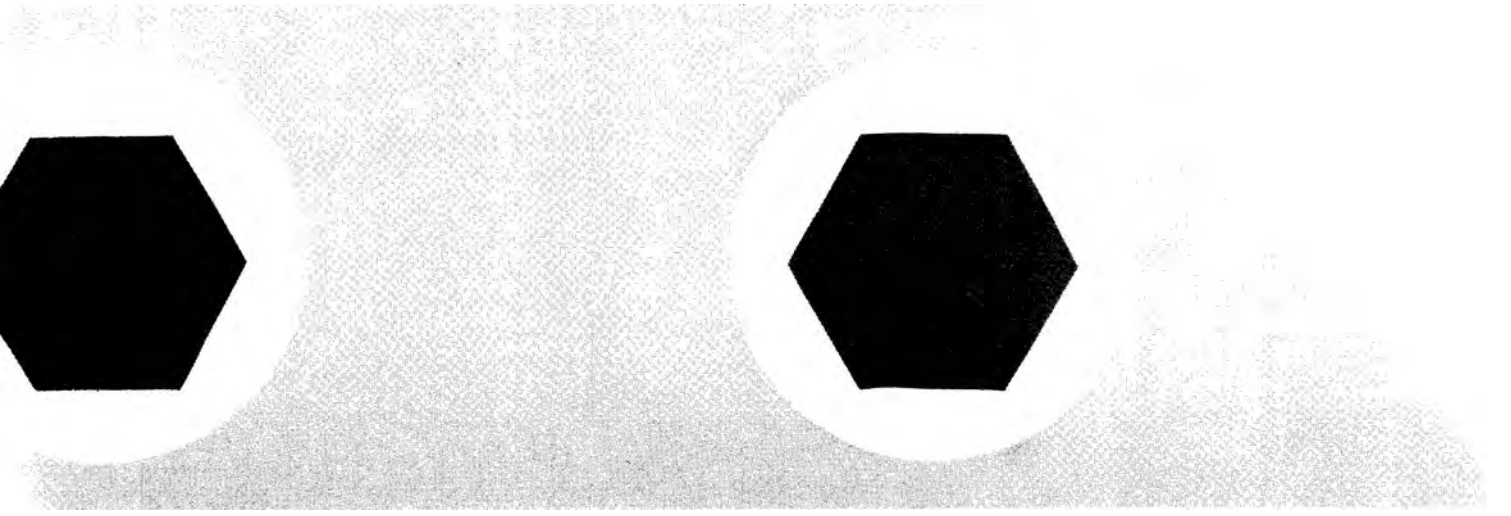
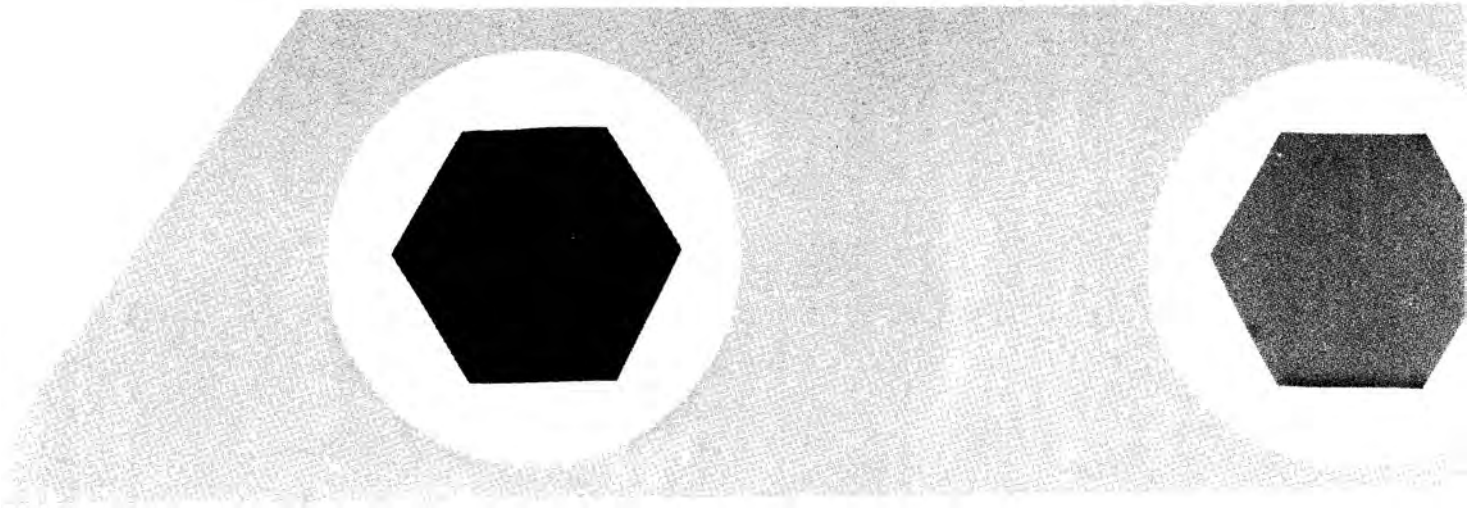
U.S.D.A. FOREST SERVICE RESEARCH PAPER FPL 117 OCTOBER 1969
U.S. Department of Agriculture Forest Service Forest Products Laboratory Madison, Wis.

RAIL SHEAR TEST FOR EVALUATING EDGEWISE SHEAR PROPERTIES OF WOOD-BASE PANEL PRODUCTS





ABSTRACT

The rail shear test used extensively at the Forest Products Laboratory to determine the edgewise shear strength of wood-base panel products is described and evaluated.

Specimens are bolted between two pairs of loading rails, providing a 1- by 10-inch stress area, and the load is applied at a uniform rate.

Failures in several types and thicknesses of specimens indicated reasonably uniform shear distribution. No significant differences were found in the shear strength of specimens 6, 10, and 12 inches long loaded at 0.01 and 0.02 inch per minute. Stress at failure increased as the stress area was narrowed to widths progressively smaller than 1 inch.

Strain distribution data from the rail shear test agreed with measured and theoretically determined distributions in other shear specimens. Good correlation was found between strength values obtained by the rail shear method and values obtained from 16- by 38-1/2-inch panels cut from hardboard webs of full-size I-beams. This correlation indicates that the rail shear test procedure can accurately predict the performance of hardboardused in full-size structural components.

Rail shear test for evaluating edgewise shear properties of wood-base panel products

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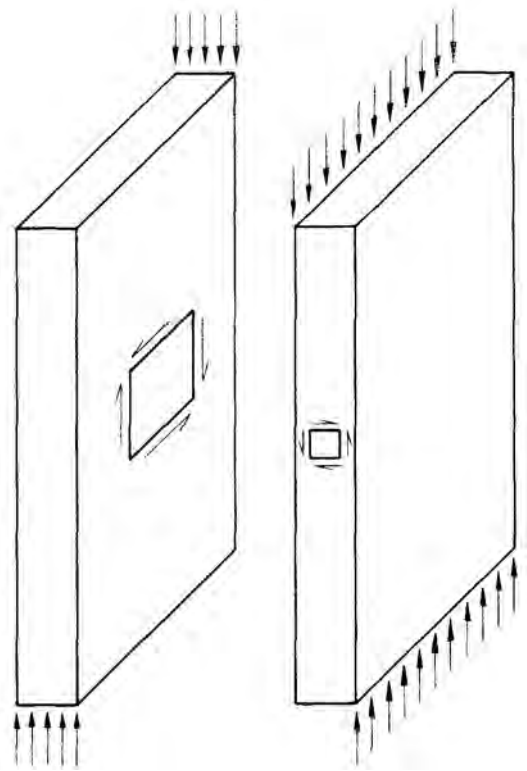
INTRODUCTION

The rail shear test described in this report was developed at the Forest Products Laboratory as a method of evaluating edgewise shear properties of wood-base panel materials. Other available panel shear tests were either too complicated for practical use or gave results which were obviously incorrect because of the nature of the failures.

Edgewise shear properties are those associated with shear deformations occurring in the plane of the panel as a result of shear forces applied to the panel edges.

Interlaminar shear properties, on the other hand, are associated with shear deformations in a plane perpendicular to the panel surface as a result of shear forces applied along the surface. The principles of edgewise and interlaminar shear are illustrated in figure 1.

In a preliminary study, the ASTM panel shear method for plywood (1)[2] was investigated as a possible procedure for evaluating the edgewise shear properties of wood-base materials. It was rejected because of the character of the failures obtained and the difficulty involved in preparing the specimens. The failures in all fiberboard panel specimens were in diagonal tension, originating at one of the four pinholes and usually accompanied by interlaminar shear and glueline



(A) EDGEWISE SHEAR (B) INTERLAMINAR SHEAR

Figure I.--Principles of edgewise and interlaminar shear. (M 124 728)

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

[2] Underlined numbers in parentheses refer to Literature Cited at the end of this report.

shear failures in the area covered by the reinforcing blocks. Figure 2 shows a specimen mounted in the ASTM panel shear test apparatus.

Both elastic and ultimate shear values are needed to permit the engineering use of wood-base panel materials. Typical of the applications for which edgewise shear knowledge is needed are:

1. Wood-base materials used as diaphragms with framing in walls and roofs to resist wind and seismic forces.
2. Hardboard used as shear webs in box or I-beams.
3. Hardboard used as gusset plates for trusses and similar glued units.

To establish the validity of rail shear test results. values obtained by this method and values obtained from 16- by 38-1/2-inch panels of hardboard shear web cut from full-size I-beams were correlated.

LITERATURE REVIEW

Investigations at the University of Tokyo showed that the shear moduli of hardboard obtained by the ASTM panel shear method for plywood were unusually high, although the ultimate strength values obtained were reasonable (5, 6). The shear moduli of hardboard obtained by the Swedish Larson-Wästlund method were much lower than those obtained by the panel shear method (7);

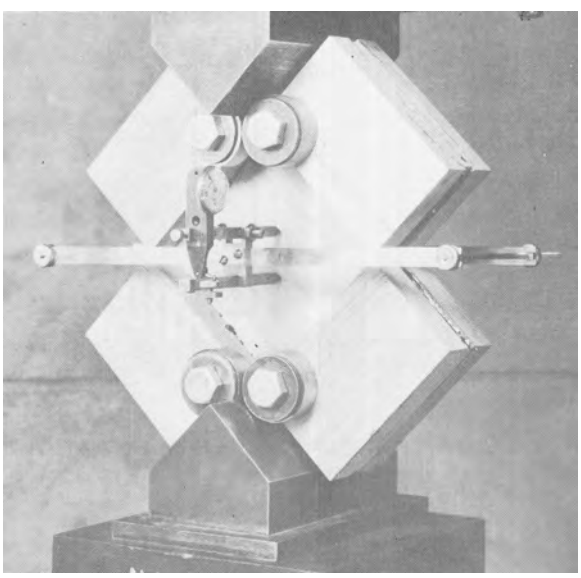


Figure 2.--Plywood specimen mounted in the ASTM panel shear test apparatus. (ZM 78386 F)

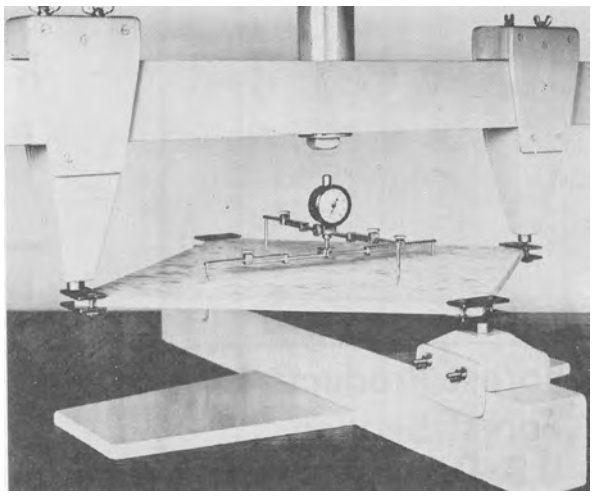


Figure 3.--Specimen ready for test by the ASTM plate shear method for plywood. (ZM 116917)

however, the Larson-Wästlund method is too complicated for practical use. Also, due to stress concentrations, the ultimate strength values obtained by the Larson-Wästlund method were less than 20 percent of expected values. Investigations at the University of Tokyo also showed that the ASTM plate shear method for plywood, which is the most accurate practical method of measuring the shear modulus of panel materials, gave satisfactory results for hardboard and particleboard (4). A specimen ready for test by this method is shown in figure 3.

Ylinen (9) reported the theoretical investigations made by Niskanen on the distribution of shear stress in a solid wood block specimen. Niskanen's study showed that for specimens with high length-width ratios the shear stresses are a maximum near the top and bottom surfaces and a minimum at the center. Filon (3) earlier had shown the same type of distribution of shear stresses through the depth of a beam with a concentrated load acting on the upper surface at a given distance from the midspan and another concentrated load acting on the lower surface at the same distance from the midspan.

Coker (2) used polarized light on a thin rectangular glass plate loaded in double edgewise shear to study the stress distributions as the specimen length was changed. The distributions are essentially the same as those reported by Ylinen and Filon. Post (8) used electrical resistance strain rosettes to analyze the shear strain distribution in plywood panel specimens. The panels were all

24 inches long. The panel widths between the loading rails ranged from 3 to 24 inches. The strain distributions obtained agree with the results obtained by Coker.

THE RAIL SHEAR TEST

The rail shear test has been used extensively at the Forest Products Laboratory to determine the edgewise shear strength of both standard and tempered hardboard, 1/8, 1/4, and 3/8 inch thick. In addition, a limited number of specimens of insulation board, particleboard, plywood, solid wood, and glass-reinforced plastic laminates have been successfully tested.

Two pairs of steel loading rails 10-1/2 inches long, 1-1/4 inches wide, and 1/2 inch thick are bolted tightly to the long edges of the specimen. The inside surface of each rail is serrated to produce "rasp-like" teeth that improve gripping and prevent slipping of the specimen during loading. The ends of the rails are beveled to fit into the testing machine's bearing blocks.

The 3-1/2- by 10-inch specimen (fig. 4) is bolted within the rails, leaving a distance of 1 inch between the pairs of rails. This provides a 1- by 10-inch stress area. Figure 5 shows details of a specimen with loading rails attached.

The beveled ends of the rails fit into notches in the testing machine's bearing blocks, as shown in figure 6. The lower bearing block is placed on a spherically seated base plate so that the

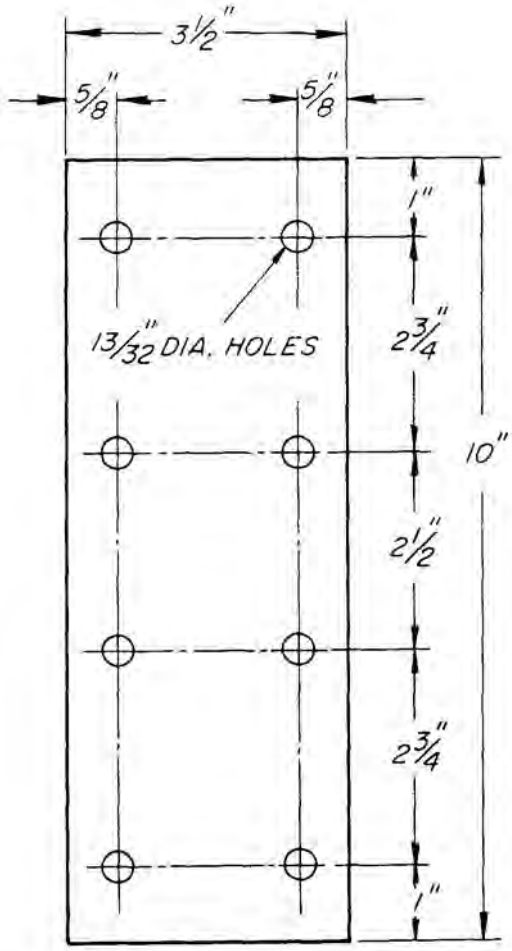


Figure 4.--Details of the 3-1/2- by 10-inch rail shear specimen. (M 124277)

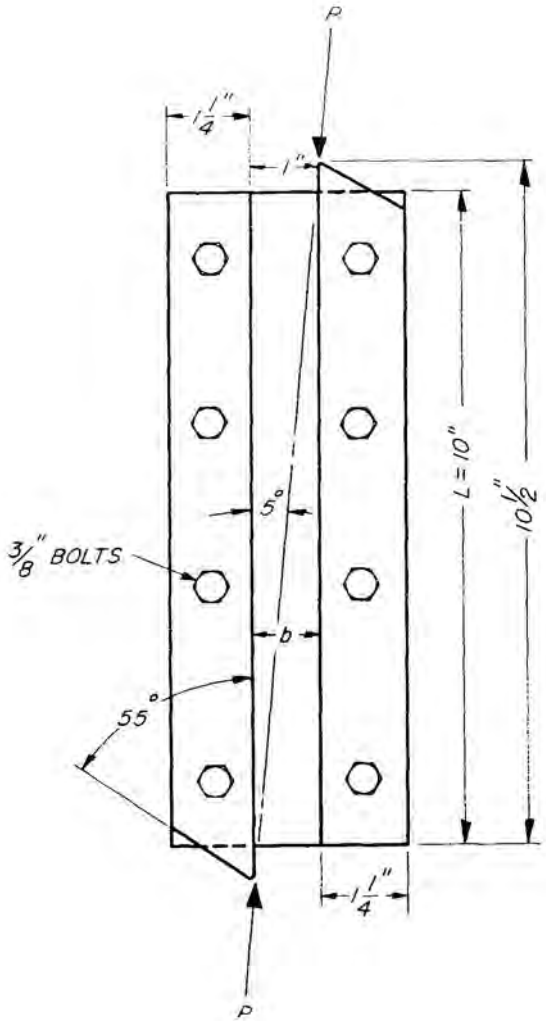


Figure 5.--Details of the rail shear specimen with the loading rails attached. (M 124 276)

load is applied along the diagonal of the shear area. To orient this diagonal plane vertically, the edges of the plates are tilted about 5° from vertical. Care must be taken to insure that the specimen is correctly oriented and that the load is uniformly applied across the width of the beveled plate edges. The specimen is loaded to failure at a uniform rate of 0.02 inch per minute. The maximuin edgewise shear stress is obtained from the formula:

$$\tau_E = \frac{P}{Lt} \qquad (1)$$

where: τ_E = maximum edgewise shear stress
P = maximum compressive load applied
L = specimen length
t = specimen thickness

EFFECT OF SPECIMEN LENGTH AND RATE OF LOADING ON ULTIMATE SHEAR STRESS

A series of 1/4-inch-thick standard hardboard specimens 6, 10, and 12 inches long were evaluated lo determine the effect of specimen length and rate of loading on the maximum loads obtained.

Twenty-four specimens, eight of each length, were cut from a 2- by 4-foot panel. All the specimens were 3-1/2 inches wide, so the stressed area was 1 inch wide.

The sets of loading rails were 6-1/2, 10-1/2, and 12-1/2 inches long; 1/2 inch longer than the corresponding specimens. The rails were tightly bolted to the specimens, which were tested as described previously. Four specimens of each length were loaded at a uniform rate of 0.01 inch per minute, and the remaining four specimens were loaded at 0.02 inch per minute.[3] The maximum loads only were recorded, from which the ultimate edgewise shearing strengths were calculated. The relationships between specimen length and edgewise shear strength for the two rates of loading are shown graphically in figure 7.

The maximum stresses at failure were not measurably affected by changing the specimen length (6, 10, or 12 inches) or by increasing the rate of loading from 0.01 to 0.02 inch per minute. The individual values for the longer specimens were less scattered than the same values for the 6-inch specimens. The coefficients of variation were 10.5 percent for the 6-inch specimens, 9.7 for the 10-inch, and 8.8 for the 12-inch.

EFFECT OF SPECIMEN WIDTH ON ULTIMATE SHEAR STRESS

Twenty 10-inch-long rail shear test specimens were prepared from 1/4-inch-thick tempered hardboard to determine the effect of specimen width on the ultimate edgewise shear stress. The widths of the area between the pairs of rails were 1/16,1/4,1/2,3/4, and 1 inch. Four specimens

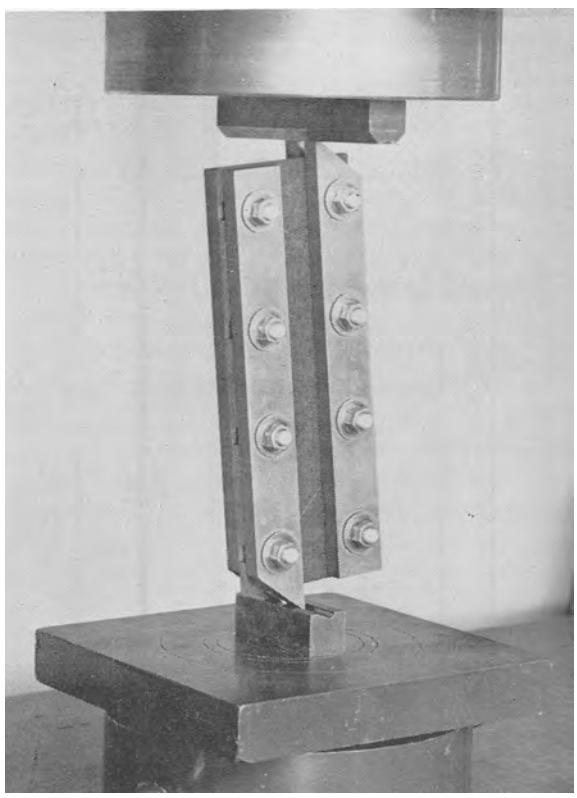


Figure 6.--Assembly for loading rail shear test specimen. (M 125 798)

[3]Five of the 12-inch-long specimens were loaded at 0.01 inch per minute, and three were loaded at 0.02 inch per minute.

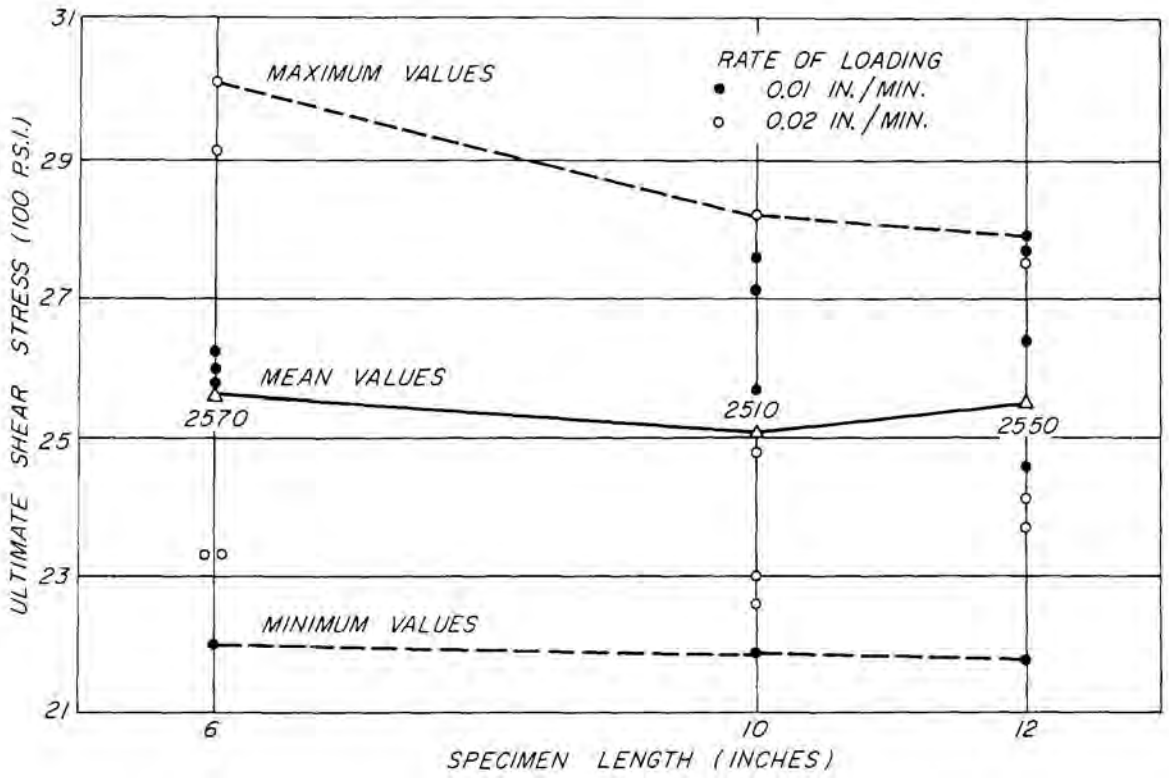


Figure 7.--Relationship between specimen length and ultimate shear stress obtained from rail shear test specimens for two rates of loading considered collectively. (M 124 275)

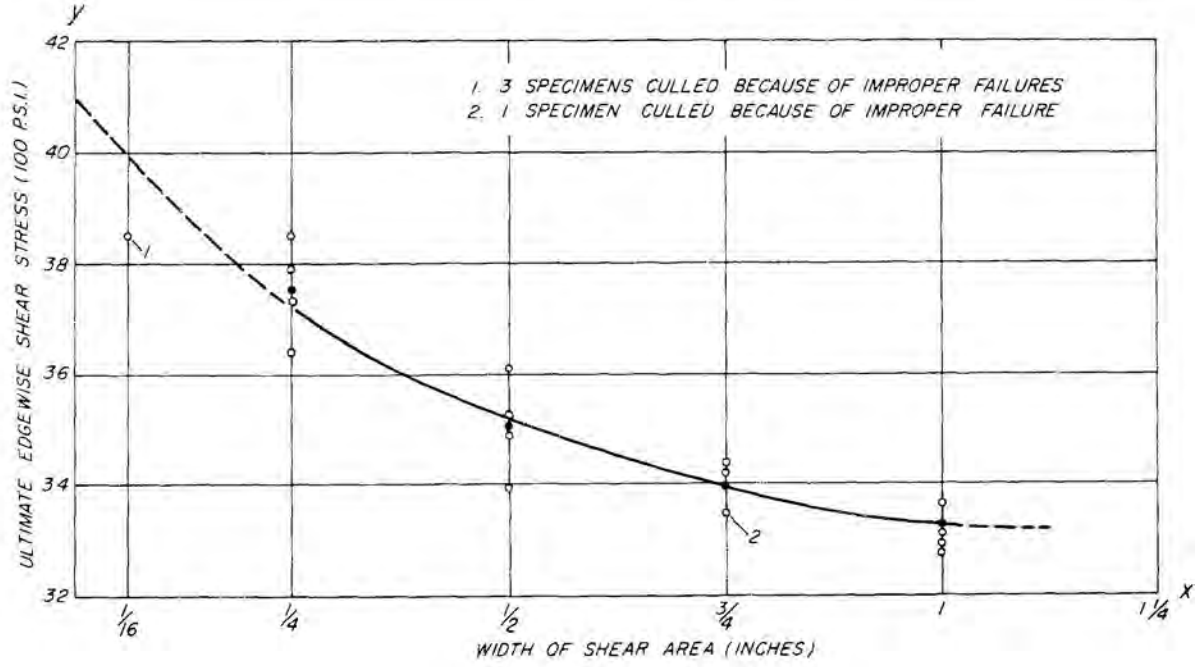


Figure 8.--Relationship between shear area width and ultimate shear stress obtained from rail shear test specimens. (M 124 271)

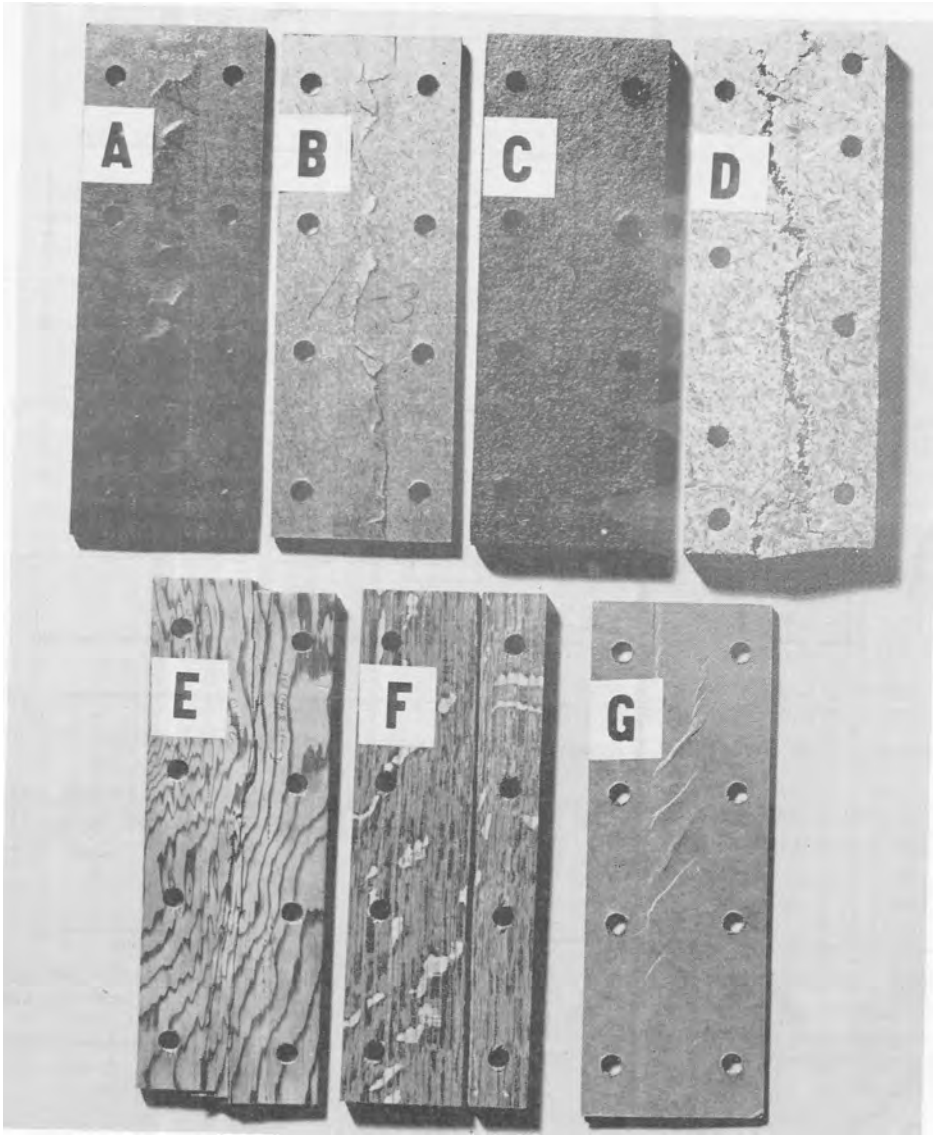


Figure 9.--Typical rail shear test failures obtained from seven different types of material: A, 1/4-inch-thick tempered hardboard; B, 1/4-inch-thick standard hardboard; C, 1/2-inch-thick, low-density insulation board; D, 5/8-inch-thick particleboard; E, 1/4-inch-thick, three-ply, Douglas-fir plywood; F, 3/8-inch-+hick, radially cut white oak; G, 1/8-inch-thick corrugated fiberboard.

(M 124 251)

of each width were cut from a 2- by 3-foot panel. The specimens were loaded at a uniform rate of 0.02 inch per minute, and the maximum loads only were recorded.

The results of the evaluations are presented graphically in figure 8. Four values were not included in the results because failures developed in the clamped area of the specimens. These failures occurred because the bolts were not tight enough to prevent the rails from slipping.

These limited test results cannot be considered conclusive, but they do indicate that the ultimate shear stress increases as the width of the area under stress is decreased. As the width decreases, the failure is confined to a progressively smaller area, and the usual diagonal tension and compression failures cannot develop.

Figure 8 also indicates that beyond a certain

shear area width (1 inch for this evaluation), the ultimate shear stress values will be essentially constant so long as the specimen is not wide enough for buckling to develop.

FAILURES DEVELOPED IN DIFFERENT PANEL MATERIALS

Typical failures obtained from seven different materials are shown in figure 9.

The failures in the tempered hardboard specimen consisted first of a series of compression "wrinkles" across the exposed area of the specimen oriented approximately at 55° angles to the specimen length. The wrinkles were followed almost immediately by tension cracks which crossed the compression failures approximately at right angles, as diagramed in figure 10, A. This type of failure indicates that the tensile and compressive strength of the tempered hardboard, parallel to the surface, is lower than the edgewise shear strength.

According to elastic theory, the maximum normal stresses occur at an angle of 45° from the direction of the maximum shear stress. Assuming, then, that the directions of the maximum normal stresses are indicated by the diagonal tension and compression failures, the principal stresses and the maximum shear stress can be represented by the diagram in figure 10, B. The line of action of the force applied to the loading rails is tilted 5° to the right of a line parallel to the specimen length; however, the direction of the maximum shear stress is tilted 10° to the left of the same line. Distributions and directions of strains along the specimen length are discussed in detail in the next section of this report.

Unlike the tempered hardboard specimen which failed in tension and compression, the standard hardboard specimen failed in edgewise shear. The visible failure, which did not appear until after the maximum load was reached, consisted of an irregular line which ran the entire length of the specimen. A slight unevenness of the surface could be felt just before the maximum load was reached by rubbing a finger over the exposed area of the specimen. This type of failure indicates that the edgewise shear strength is less than the tensile or compressive strength. The regular-density insulation board failure was similar to the standard hardboard failure, except that it was difficult to see until the specimen was loaded well beyond the maximum load. The irregular line of edgewise shear failure in the flakeboard specimen occurred more suddenly and was clearly visible immediately after maximum load was reached.

The three-ply Douglas-fir plywood specimen was cut so that the length of the specimen was parallel to the grain of the face plies. The failure, which was not visible until after the maximum load was reached, consisted of a fracture along the grain of the face plies running the entire length of the specimen. The load fell off very gradually after the maximum load was reached.

The solid white oak specimen was cut from a radially sawn board and the length was parallel to the grain. The failure occurred suddenly and the specimen broke into two pieces.

The corrugated fiberboard specimen was cut so that the corrugations were parallel to the length of the specimen. The specimen areas covered by

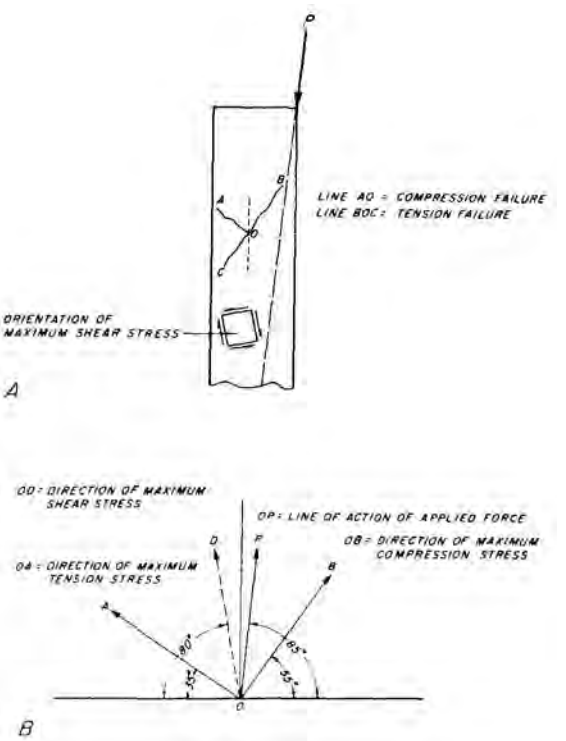


Figure 10. --Drawing showing : A, Diagonal tension and compression failures in a tempered hardboard rail shear specimen; B, directions of principal stresses and maximum shear stresses for the failure shown in A. (M 124 272)

the loading rails were compressed somewhat when the bolts were tightened. The visible failure consisted of a series of diagonal compression wrinkles across the stress area of the specimen at angles of approximately 40° to the specimen length. The wrinkles were not clearly visible until the maximum load was reached. Beyond the maximum load, slight buckling was evident, which probably would have become greater if the loading had been continued.

Thus, the rail shear test should be suitable for evaluating edgewise shear properties of plywood and parallel-to-grain shear properties of solid wood, as well as edgewise shear properties of all types of wood-base panel materials. A study conducted for the military at the Forest Products Laboratory by L. H. Floeter and K. H. Boller indicates that the procedure can be used for panel products with shear strengths of approximately 15,000 pounds per square inch. Floeter and Boller tested glass-reinforced plastic laminates and described a method for measuring the modulus of rigidity in addition to strength.

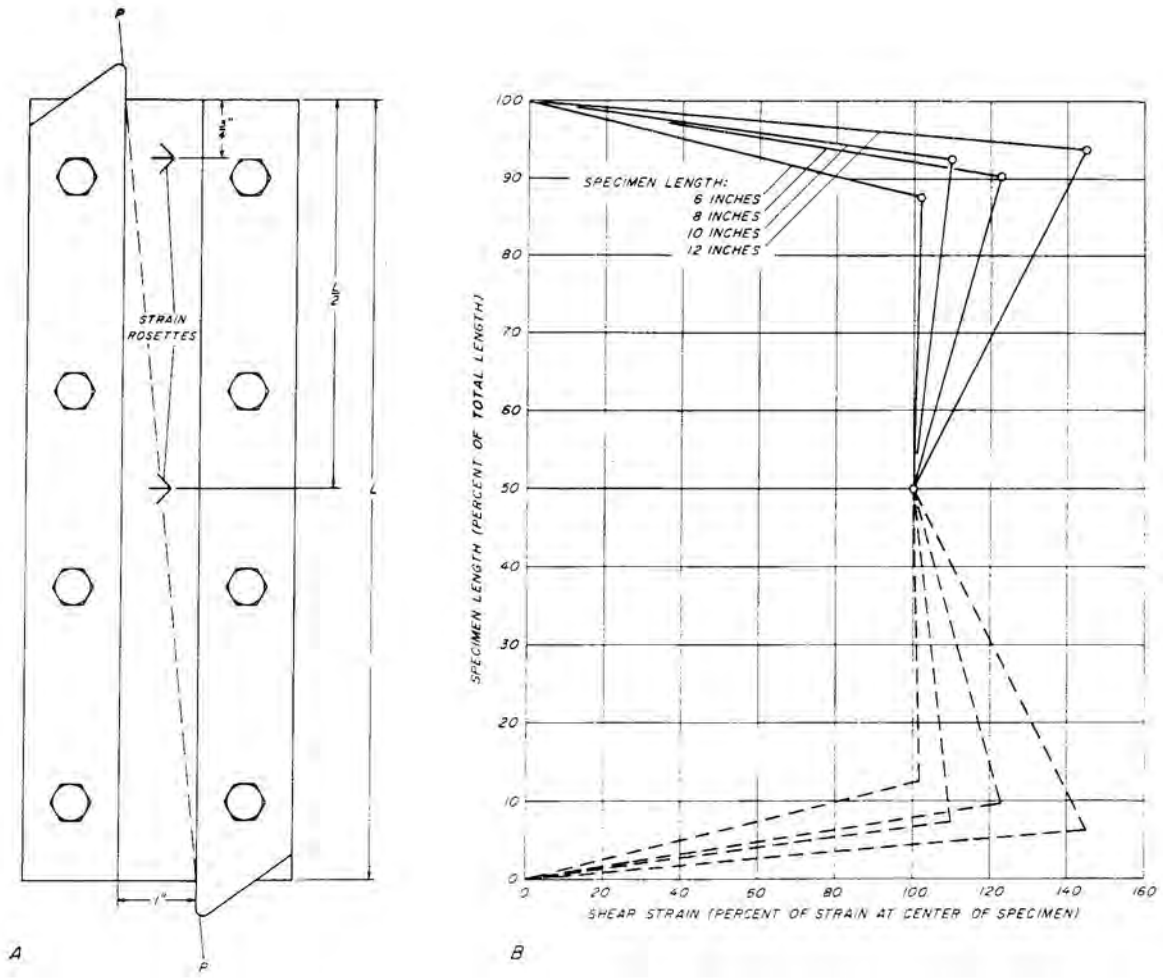


Figure 11.--Drawings illustrating direction and distribution of maximum shear along specimen length. A, Rail shear specimen showing location of strain rosettes; B, shear strains at two points along the length, of specimens, corresponding to an average shear stress of 600 p.s.i. Dotted lines are based on the assumption that shear strains are symmetrical about the center of the specimen length.

(M 136 864)

Table 1.--Magnitude and directions of maximum shear strains and principal strains measured by strain rosettes or rail shear test specimens

Rosette location	Load[1]	Maximum shear strains: Magnitude	Maximum shear strains: Direction relative to specimen length	Magnitude of normal strains in direction of maximum shear strains	Principal strains: Magnitude: Tension	Principal strains: Magnitude: Compression	Principal strains: Direction relative to specimen length
	Lb.	Microinches/inch	Degrees of rotation[2]	Microinches/inch	Microinches/inch	Microinches/inch	Degrees of rotation[2]
				6-INCH-LONG SPECIMEN			
Top	515	2160	- 3	-260	820	1340	-48
Center	515	2110	+ 8	- 55	1000	1100	-37
				8-INCH-LONG SPECIMEN			
Top	685	2220	- 4	-300	830	1390	-49
Center	685	1800	+ 6	+ 75	970	830	-39
				10-INCH-LONG SPECIMEN			
Top	850	2480	- 4	-120	1120	1360	-49
Center	850	2250	+12	+120	1250	1000	-33
				12-INCH-LONG SPECIMEN			
Top	1020	2800	- 1	-220	1180	1620	-46
Center	1020	1930	+ 1	+310	1280	650	-44

[1]Loads correspond to an average shear stress of 600 p.s.i. over the length of the specimens.
[2]Clockwise (+) or counterclockwise (-) from a line parallel to specimen length.

DIRECTION AND DISTRIBUTION OF MAXIMUM SHEAR ALONG THE SPECIMEN LENGTH

Single rail shear test specimens 6, 8, 10, and 12 inches long were cut from a 12- by 24-inch sample of 1/8-inch-thick standard hardboard to determine the direction and distribution of maximum shear along the length of the specimens. All the specimens were 3-1/2 inches wide, and the exposed area between the loading rails was 1 inch wide by the length of the specimen.

Two rectangular electrical resistance strain rosettes with 1/4-inch gage lengths were attached to each specimen; one located 3/4 inch from the top of the specimen and one located at the center of the specimen length, as shown in figure 11, A. The specimens were loaded at a uniform rate of head travel of the testing machine of 0.01 inch per minute. Strain gage readings were taken at 200-pound intervals up to 1,000 pounds for the ti-inch-long specimen and up to 2,400 pounds for the other three specimens.

Mohr's circle for strain was used to graphically analyze the data from the strain rosettes. The shear and normal strains were determined at a load level corresponding to a theoretical average shear stress of 600 pounds per square inch. The loads were 515, 685, 850, and 1,020 pounds, respectively, for the 6-, 8-, 10-, and 12-inch-long specimens.

Table 1 shows the magnitudes of the maximum shear and normal strains at the location of each rosette and the direction of the strains relative to the specimen length. The maximum shear strains 3/4 inch from the top of the specimens were not parallel to the specimen length but were rotated a few degrees counterclockwise. The angle of rotation varied from 1° in the 12-inch-long specimen to 4° in the 8- and 10-inch-long specimens. The line of action of the compressive force applied to the beveled ends of the loading rails probably influenced the direction of the maximum shear strains since it, too, was oriented a few degrees counterclockwise from the length of the specimen, as shown in figure 11, A. The method of loading most likely accounts for the compressive strains present in the same direction as the maximum shear strains near the

upper end of the specimens. The compression strains 3/4 inch from the top end of all four specimens were larger than the tensile strains due to the method of loading the specimens. For an isotropic material subjected to pure shear, no normal forces are present in the direction of the maximum shear stresses; and the principal stresses, oriented 45° from the direction of the maximum shear stresses, are equal in magnitude and opposite in sign.

The maximum shear strains at the center of the specimen length were oriented at an angle a few degrees clockwise from the direction of the specimen length. The normal strains at the same orientation as the maximum shear strains were -55, 75, 120, and 310 microinches per inch for the 6-, 8-, 10-, and 12-inch-long specimens, respectively. The principal strains in tension at the center of the specimen, except for the 6-inch-long specimen, were larger than the compression strains and became proportionately larger as specimen length was increased.

In figure 11, B the maximum shear strains determined from the two strain rosettes on each specimen are plotted as a percentage of the strain at the center of the specimen. The graphs are quite similar in shape to the distributions obtained by Post (8) from two-rail shear specimens. They also agree closely with the theoretical distribution of shear stress in a solid wood block shear specimen, the shear distribution through the cross section of a beam loaded as described by Filon (3), and the shear distribution in the double shear specimen described by Coker (2).

Figure 11, B shows that the maximum shear strains near the ends of the rail shear test specimens were larger than the strains at the center of the specimens and became proportionately larger as specimen length was increased. In the 6-inch-long specimen, the strains 3/4 inch from the end of the specimen were only 2 percent larger than the strains at the center; in the 12-inch-long specimen the strains near the top of the specimen were 45 percent larger.

MEASUREMENT OF SHEAR MODULUS

Theoretically, the rail shear test can be used to determine the edgewise shear modulus as well as the ultimate shear stress. The formula which gives this value is:

$$G = \frac{P_1 b}{L t \delta} \qquad (2)$$

where: G = edgewise shear modulus
P_1 = load at some point on the straight-line portion of the load-deformation curve
b = width of specimen areaunder stress; i.e., distance betweenpairs of rails (see fig. 5)
L = specimen length
t = specimen thickness
δ = deflection of one pair of rails with respect to the other pair at P_1

The derivation of this formula is given in the Appendix of this report.

Formula (2) assumes three conditions:

1. The area under stress is subjected to uniform pure shear.
2. Shear deformations are confined entirely to the exposed area of the specimen between the pairs of rails.
3. No slipping occurs between the specimen and the loading rails.

Undoubtedly, areas of stress concentration as well as secondary normal stresses exist in the specimen. In most instances, shear deformations cannot be entirely confined to the exposed area of the specimen between the pairs of rails, nor can slipping between the rails and the specimen be entirely eliminated. These factors do not significantly affect the maximum load to failure: however, they can reduce the apparent shear modulus.

Interlaminar shear distortions may develop when the specimen is loaded, because the interlaminar shear strength of wood-base materials is less than the edgewise shear strength. (For hardboards, the interlaminar shear strength is less than one-fifth the edgewise shear strength.) The interlaminar shear strains often progress into the specimen area covered by the loading rails and, as a result, the area under stress is larger than it is assumed to be in the calculation of shear moduli.

Also, any slipping between the rails and the

specimen would increase the deformation above that caused by shear forces themselves. The larger deformation reading would decrease the value of G calculated from formula (2).

In light of these factors, it is recommended that the ASTM plate shear test (fig. 3) be used to determine the shear modulus across the plane of panel products.

In a comparison of a few matched specimens of 1/8-inch-thick standard hardboard, the average shear modulus obtained by the ASTM plate shear method was 31.0 x 10^4 pounds per square inch. The value obtained from the rail shear method was 24.2 x 10^4 pounds per square inch.

It must be remembered however, that the shear moduli measured by thses two methods are the same only if the panel is homogeneous through the thickness. In the plate shear specimen, both surfaces develop strains of the same magnitude but opposite in direction, which decrease linearly to zero at the neutral plane of the panel. In the rail shear specimen, the strains are equal in both magnitude and direction at all points through the thickness of the panel. For panel materials which have surface "layers" stiffer than the core, the plate shear test would give a higher modulus value than the rail shear test.

COMPARISON OF TEST RESULTS FROM RAIL SHEAR SPECIMENS AND LARGE SIZE SHEAR PANELS

A study was undertaken at the Forest Products Laboratory to investigate the use of 1/4-inch-thick tempered hardboard as the shear web in a built-up wood beam. Three beams were fabricated and loaded in bending to simulate uniform loading of a roof truss with a clear span of 30 feet. The method of loading the beam is shown in figure 12.

All three beams failed in tension in the lower Douglas-fir flanges. To determine the shear stress required to cause failure in the hardboard web, the undamaged panel sections at each end of the beam immediately inside the beam supports were cut out of the failed beam as illustrated

Figure 12.--Loading method used in testing I-beam to failure. (M 134 326)

in figure 13 and loaded in edgewise shear as shown in figure 14. The direction of the shear stress for each panel coincided with the direction of the shear stress in the panels during loading of the whole beam.

The panel failures consisted of a combination of diagonal tension and compression preceded by slight buckling, which was detectable only by holding a straightedge against the hardboard web. Two of the panel failures are shown in figure 15.

The edgewise shear strength of the hardboard used in fabricating the beams from which the shear panels were cut had previously been determined by the rail shear test procedure. A comparison of the strength values obtained from the large shear panels and the rail shear specimens is given in table 2.

Table 2.--Shear strength values from large panels and rail shear test specimens

Beam	Rail shear specimen	Large shear panel	Percent difference (based on small specimen)
	P.s.i.	P.s.i.	
1	3,030	2,925	-3.5
2	2,860	2,920	+2.0
3	2,840	2,795	-1.5

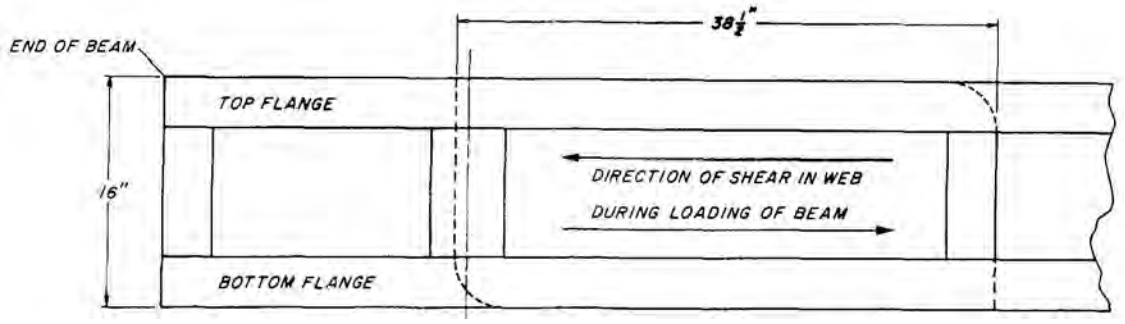


Figure 13.--Location of panel cut from I-beam to be loaded in edgewise shear. (M 136 862)

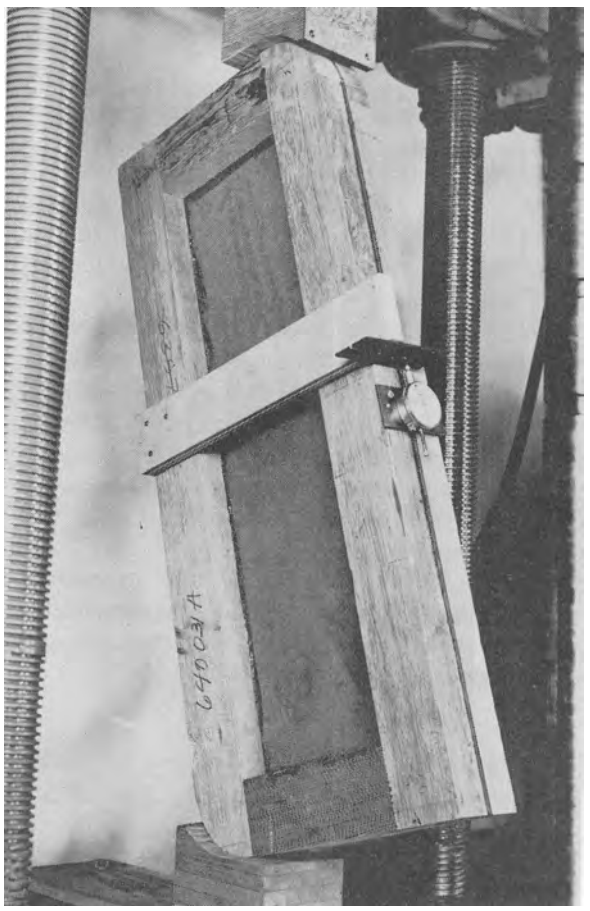


Figure 14.--I-beam panel ready for loading in edgewise shear. (M 134 412).

SUMMARY

The rail shear test provides a simple and yet reasonably accurate method for determining the edgewise shear properties of wood-base fiber and particle panel materials. Values obtained from this procedure for edgewise (panel) shear are comparable to those obtained from actual structures stressed in shear in the same plane when panel areas are small enough so elastic buckling does not occur.

The failures obtained from the rail shear test indicate a fairly uniform shear distribution for specimens 6, 8, 10, and 12 inches long. Strength values were approximately the same for specimens 6 to 12 inches long. However, the maximum loads obtained increased as the width of the specimen area under stress was decreased.

Analysis of shear distribution along the length

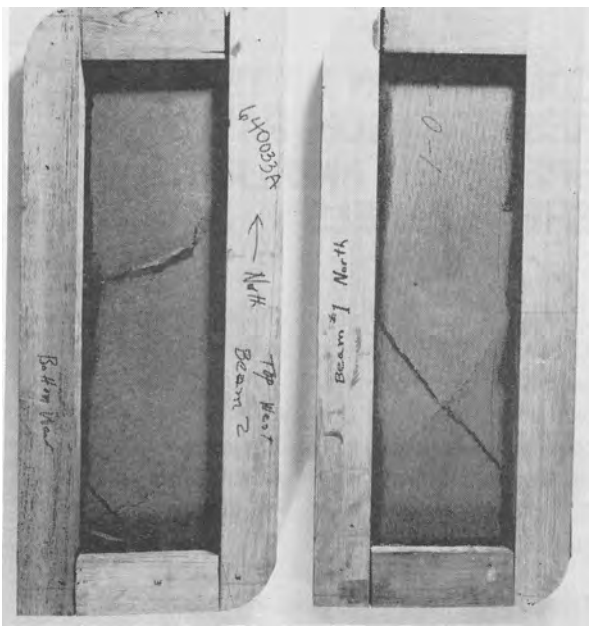


Figure 15.--Typical failures of I-beam panels loaded in edgewise shear. (M 134 413)

of specimens 8, 10, and 12 inches long revealed that the shear strains were greater near the ends of the specimen than at the center of the specimen length and became proportionately larger as the length of the specimen was increased. This distribution of strains agrees with measured and theoretically determined distributions in other shear specimens. The small secondary normal strains measured in the direction of the maximum shear were expected, because it is not possible to obtain pure shear in specimens of the types studied.

Other results obtained from this study are:

1. Measurement of the relative movement of opposite pairs of loading rails to determine the shear modulus is correct in theory, but in practice it yields values that are low.
2. Changing the rate of loading from 0.01 to 0.02 inch per minute did not affect the maximum loads obtained.
3. The compressive force applied to the loading rails to produce shear in the specimen affects the state of stress near the ends of the specimens but does not adversely influence ultimate strength values.
3. When testing specimens of low-density materials, some crushing of the specimen edges will most likely occur when the bolts are tightened.

APPENDIX

Derivation of the equation for the shear modulus obtained by the rail shear method:

The shear modulus, G, is the ratio of the shear stress, τ, to the shear strain γ, assuming the material is not loaded beyond the elastic limit.

$$G = \frac{\tau}{\gamma} \qquad (1)$$

For the type of loading in the rail shear specimen,

$$\tau = \frac{P_1}{Lt} \qquad (2)$$

where P_1 = any load within the elastic limit
L = length of the specimen
t = thickness of the specimen

The shear strain is equal to the change in the angle $\Delta\theta$, due to shear deformation. Referring to figure 16,

$$\gamma = \theta^{\circ} - 0^{\circ} = \theta^{\circ} \qquad (3)$$

For small angles of θ,

$$\theta = \tan\theta \qquad (4)$$

From figure 16,

$$\tan\theta = \frac{\delta}{b} = \theta \qquad (5)$$

Therefore, from equations (3) and (4),

$$\gamma = \frac{\delta}{b} \qquad (6)$$

Substituting equations (2) and (6) into (1),

$$G = \frac{P_1/Lt}{\delta/b} \quad \text{or} \quad G = \frac{P_1 b}{L t \delta} \qquad (7)$$

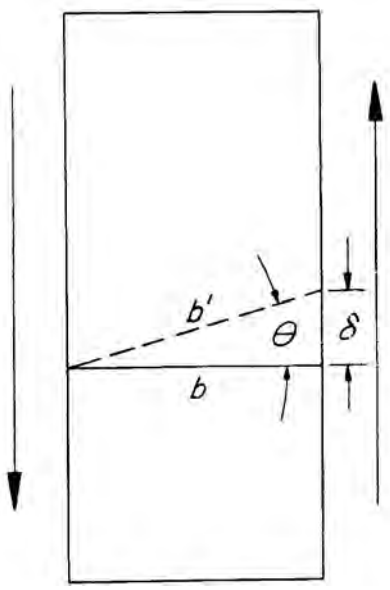


Figure 16.--Panel loaded in edgewise shear. (M 136 862)

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