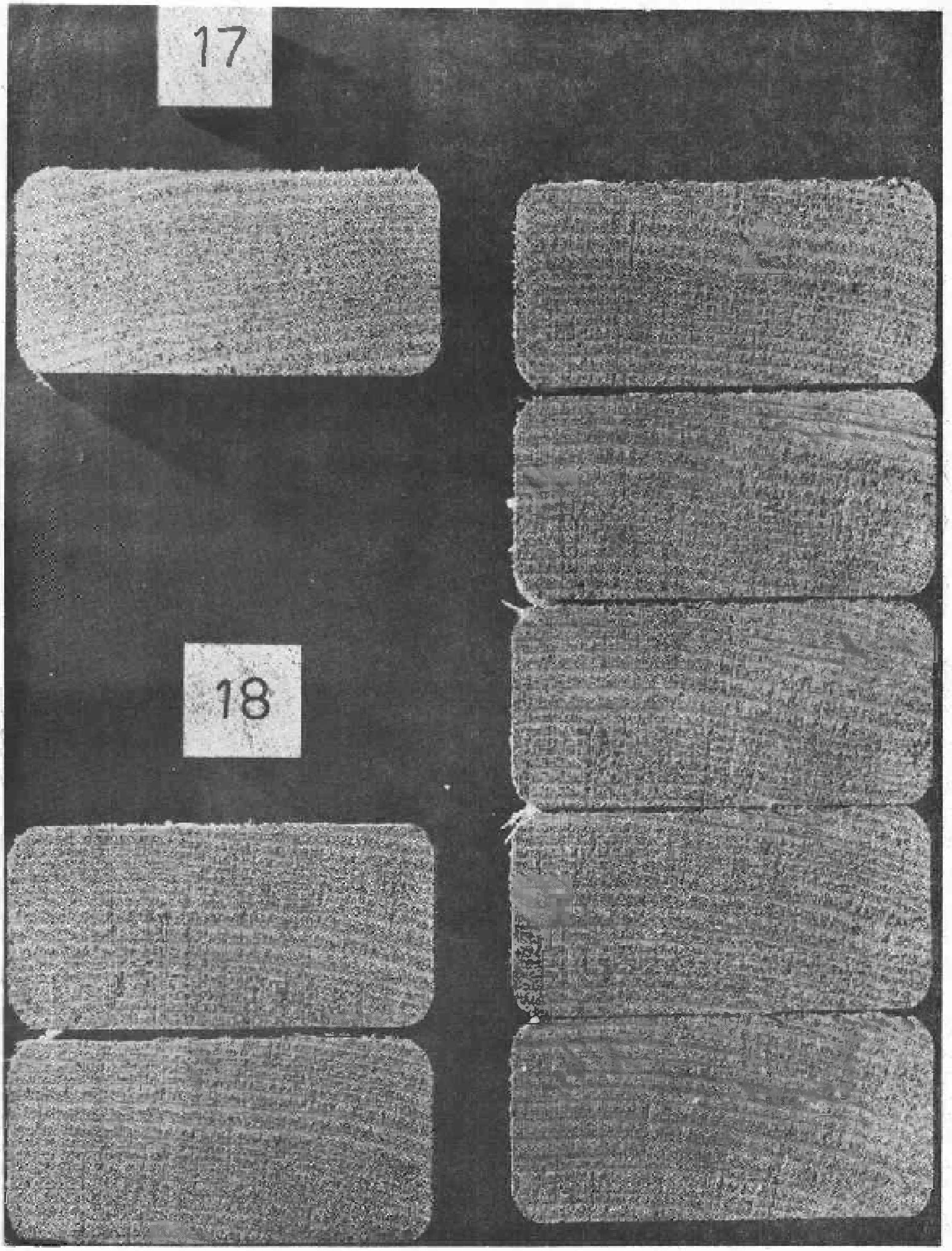

Figure 7.--Cross sections from a ladder rail cut at about 2-foot intervals, all of which show fiber breakage to lesser or greater extents, indicating the presence of uniformly distributed compression failures along the length.

Z M 80318 F

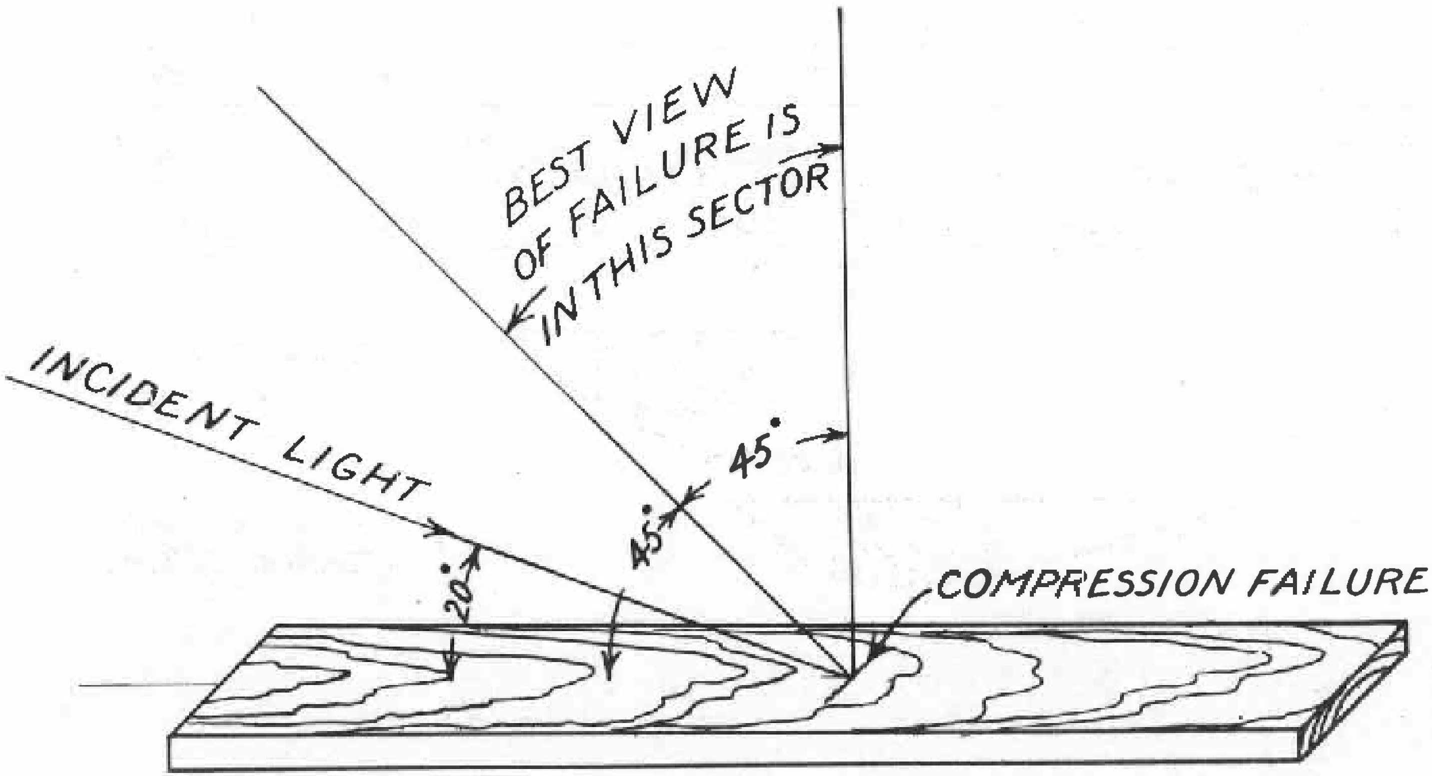

Figure 8.--Most effective angle of view and angle between wood surface and incident light when searching for compression failures.

Z M 54161 F

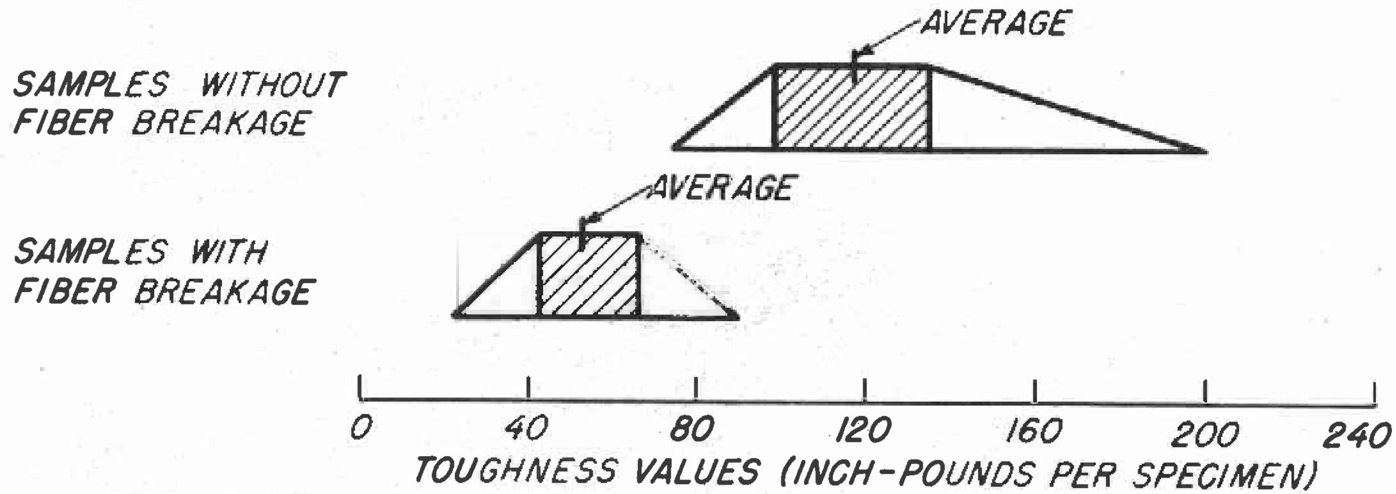

Figure 9.--Total range, range of the middle two-thirds of the specimens (cross-hatched), and average of toughness-test values of specimens obtained from samples of ladder rails, some that showed fiber breakage on end-grain surfaces and, also, other samples without this characteristic.

Z M 80319 F

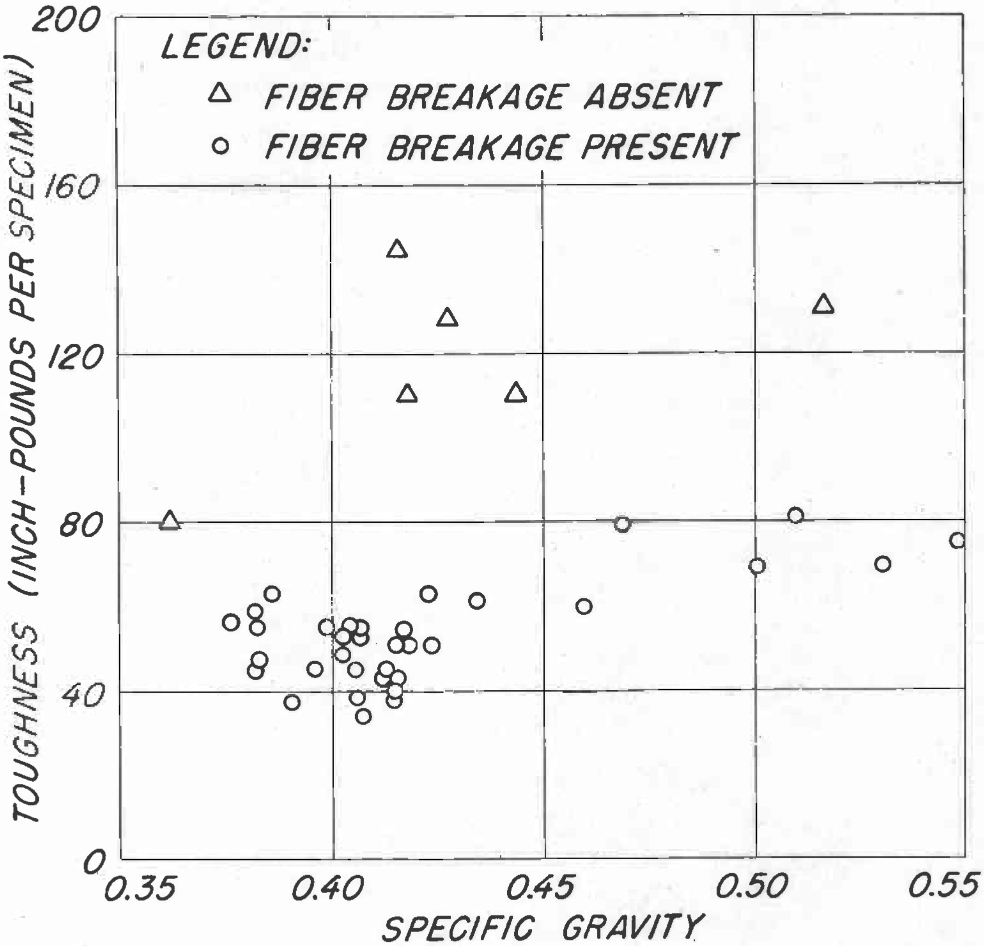

Figure 10.--Relation of average toughness-test values to specific gravity of three specimens from each sample with fiber breakage in comparison to similar values of specimens from samples without fiber breakage.

Z M 80320 F

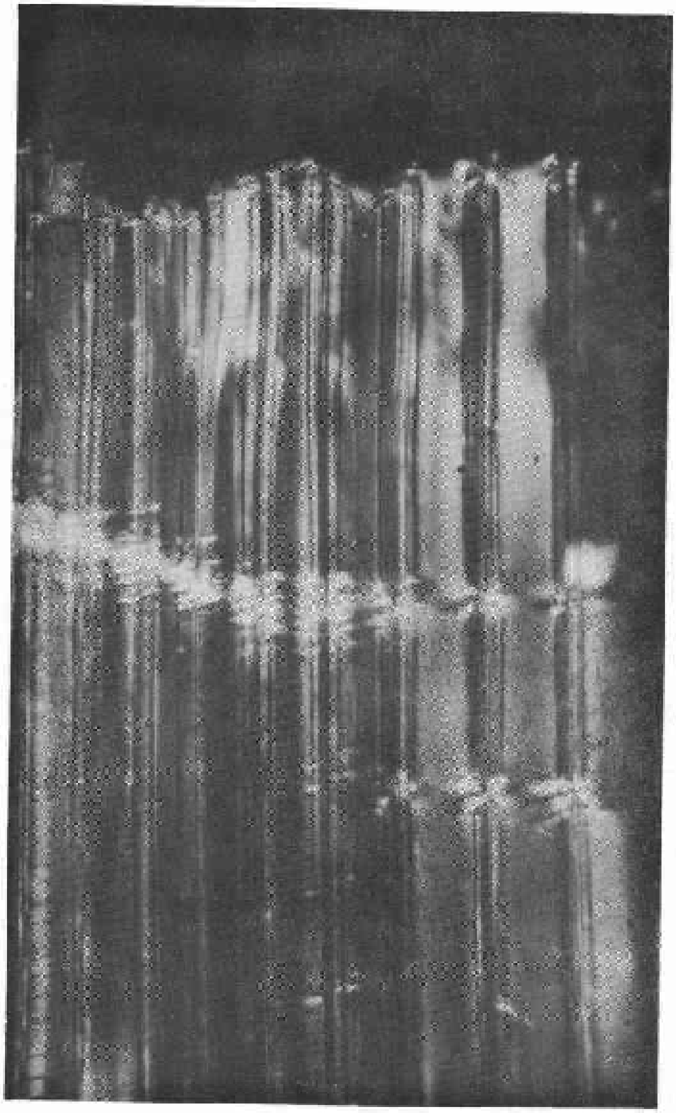

Figure 11.--Photomicrograph of a brittle break in tension that occurred at a compression failure already present before the piece ultimately broke. X450 by polarized light.

Z M 80321 F

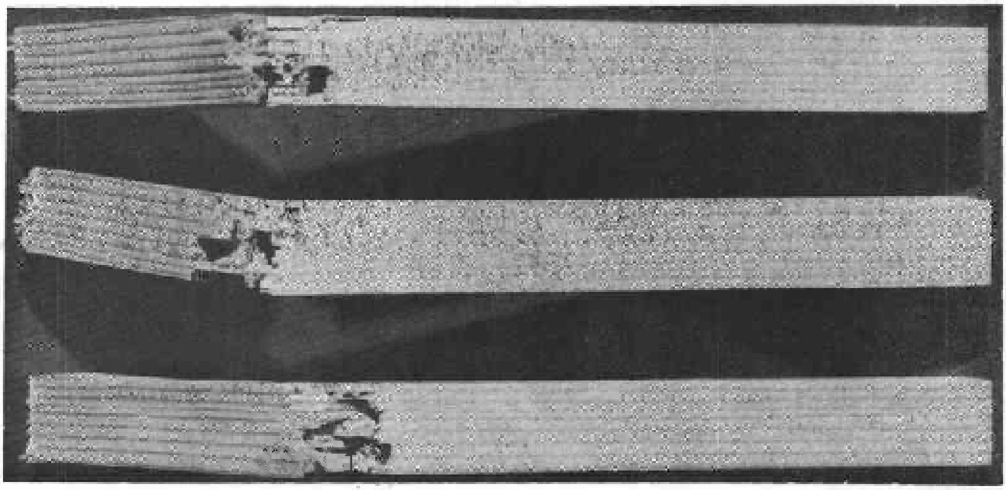

Figure 12.--Brittle breaks across the grain of toughness-test specimens from a ladder-rail sample that showed fiber breakage on end-grain surfaces.

Z M 80322 F

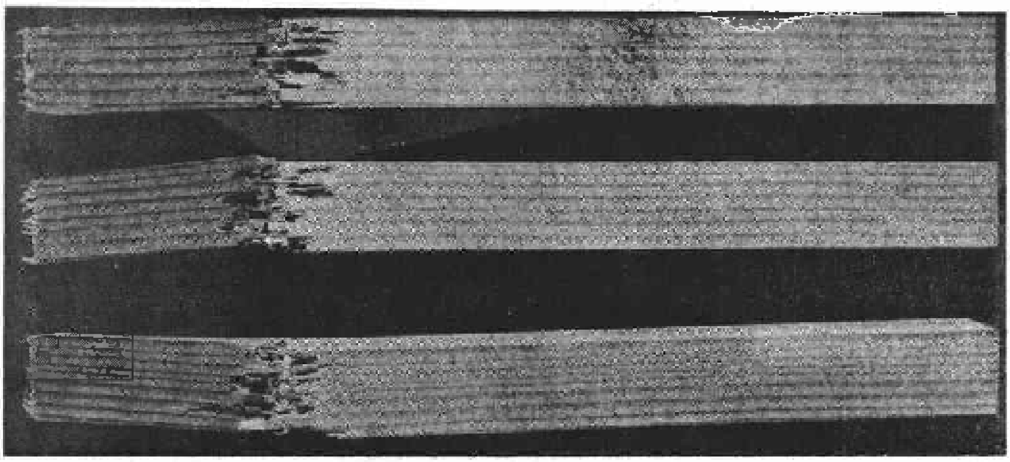

Figure 13.--Splintering toughness-test failures of specimens from sample without fiber breakage on end-grain surface.

Z M 80323 F

Figure 14.--Steplike break in a toughness-test specimen that is characteristic of a fracture through several compression failures already present before the ultimate break occurred. X5 photographed by reflected light.

Z M 80324 F

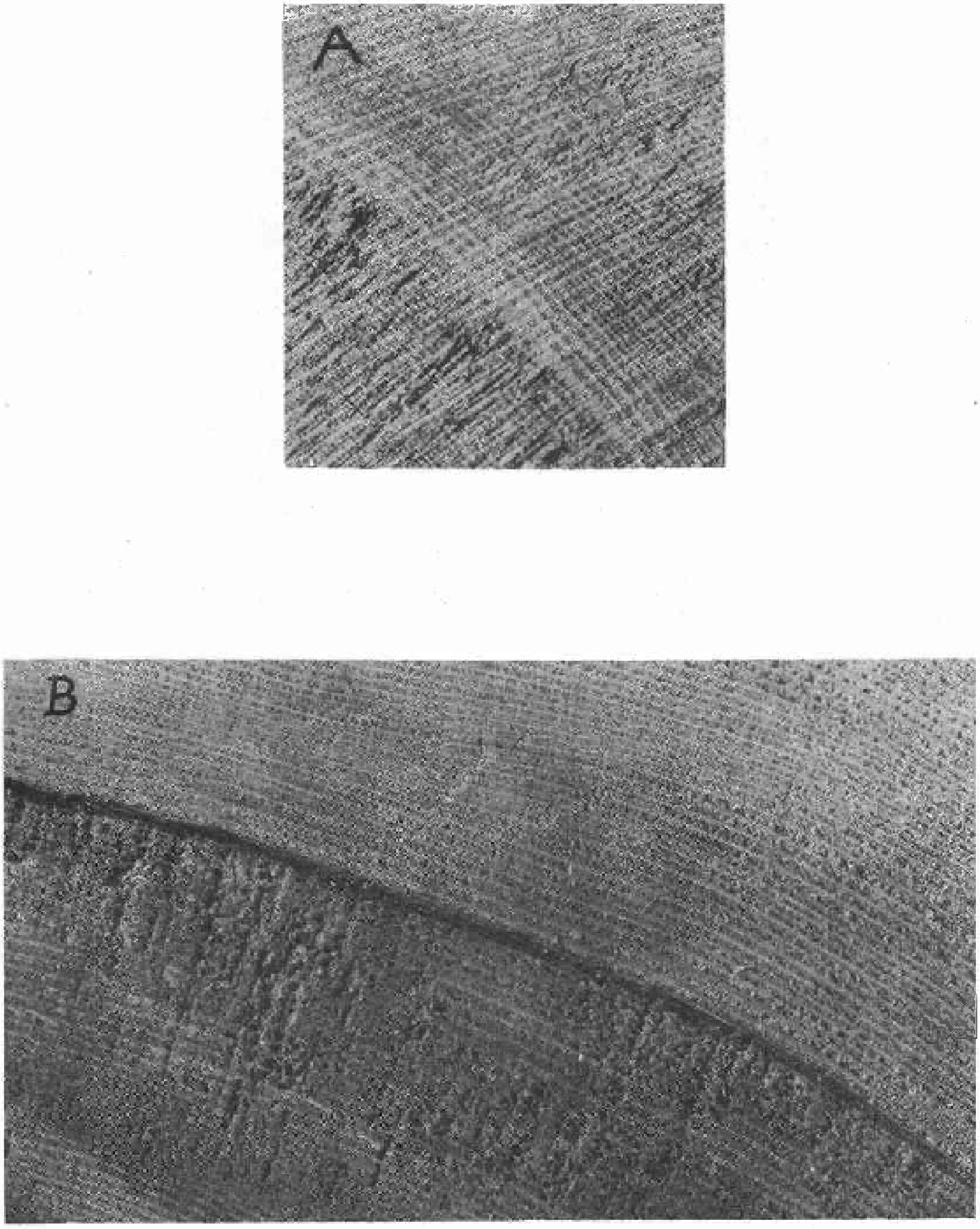

Figure 15.--End-grain surfaces of Sitka spruce lumber showing fiber breakage: A, distributed across most of the surface; and B, in the part below the black line in comparison to wood free from this characteristic above the line.

Z M 54160 F

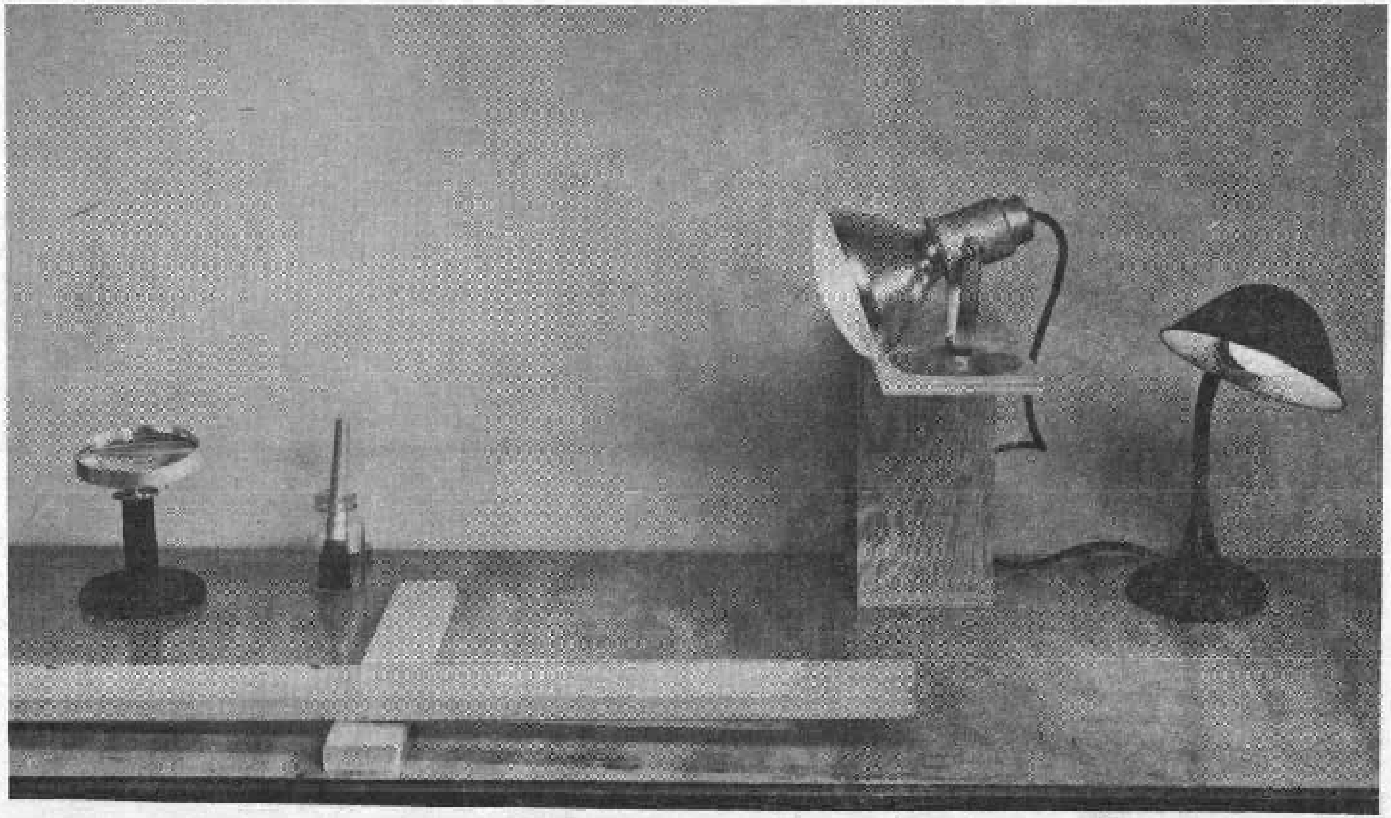

Figure 16.--A convenient arrangement of a reflector spotlight and an ordinary incandescent-bulb desk lamp placed on a work table for examination of ladder rails to detect visible compression failures and fiber breakage on the side- and end-grain surfaces.

Z M 80325 F