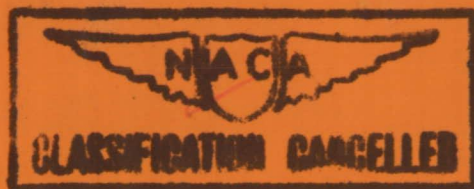## General Disclaimer

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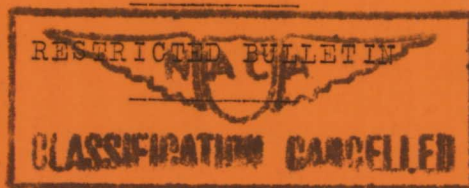
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A STUDY OF THE COMPRESSIVE STRENGTH OF

STIFFENED PLYWOOD PANELS

By Eugene E. Lundquist, Joseph N. Kotanchik, and
George W. Zender

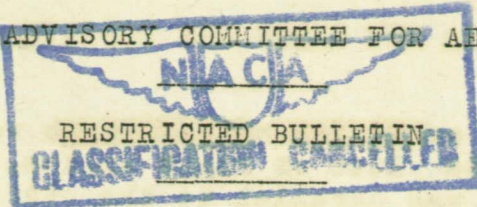Langley Memorial Aeronautical Laboratory
Langley Field, Va.

August 1942

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RESTRICTED BULLETIN

A STUDY OF THE COMPRESSIVE STRENGTH OF

STIFFENED PLYWOOD PANELS

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SUMMARY

The results of compression tests on 44 stiffened ply-
wood panels are presented and correlated in groups for the
three types of failure observed: column failure, failure
by separation of plywood from stiffener, and crushing
failure.

INTRODUCTION

The expanded program of military aircraft construc-
tion has made it necessary to seek substitute materials
that can be used in aircraft in place of aluminum alloys.
Wood is one of these substitute materials. The development
of synthetic resins as bonding and impregnating agents has
resulted in the production of plywood which is being used
in stressed-skin structures for aircraft. The use of ply-
wood in such structures necessitates that tests be per-
formed to determine allowable stress values for use in
design. This report presents a preliminary analysis of the
results of compression tests on 44 stiffened plywood panels
made by the Universal Moulded Products Corporation. The
tests were made in a testing machine of 1,200,000 pounds
capacity in the NACA structures research laboratory.

TEST SPECIMENS

The manufacturer reported that the specimens consisted
of yellow poplar plywood bonded to Eastern spruce stiffeners
with hot Plaskon 700-2. The four sizes of stiffeners used
in this group of specimens are shown in figure 1 and are
designated A, B, C, and D, in order of increasing size.

The plywood consisted of 1/28-inch veneers with the grain of alternate plies at right angles. The grain of the face veneers was parallel to the stiffeners. The bonding agent used in assembling the veneers into plywood was reported by the manufacturer to be cold Plaskon PCP-7.

The length of each specimen, as manufactured, was approximately 12 inches greater than the length of the finished test specimen. This excess length was cut off to provide a coupon for each test specimen. Minor specimens for the determination of moisture content and physical properties of the material were cut from the coupons. The complete dimensions of the specimens, the loads developed, and the type of failure are given in table I. In this table the specimens are grouped according to stiffener size, nominal length, number of plies, and clear distance between adjacent stiffeners.

METHOD OF TESTING

The ends of the specimens were ground flat, square, and parallel in a planer specially adapted for this purpose. The ends of the specimen were placed directly against the bearing plates of the testing machine. The specimens were alined by means of guide bars that extended across the bearing plates. These guide bars were backed away before the maximum load was reached in order to avoid interference with the action of the specimen at failure.

Strain gages were attached to both sides of each specimen on the stiffeners and between the stiffeners. The shortening of most of the specimens was also measured with dial gages.

MOISTURE CONTENT

A determination of moisture content was made for the poplar plywood and the spruce of all test specimens. The average moisture contents are given in table II.

The panel test data are presented and analyzed for the moisture content at the time of test. The use of the design charts derived is illustrated in the problem given in appendix A. In appendix B the adjustment to standard 15-percent moisture content of the design charts and stress-strain curves is described and the adjusted figures are

presented. These adjusted figures should be used in all general design problems. It was considered more expedient to make the adjustments for moisture content to the final design charts rather than to adjust the individual test data for each specimen before making the analysis.

STRESS-STRAIN CURVES

A number of compression stress-strain curves were determined for the stiffeners and the plywood. These curves are shown in figures 2 and 3. Figure 3 presents the stress-strain curves for repeat groups of plywood specimens of 5, 7, 9, and 11 plies with the grain of the face veneers parallel to the direction of load.

TYPES OF FAILURE

The three types of failure that were observed to occur are designated and described as follows:

Type 1, or column, failure (fig. 4):

The entire panel failed as a column by bending. The plywood remained attached to the stiffener until large deflections had taken place. This type of failure occurred in six specimens.

Type 2, or separation, failure (fig. 5):

The plywood pulled away from the stiffener. The actual separation occurred not in the plane of the glued joint but within one of the veneers of the plywood. It occurred most frequently in one of the veneers the grain of which was at right angles to the stiffeners. This type of failure occurred in 32 specimens.

Type 3, or crushing, failure (fig. 6):

The panel failed by crushing of the plywood, the stiffener, or both. This type of failure occurred in six specimens.

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It will be noted that the separation type of failure occurred in most specimens. Figure 7 illustrates the path generally followed by the fracture in the separation failures. As the wave in the buckled plywood increased in depth, tending to pull the plywood away from the stiffener, a tensile stress due to bending developed in the veneer nearest the stiffener. This tensile stress was at right angles to the direction of the grain of the veneer — a loading condition in which wood has very low strength. The plywood veneer nearest the stiffener then split parallel to its own grain and the fracture entered the second veneer, the grain of which was at right angles to the stiffener. This veneer was then subjected to a cleavage action and the fracture moved parallel to the grain of this second veneer until complete separation of plywood from stiffener had occurred. In some specimens the separation of the plywood occurred in the fourth veneer from the stiffener rather than the second veneer, as shown in figure 7.

<center>DISCUSSION</center>

Type 1, or column, failure.— When failure occurred by column action with bending normal to the plane of the plywood, the direction of the deflection was such as to put additional compression in the plywood. As so few specimens developed this type of failure, no analysis has been attempted other than to present the results graphically in figure 8.

Type 2, or separation, failure.— When failure occurred by separation of the plywood from the stiffener, it was observed that the plywood between stiffeners was in a buckled state.

An approximate theoretical analysis of a buckled plate, based upon the theory of large deflections, revealed that for an isotropic material the ratio of edge strain to critical strain varies linearly with the reciprocal of the square of the critical compressive strain in the sheet between stiffeners if the relative shape of the buckle pattern is constant, the edges of the plate are fixed, and the bending strain in the sheet at the edge is constant. Although the material in the panels was not isotropic, the buckle patterns were always of the same relative shape,

the plywood appeared to be fixed to the stiffeners, and the internal strain (or stress) condition at which separation of plywood and stiffener occurred was probably a constant for a given type of plywood and species of wood. The form of the theoretical solution for an isotropic material was therefore used to indicate the method of presenting the test results.

The critical compressive strain ϵ_{cr} was established by analysis of the strain-gage readings taken on the plywood between stiffeners. The analysis was made by the Southwell method of estimating critical loads from simultaneous readings of load and deflection, as generalized in reference 1. The average strain was regarded as corresponding to the load and the difference in strain on the two sides of the sheet as corresponding to deflection. Thus, critical strain rather than critical load was predicted.

The edge strain ϵ, or strain at the stiffener, was measured directly by strain gages on the stiffener. The important values of ϵ are the values ϵ_e at which separation of the plywood from the stiffener occurred.

The values of ϵ_{cr} determined from the panel tests are plotted in figure 9 against b/t, the ratio of width of plywood between stiffeners to the thickness of the plywood. The solid curve drawn through the experimental points is given by the equation

$$\epsilon_{cr} = 2.5 \frac{t^2}{b^2}$$

Although the experimental points in figure 9 scatter over a rather wide band, this equation gives the average critical compressive strain for the plywood. The fact that the points representing specimens of 5, 7, and 9 plies are distributed across the full width of the band suggests that for a given thickness of plywood the equation will apply for any number of plies greater than 5.

In figure 10 values of ϵ_e/ϵ_{cr} are plotted against $1/(\epsilon_{cr})^2$. The experimental points are observed to plot

along a straight line as suggested by the theoretical
analysis previously mentioned. As in the case of figure
9, the solid line in figure 10 gives the average rela-
tionship between the variables plotted. The solid line
in figure 10 establishes the compressive strain at the
stiffener for which separation of the plywood from the
stiffener occurs. This strain ϵ_e is given in terms of
the critical strain ϵ_{cr} for the plywood between stiff-
eners. Because ϵ_{cr} is a function of b/t, ϵ_e is also
a function of b/t. The relationship between ϵ_e and
b/t is given in figure 11 where, for convenience, ϵ_{cr}
is also plotted.

For strength calculations it is necessary to know the
ratio b_{eff}/b, effective width of plywood divided by
width of plywood between stiffeners. This ratio is assumed
to be given by Marguerre's formula for effective width of
sheet with the stresses replaced by their corresponding
strains:

$$\frac{b_{eff}}{b} = \sqrt[3]{\frac{\epsilon_{cr}}{\epsilon}}$$

For the special case of $\epsilon = \epsilon_e$, the values of b_{eff}/b
given by Marguerre's formula are plotted in figure 11.
Values of b_{eff}/b read from this curve should be used
only when calculating the load at which the plywood sepa-
rates from the stiffener. An illustrative example of the
use of figure 11 is given in appendix A.

Type 3, or crushing, failure.— When failure occurred
by crushing of the specimens, both the stiffener and the
plywood seemed to have reached their ultimate strengths
with the first evidence of failure occurring in the ply-
wood. A failure of this type would indicate that the
entire area of the plywood was effective in carrying load,
and this fact is verified by checking against the curve
of b_{eff}/b in figure 11 the six specimens that failed by
crushing. All but one of these specimens have values of
b/t for which the ratio b_{eff}/b is equal to unity and, in
the sixth case, this ratio is 0.95, or very nearly unity.

Table III was prepared to check whether the stiffener and the plywood actually reached their ultimate strengths in this type of failure. The calculated loads in table III were computed on the assumption that both plywood and stiffeners reached their ultimate strengths and that the entire area of plywood and stiffeners was effective in resisting the load. The loads thus obtained are in good agreement with the experimental loads.

CONCLUDING REMARKS

The compressive strength of stiffened plywood panels that fail by crushing of the wood or by column action with bending normal to the plane of the plywood can probably be calculated by the usual procedures used in metal specimens with proper consideration for the different material properties.

The compressive strength of stiffened plywood panels that fail by separation of the plywood from the stiffeners can be calculated by the methods developed in this report and illustrated by the example in appendix A.

From the failure of the panels, it appears that separation of the plywood from the stiffener might be delayed until a higher load is reached if the face veneers are somewhat thickened and laid with the direction of the grain normal to the stiffeners. Tests should be made, however, to check the effectiveness of this construction.

The critical compressive strain ϵ_{cr} for the plywood between stiffeners, given by $\epsilon_{cr} = 2.5 \frac{t^2}{b^2}$ (where t is plywood thickness and b is the clear distance between stiffeners), represented very well the test results herein presented. The stiffeners seemed to provide a high degree of restraint against rotation of the plywood at the stiffener. This formula for ϵ_{cr} should be used when the relative proportions of plywood and stiffeners are in the range of the specimens tested.

Langley Memorial Aeronautical Laboratory,
    National Advisory Committee for Aeronautics,
        Langley Field, Va.

APPENDIX A

ILLUSTRATIVE PROBLEM

In order to check the validity of the relationships used in determining the curves of figure 11, calculations of the load at which separation failure occurs were made for the specimens that developed this type of failure using these curves. The values thus obtained were then checked against the experimental values. (See table IV.)

The method of determining the separation load can be illustrated by means of a sample calculation for a representative specimen. Specimen 50 was selected for this purpose. The pertinent data are as follows:

```
Number of stiffeners . . . . . . . . . . . . . . . . . . 6
Clear distance between stiffeners, b, in. . . . . . 8.96
Plywood thickness, t, in. . . . . . . . . . . . . . 0.235
b/t . . . . . . : . . . . . . . . . . . . . . . . . 38.16
Width of plywood in contact with stiffener, w, in.  2.14
Number of plies . . . . . . . . . . . . . . . . . . . 7
Area of stiffeners, sq in. . . . . . . . . . . . . . 15.9
```

From figure 11, with the value of b/t given, it is found that $\epsilon_e = 0.00327$. For this value of ϵ_e, the stresses are determined from the appropriate stress-strain curves. These stresses are as follows:

$$(\sigma_e)_{stiffener} = 4.89 \text{ kips per sq in.}$$

$$(\sigma_e)_{plywood} = 3.30 \text{ kips per sq in.}$$

(Stress for plywood was obtained from group B stress-strain curves of fig. 3.)

The area of the plywood represented by the effective width is given by the equation

$$(A_{eff})_{plywood} = (6w + 5 \frac{b_{eff}}{b} \times b)t$$

The coefficients 6 and 5 represent the six stiffeners and the 5 bays between stiffeners, respectively. The ratio

b_{eff}/b is determined from figure 11. Substitution of the proper values in the foregoing equation gives, for the effective area of plywood.

$$(A_{eff})_{plywood} = (6 \times 2.14 + 5 \times 0.808 \times 8.96)0.235 = 11.5 \text{ sq in.}$$

The separation load is given by

$$P = (A_{eff}\ \sigma_e)_{plywood} + (A\ \sigma_e)_{stiffeners}$$

$$= 11.5 \times 3.30 + 15.9 \times 4.89$$

$$= 115.8 \text{ kips}$$

Similar calculations have been worked out for all the specimens that failed by separation. The calculated loads at which separation of the plywood and the stiffener occurs, for these specimens, are compared with the experimental separation loads in table IV. For most of the specimens there is reasonably good agreement between the experimental and the calculated loads. It will be noted that, for specimens 21, 20, 39, 57, and 1, the experimental load is considerably below the calculated load. The manufacturer of the test specimens reported that close visual inspection after manufacture resulted in the rejection of some specimens because of defects in bonding. The appearance of the specimen after failure indicated that the foregoing listed specimens may also have had bonding defects that caused premature separation. A visual examination of these specimens showed that some of the separation had occurred in the plane of the glued joint. Additional evidence that these specimens were not perfectly bonded is contained in the fact that all five of these specimens had one or more duplicate specimens, each of which developed separation loads that are in good agreement with the calculated loads. Duplicate specimens are indicated in table IV.

APPENDIX B

ADJUSTMENT TO STANDARD MOISTURE CONTENT OF 15 PERCENT

In this study of the compressive strength of stiffened plywood panels, the principal analysis of the test data has been made for the case of failure by separation of the plywood from the stiffeners. The analysis has been carried out on the basis of the moisture content of the plywood and the stiffeners at the time of test. These moisture contents are listed in table II. This appendix discusses the adjustment of the design charts and the stress-strain curves to a standard moisture content of 15 percent.

Figure 10 gives the relation between $\dfrac{\epsilon_e}{\epsilon_{cr}}$ and $\dfrac{1}{\epsilon_{cr}^2}$ for an average moisture content of the plywood of 10 percent. On the basis of information contained in reference 2 concerning the effect of moisture content on the strength properties of wood, it is found that the slope of the straight line in figure 10 will vary with the moisture content of the wood. In order to adjust the slope of this straight line to a moisture content D, it is necessary to multiply the slope of the straight line in figure 10 by the quantity

$$\left(\frac{\sigma_{y_B} E_{b_A}}{\sigma_{y_A} E_{b_B}} \right)^{2\frac{C-D}{A-B}}$$

where

σ_y tensile strength of yellow poplar perpendicular to grain

E_b modulus of elasticity of yellow poplar in bending

A,B   two moisture contents found by tests on matched specimens of the same species of wood (Subscripts

A and B indicate that the properties to which the subscripts apply are the properties for the moisture content A or B.)

C   moisture content at time of test

D   moisture content to which adjustment is being made

The values of σ_y, E_b, A, and B for yellow poplar are obtained from table I of reference 2.

For moisture contents of C = 10 percent and D = 15 percent, the slope of the straight line in figure 10 is, therefore, multiplied by the quantity

$$(0.84)^{-\frac{5}{6}} = 1.16$$

In the adjustment of the stress—strain curves to a moisture content of 15 percent, the method described in reference 2 (p. 50) was used. In the application of this method to the data of this report, the following assumptions were made:

(1) The equation on page 51 of reference 2, which gives the relation between moisture content and strength properties for a clear specimen of a given species of wood, applies to plywood with alternate plies at right angles because the greater part of the load is carried by those plies in which the grain is parallel to the load.

(2) The ratio S_A/S_B, when S is a stress, varies linearly between the stress at proportional limit and the maximum stress.

(3) The fiber saturation moisture content for yellow poplar plywood is 24 percent.

The figures that require adjustment for moisture content have been redrawn for a standard moisture content of 15 percent. (See figs. 12, 13, 14, and 15, which are figs. 2, 3, 10, and 11, respectively, adjusted to 15—percent moisture content.) These figures should be used when applying the method of appendix A to predict the load that a panel constructed of Eastern spruce stiffeners and yellow poplar plywood will carry when the moisture content of the wood is 15 percent.

REFERENCES

1. Lundquist, Eugene E.: Generalized Analysis of Experi-
   mental Observations in Problems of Elastic Stability.
   T.N. No. 658, NACA, 1938.

2. Markwardt, L. J. and Wilson, T. R. C.: Strength and
   Related Properties of Woods Grown in the United
   States. Tech. Bull. No. 479, U. S. Dept. Agric.,
   1935.

SPECIMEN DIMENSIONS AND TEST DATA

Specimen no.	Stiffener	Specimen length (in.)	Specimen width (in.)	b (in.)	Plies	t (in.)	Area Plywood (sq in.)	Area Stiffener (sq in.)	Area Total (sq in.)	Failure load Initial (kips)	Failure load Maximum (Kips)	Failure type
13	A	24	45	7.56	3	0.101	4.5	3.9	8.4	28.5	30.9	1
17					5	.166	7.4	3.9	11.3	35.4	35.5	1
19					5	.168	7.4	4.0	11.4	36.5	36.5	1
12	B	24	45	7.12	3	.101	4.5	7.8	12.3	48.4	57.2	1
15					3	.104	4.6	7.9	12.5	52.5	62.0	1
21					5	.169	7.5	7.8	15.3	45.9	61.2	2
23					5	.167	7.5	7.8	15.3	57.4	59.0	2
24					5	.169	7.5	7.8	15.3	61.4	62.4	2
20					7	.235	10.5	7.8	18.3	53.6	55.2	2
22					7	.234	10.4	7.9	18.3	80.0	80.0	2
25					7	.236	10.5	8.0	18.5	74.0	74.0	2
26					7	.234	10.5	7.8	18.3	73.2	73.2	2
38		36			5	.165	7.4	8.0	15.4	50.8	55.0	1
39					7	.244	10.9	8.0	18.9	64.6	64.6	2
42					7	.243	10.8	8.0	18.8	72.3	72.3	2
14	C		45	6.46	5	.167	7.5	15.9	23.4	113.4	113.4	2
78					9	.300	13.7	16.0	29.7	153.0	153.0	2
51		24			5	.170	9.7	16.0	25.7	115.0	115.0	2
50					7	.235	13.5	15.9	29.4	119.0	126.9	2
57					7	.238	13.6	15.8	29.4	93.8	116.8	2
55			57	8.86	9	.306	17.5	16.1	33.6	153.4	153.4	2
8					9	.305	17.4	16.1	33.5	146.0	151.5	2
66		36			5	.173	9.9	16.0	25.9	108.0	124.6	2
63					9	.316	18.1	16.0	34.1	150.5	150.5	2
33	D		45	5.94	7	.236	10.8	25.3	36.1	171.4	177.4	2
90					7	.233	10.7	25.3	36.0	190.4	198.8	2
4					9	.301	13.8	25.8	39.6	240.4	240.4	2
29		24			9	.305	14.0	25.2	39.2	225.2	225.2	3
36					9	.300	13.7	25.5	39.2	236.2	236.2	3
30					11	.368	16.9	25.3	42.2	241.0	241.0	3
52			57	8.30	7	.236	13.6	25.7	39.3	188.0	194.5	2
53					7	.238	13.7	25.7	39.4	176.0	176.0	2
9					9	.306	17.6	25.2	42.8	210.0	220.1	2
56					9	.306	17.7	25.6	43.3	219.6	219.6	2
45			45	5.90	7	.242	11.1	25.3	36.4	184.6	193.5	2
46					7	.243	11.2	26.2	37.4	223.0	223.0	2
1					9	.306	14.0	26.5	40.5	180.0	207.0	2
5		36			9	.318	14.6	26.5	40.5	226.6	226.6	2
48					9	.309	14.2	26.5	40.7	201.0	201.0	3
49					11	.374	17.2	26.5	43.7	234.6	234.6	3
59			57	8.33	7	.240	13.8	24.9	38.7	210.0	213.8	2
62					7	.242	14.0	25.6	39.6	172.0	179.6	3
54					9	.309	17.9	24.6	42.5	221.0	221.0	2
61					9	.309	17.8	25.5	43.3	200.8	200.8	2

TABLE II

MOISTURE CONTENT OF SPRUCE STIFFENERS

AND POPLAR PLYWOOD

	Moisture content	
Element	Panel specimens (percent)	Stress—strain specimens (percent)
Stiffeners	9.1	8.0
5—ply	9.6	8.5
7—ply	10.2	8.0
9—ply	10.8	8.9
11—ply	9.6	9.1

TABLE III

COMPARISON OF CALCULATED AND EXPERIMENTAL

LOADS AT WHICH CRUSHING FAILURE OCCURS

Specimen number	P_{exp} (kips)	P_{calc} (kips)	$\dfrac{P_{exp} - P_{calc}}{P_{calc}}$ (percent)
29	225.2	214.1	5.18
30	241.0	221.0	9.05
36	236.2	214.8	9.96
48	201.0	223.1	—9.91
49	234.6	229.7	2.13
54	221.0	224.6	—1.60

TABLE IV

COMPARISON OF CALCULATED AND EXPERIMENTAL LOADS AT WHICH

THE PLYWOOD SEPARATES FROM THE STIFFENERS

Specimen number	P_{exp} (kips)	P_{calc} (kips)	$\dfrac{P_{exp} - P_{calc}}{P_{calc}}$ (percent) (a)
21	45.9	60.1	−23.6 ⎤
23	57.4	59.9	−4.2 ⎬
24	61.4	60.0	2.3 ⎦
20	53.6	74.8	−28.3 ⎤
22	80.0	74.9	6.8 ⎥
25	74.0	76.0	−2.6 ⎥
26	73.2	74.8	−2.1 ⎦
39	64.6	79.2	−18.4 ⎤
42	72.3	79.0	−8.5 ⎦
14	113.4	99.9	13.5
78	153.0	151.6	.9
51	115.0	118.5	−3.0
50	119.0	115.8	2.8 ⎤
57	93.8	116.0	−19.1 ⎦
55	153.4	136.1	12.7 ⎤
8	146.0	136.0	7.4 ⎦
66	108.0	118.2	−8.6
63	150.5	140.1	7.4
33	171.4	192.4	−10.9 ⎤
90	190.4	189.7	.4 ⎦
4	240.4	229.1	4.9
52	188.0	166.9	12.6 ⎤
53	176.0	167.4	5.1 ⎦
9	210.0	195.6	7.4 ⎤
56	219.6	197.6	11.1 ⎦
45	184.6	195.9	−5.8 ⎤
46	223.0	202.9	9.9 ⎦
1	180.0	236.7	−24.0 ⎤
5	226.6	243.4	−6.9 ⎦
59	210.0	163.5	28.4
54	221.0	193.3	14.3 ⎤
61	200.8	198.4	1.2 ⎦

[a] Braces indicate groups of duplicate specimens.
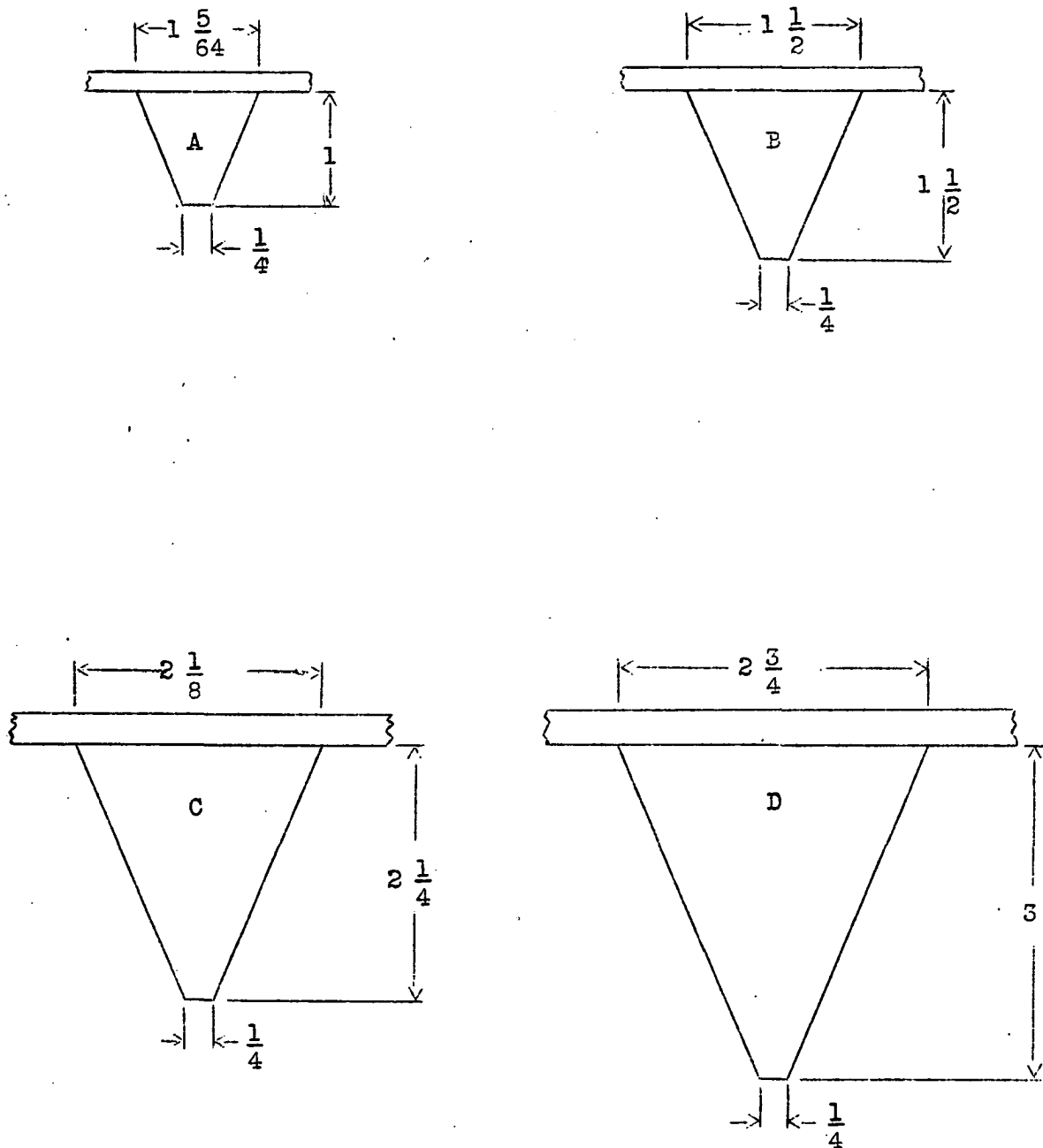
Figure 1.- Stiffener sizes used in panels.
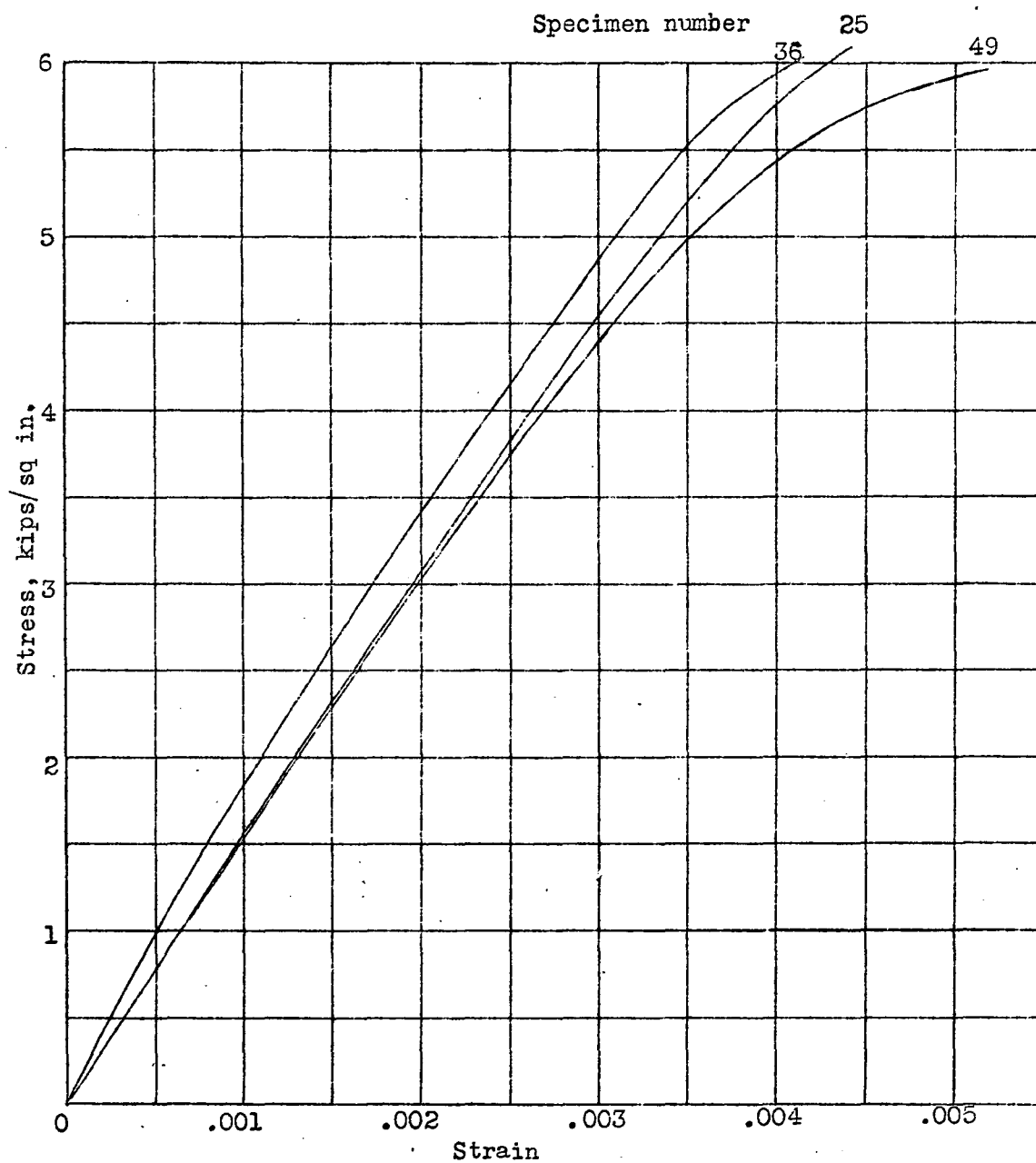
Figure 2.— Compressive stress–strain curves for stiffener material load-
ed parallel to the grain.
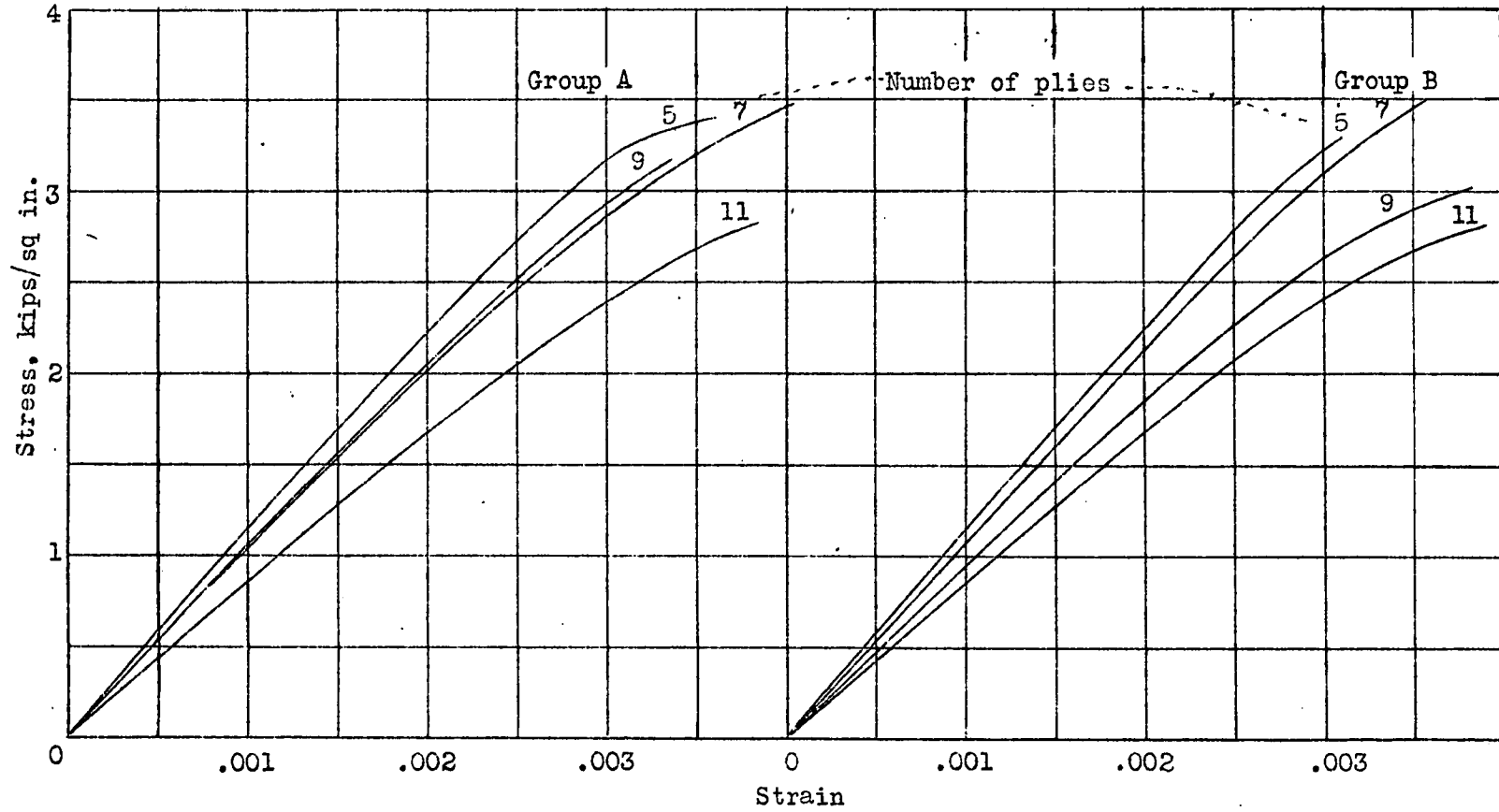
Figure 3.— Compressive stress–strain curves for plywood material loaded parallel to the face grains.
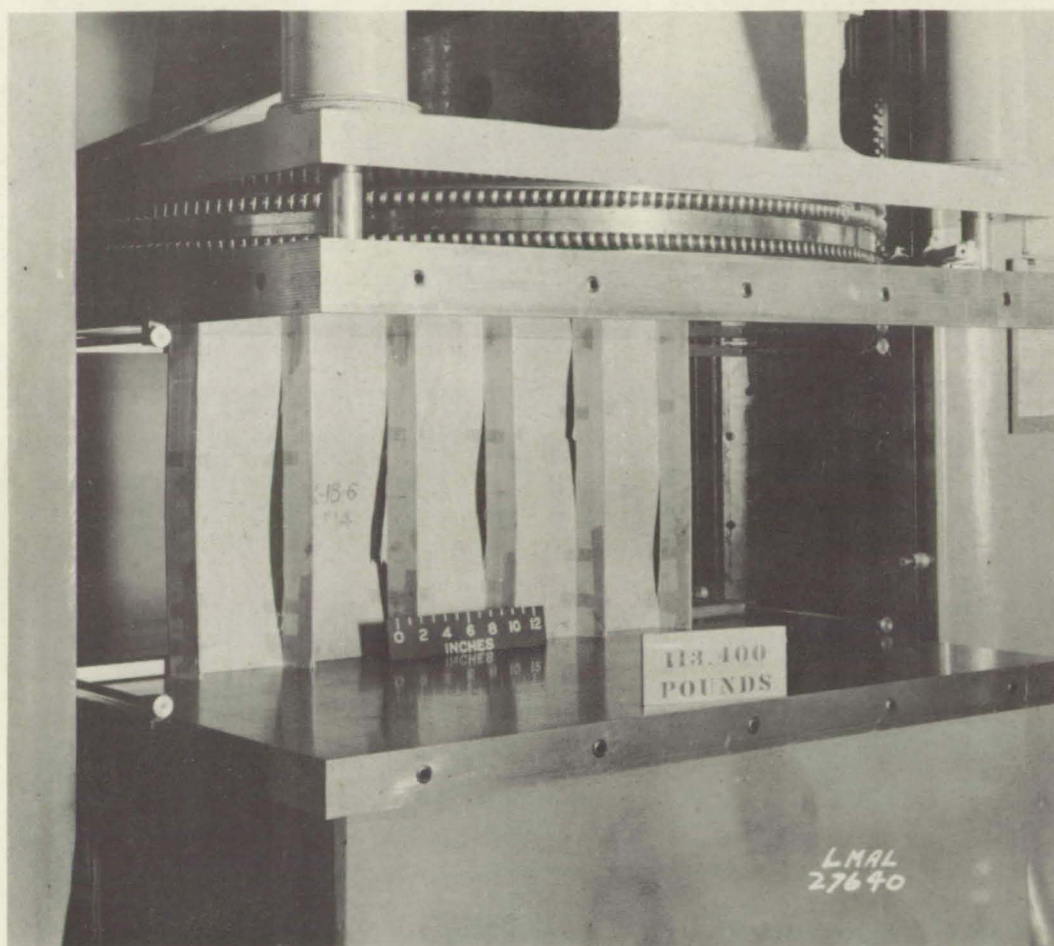
Fig. 3

LMAL
27578
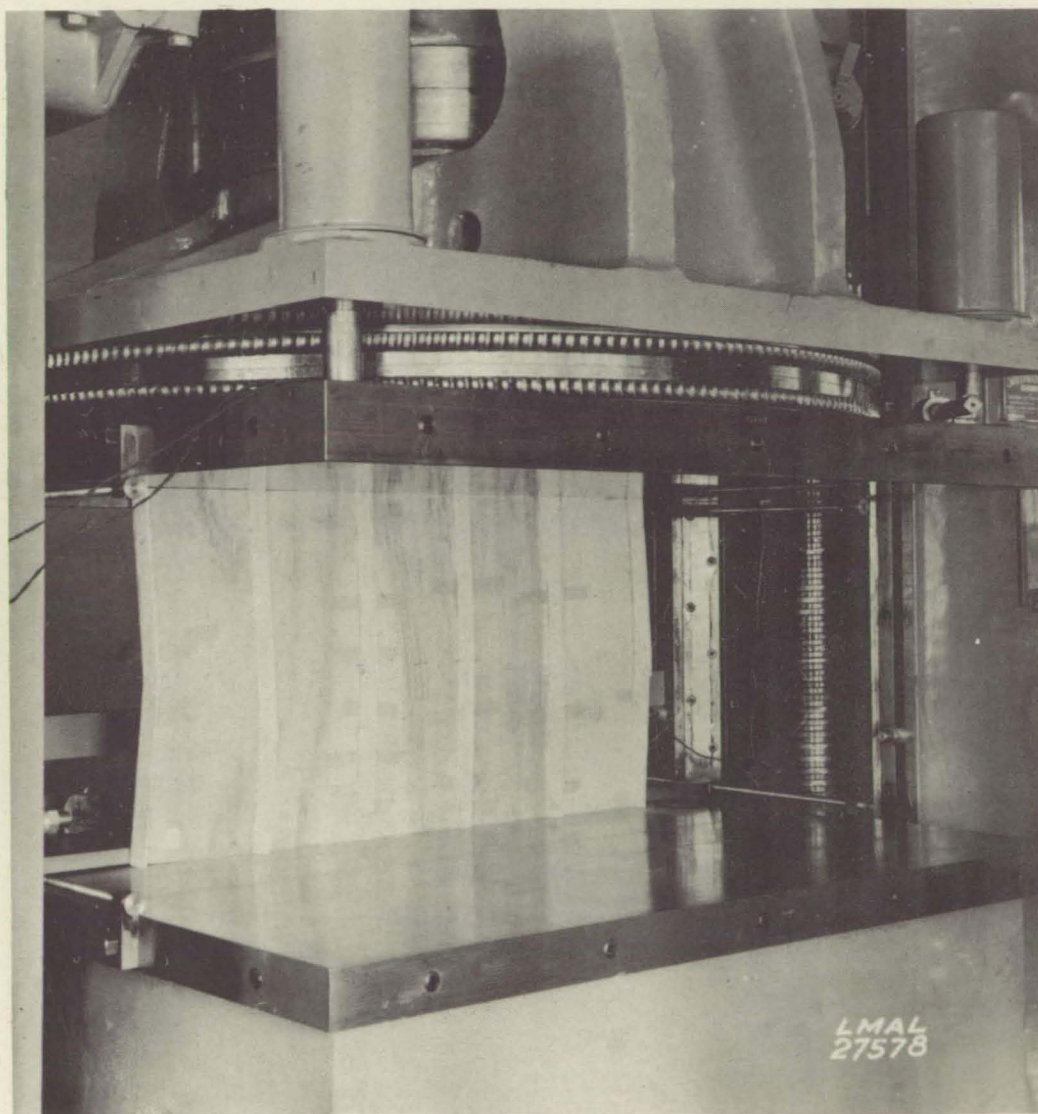
Figure 4. - Type 1, or column, failure of specimen.
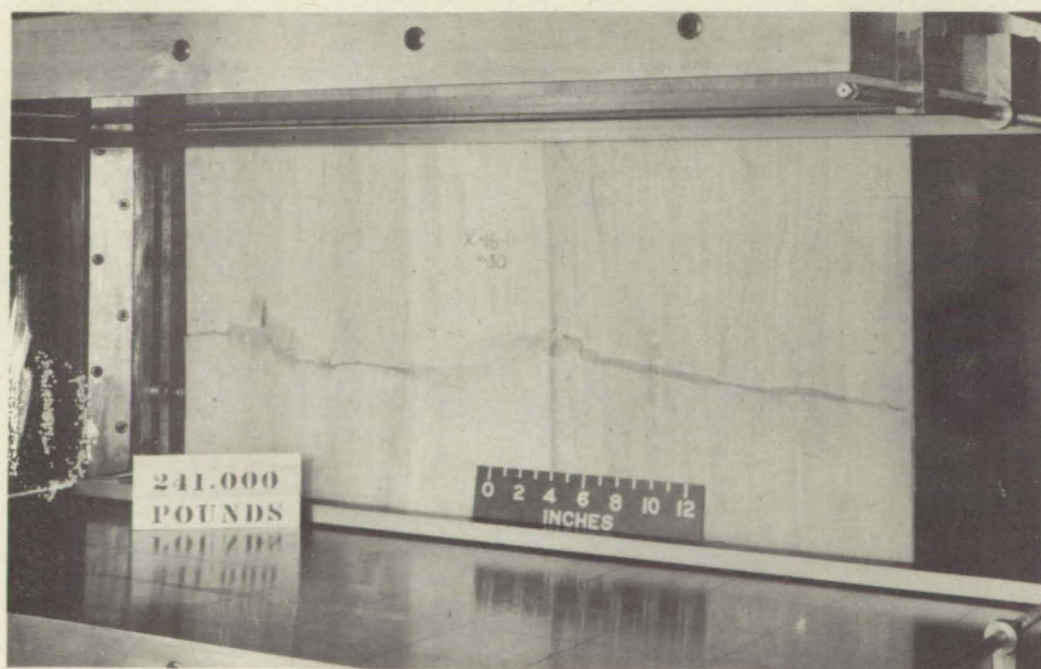
Figure 5.- Type 2, or separation, failure of specimen.

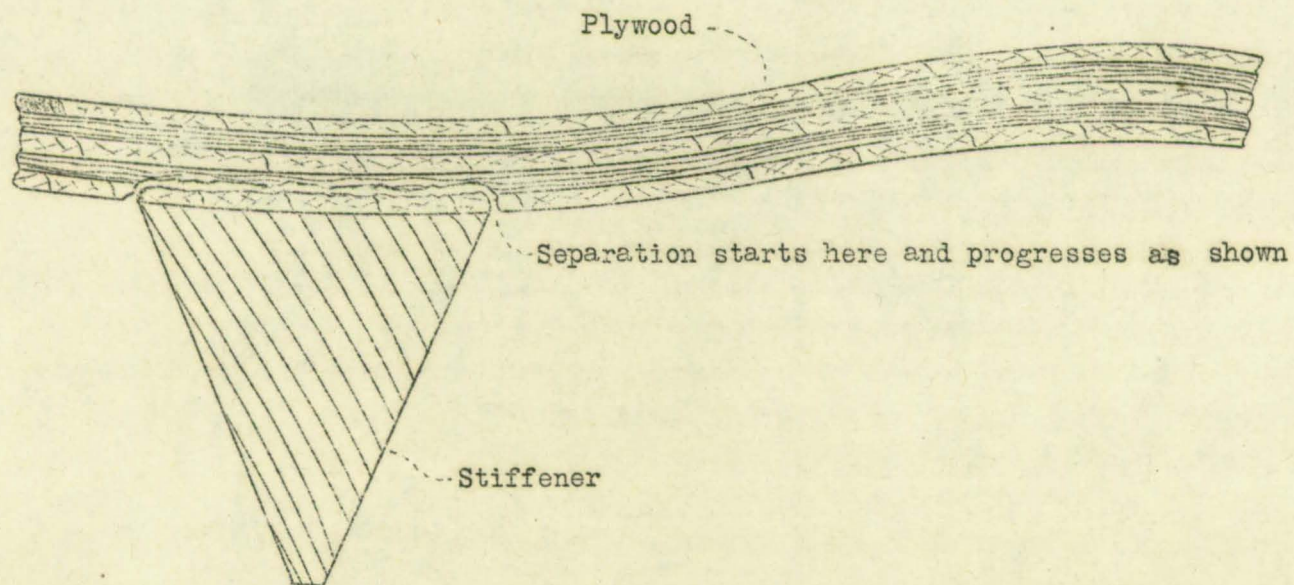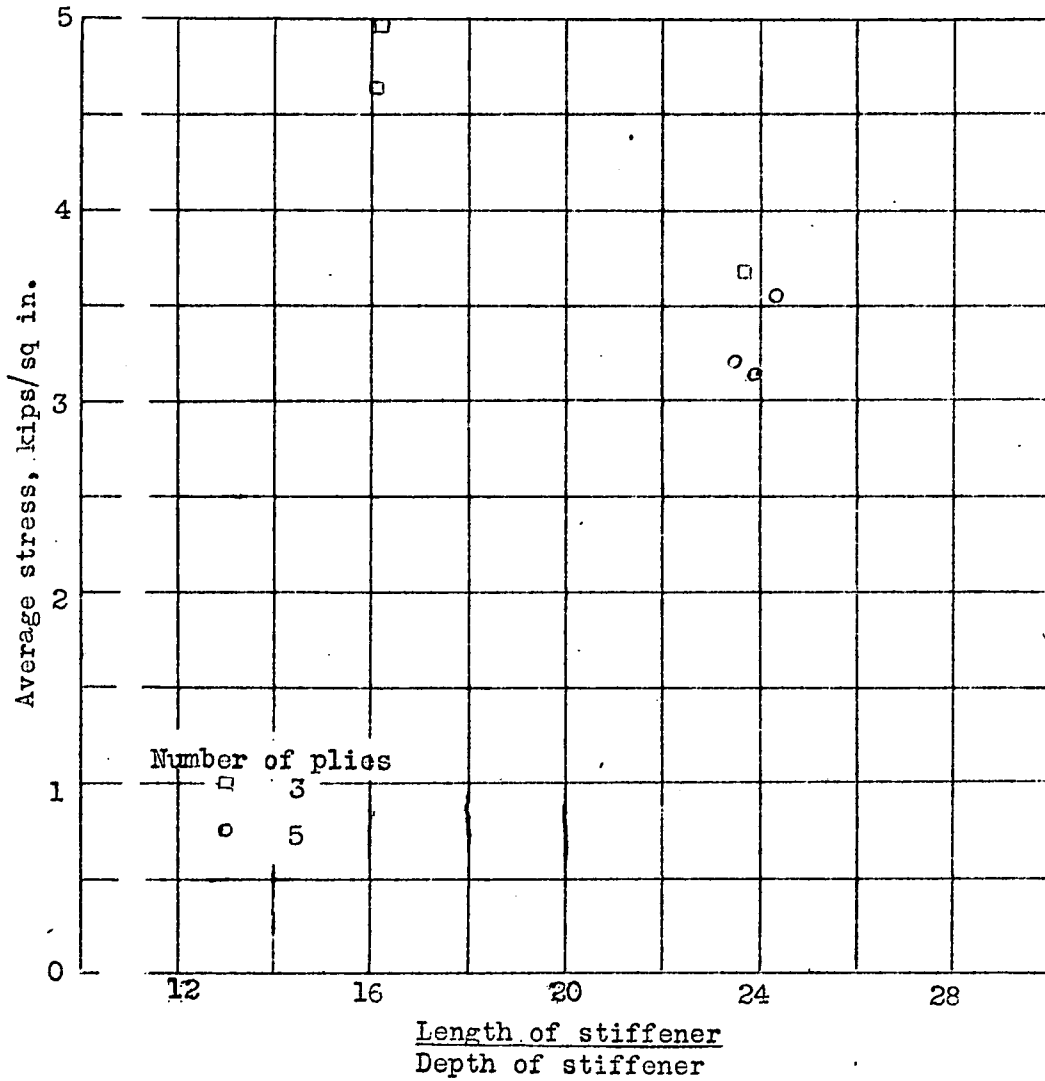Figure 6. - Type 3, or crushing, failure of specimen.

Plywood

Separation starts here and progresses as shown

Stiffener

Figure 7.- Path of separation in type 2 failure.

Fig. 7

Fig. 8

Figure 8.- Variation of average stress with the ratio $\dfrac{\text{Length of stiffener}}{\text{Depth of stiffener}}$ for specimens that developed type I or column failure.

Fig. 9
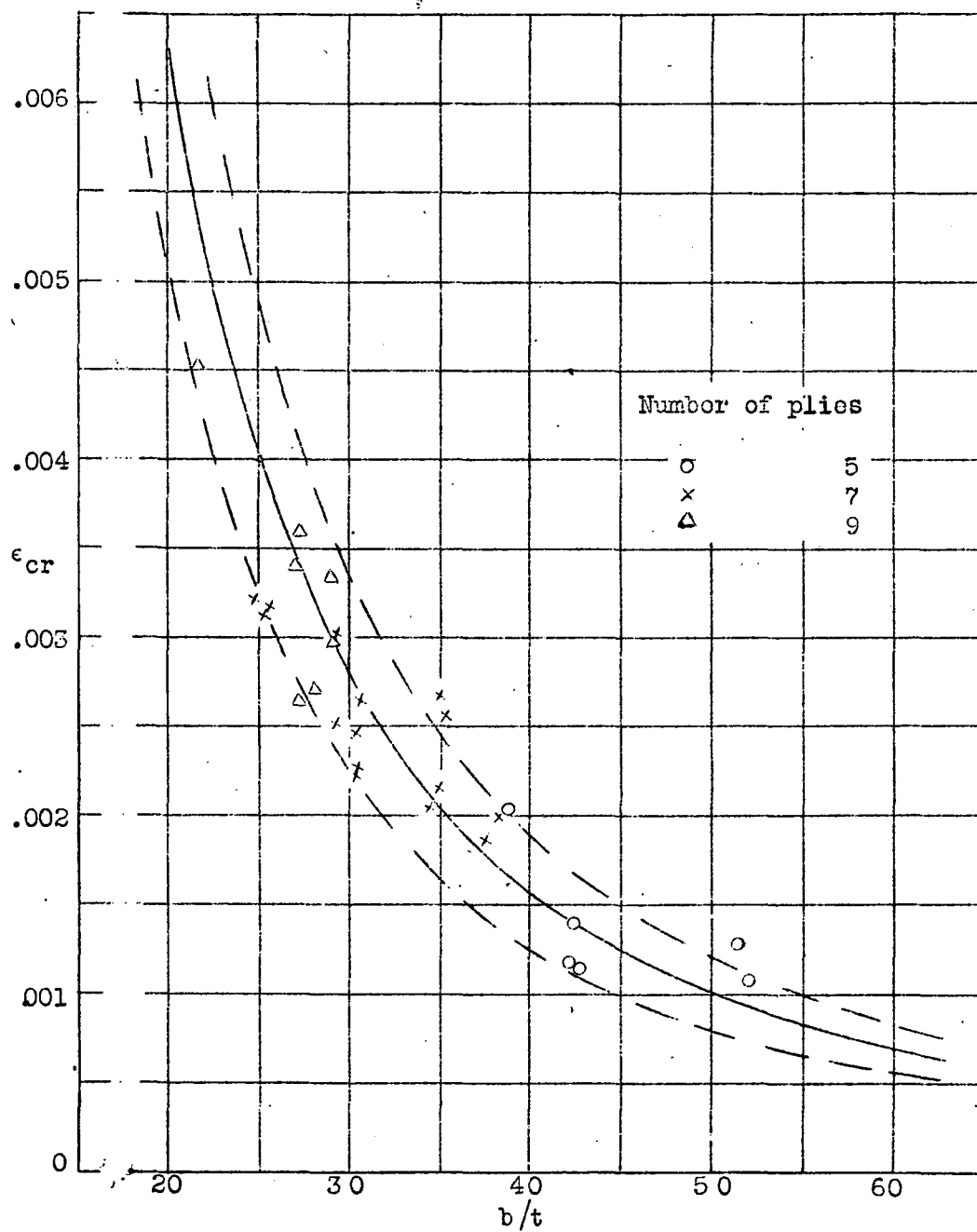
Figure 9.- Variation of critical strain for plywood with b/t.
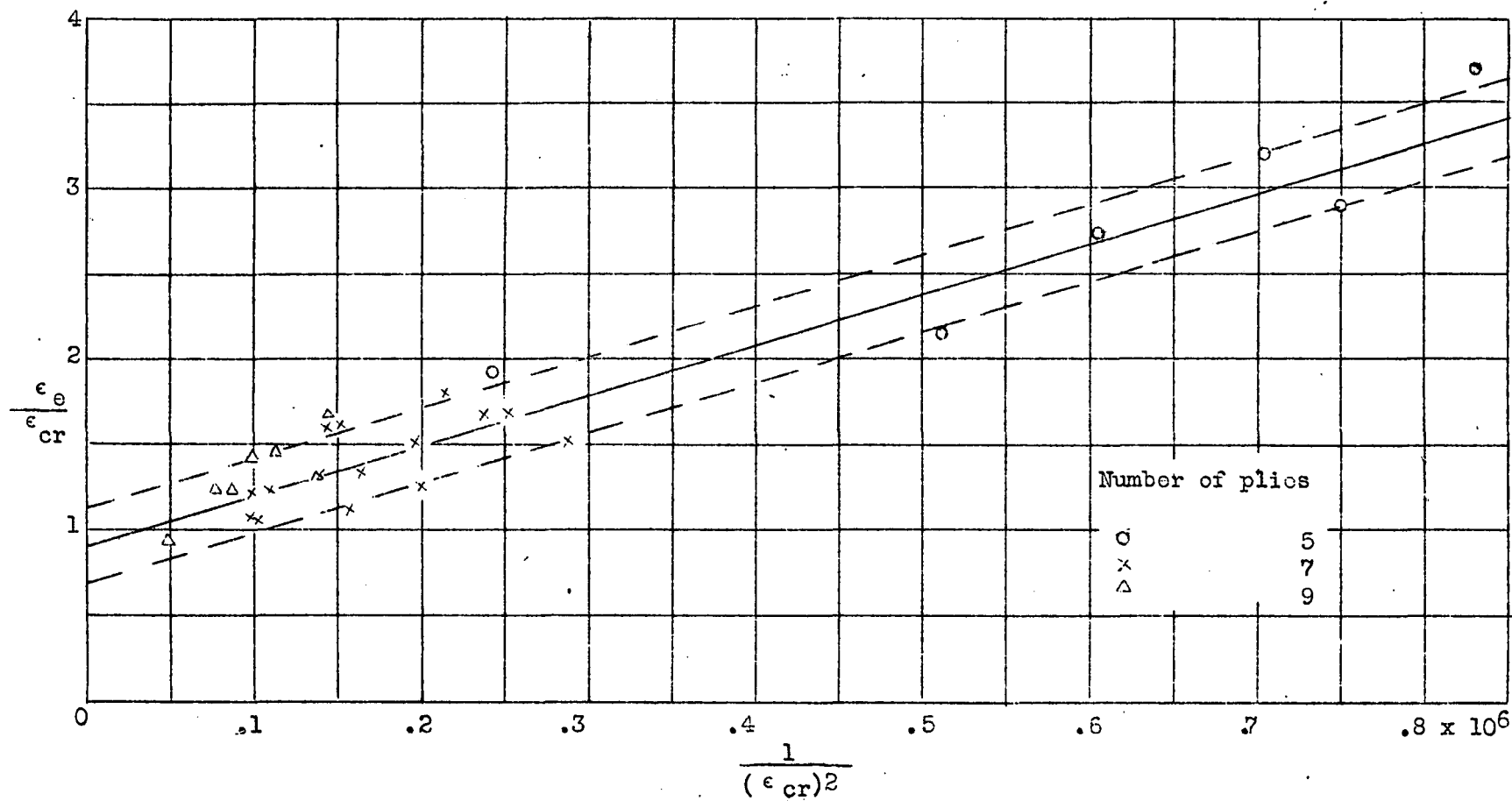
Figure 10.- Variation of $\dfrac{\epsilon_\theta}{\epsilon_{cr}}$ with $\dfrac{1}{(\epsilon_{cr})^2}$.

Fig. 10
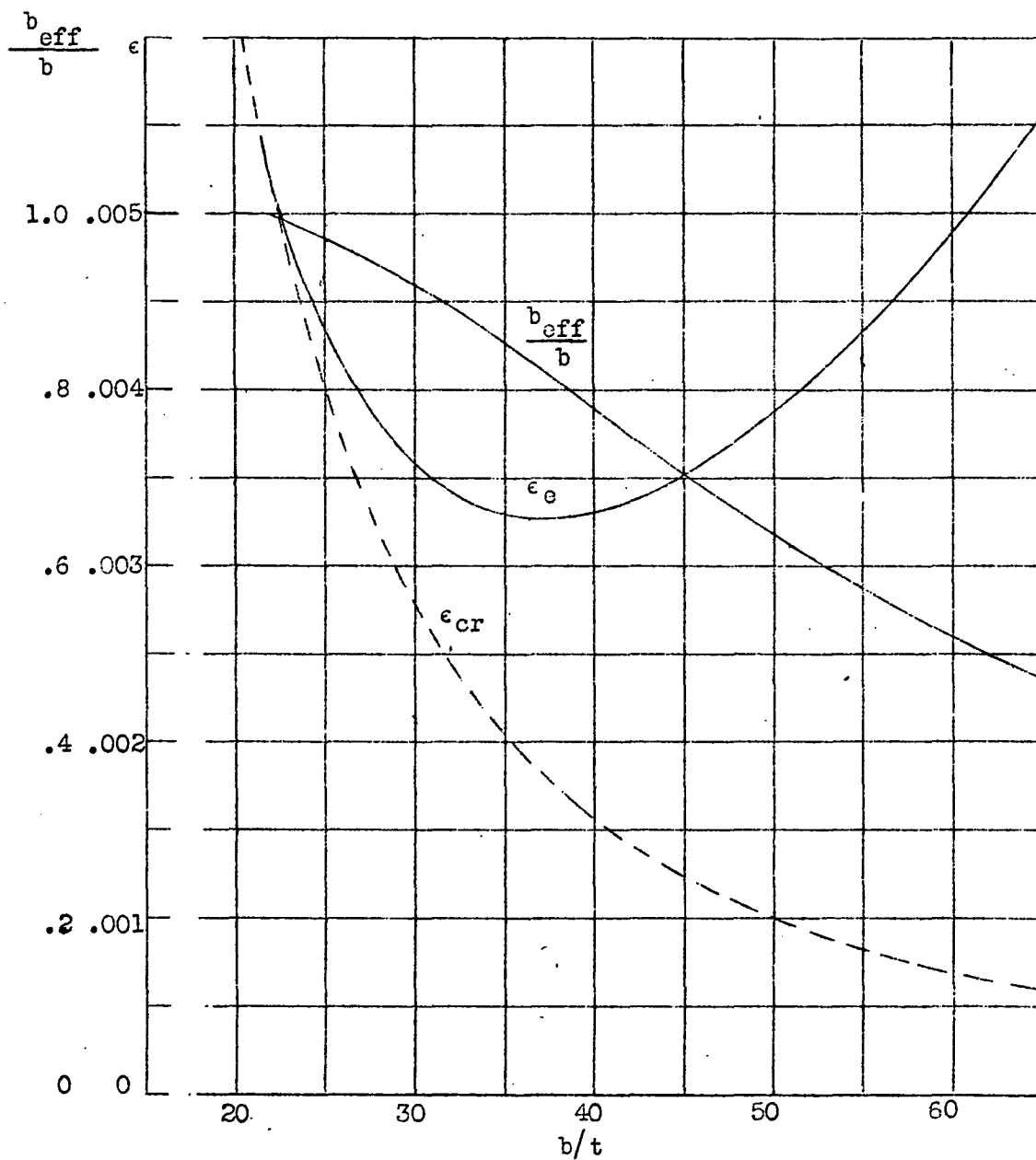
Figure 11.- Variation of ϵ_e, ϵ_{cr}, and $\dfrac{b_{eff}}{b}$ with $\dfrac{b}{t}$. Curve of $\dfrac{b_{eff}}{b}$ to be used for calculation of separation load only.
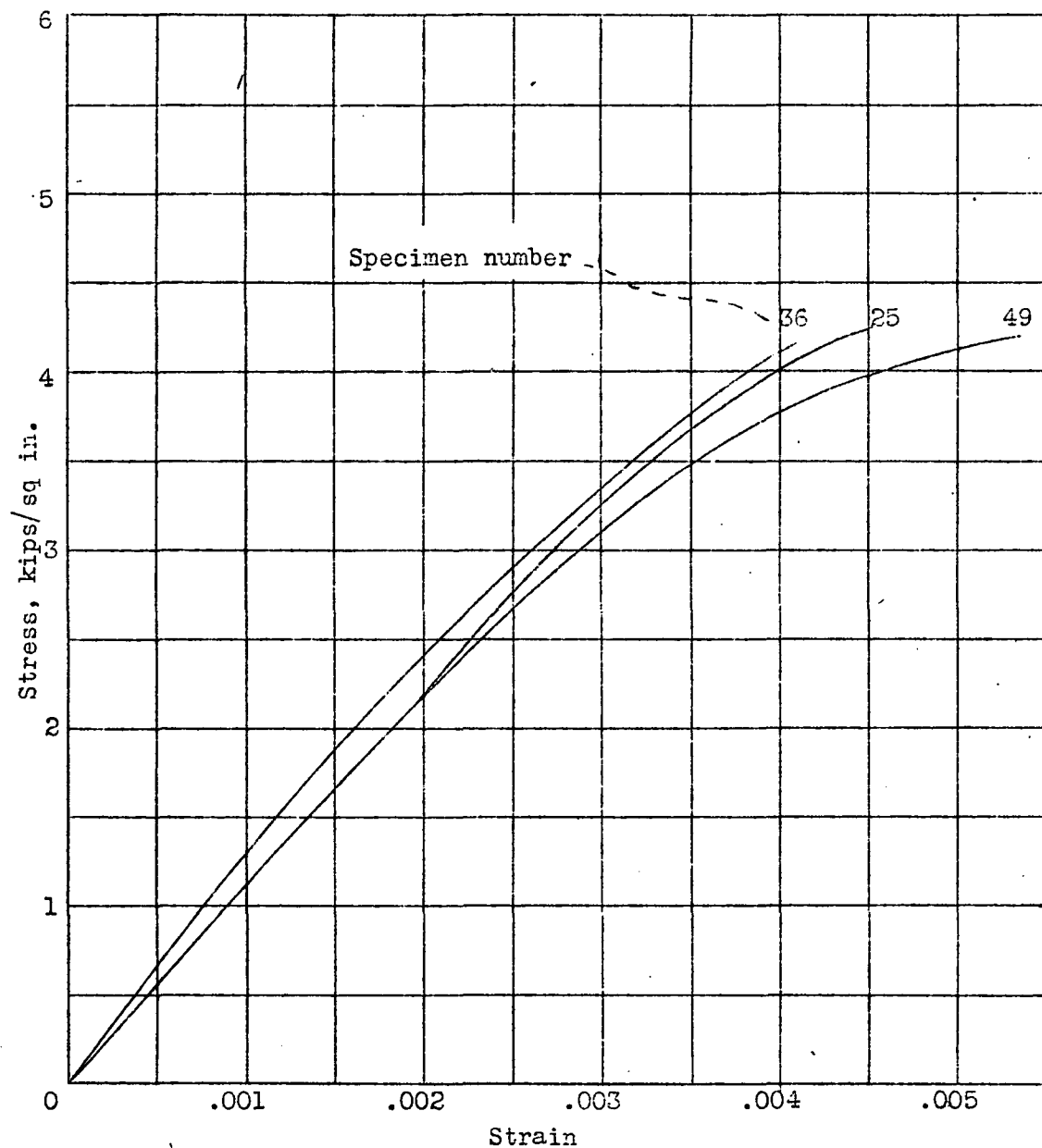
Figure 12.- Compressive stress-strain curves for stiffener material
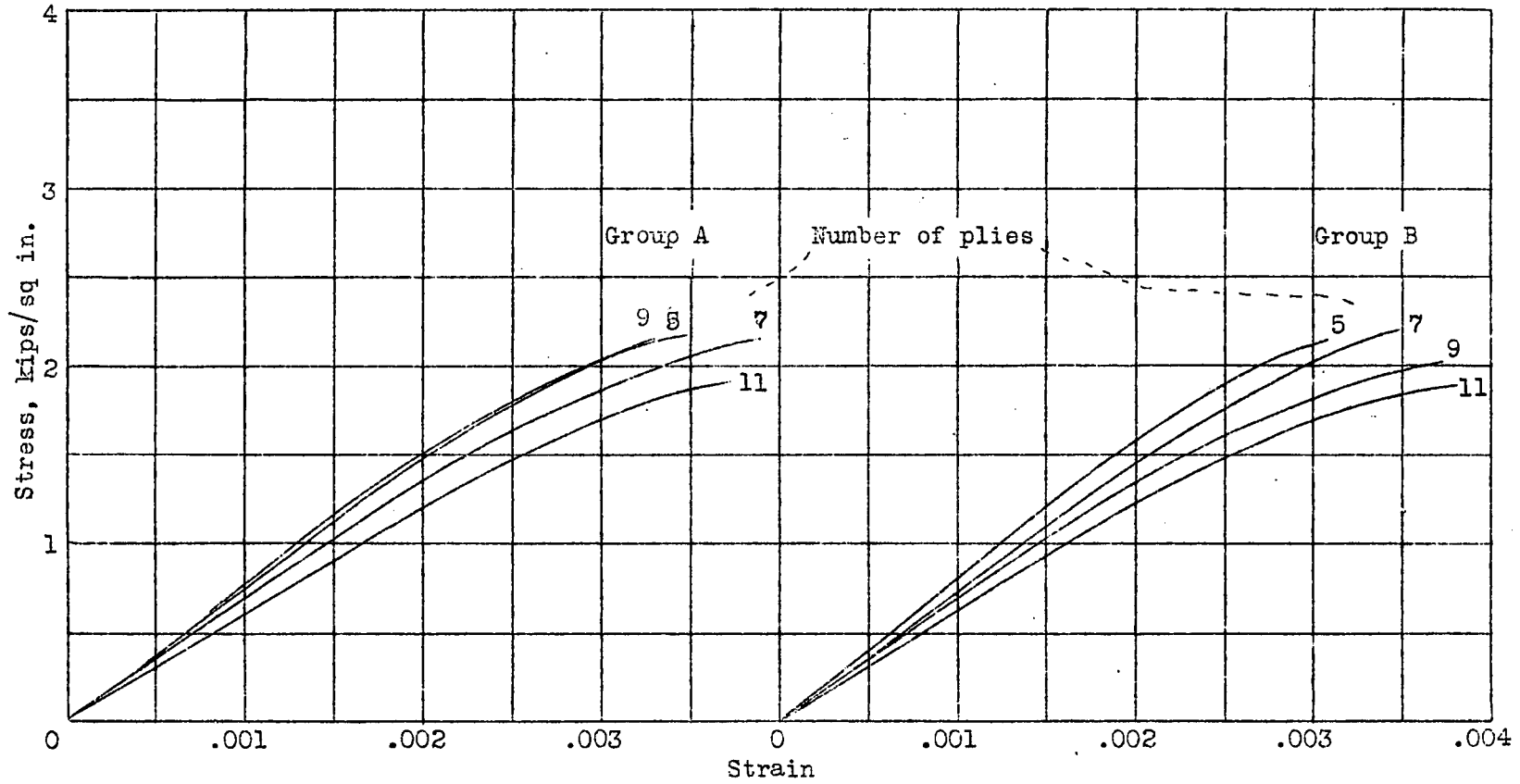loaded parallel to the grain adjusted to 15-percent
moisture content.

Figure 13.- Compressive stress-strain curves for plywood material loaded parallel to the face grain adjusted to 15-percent moisture content.
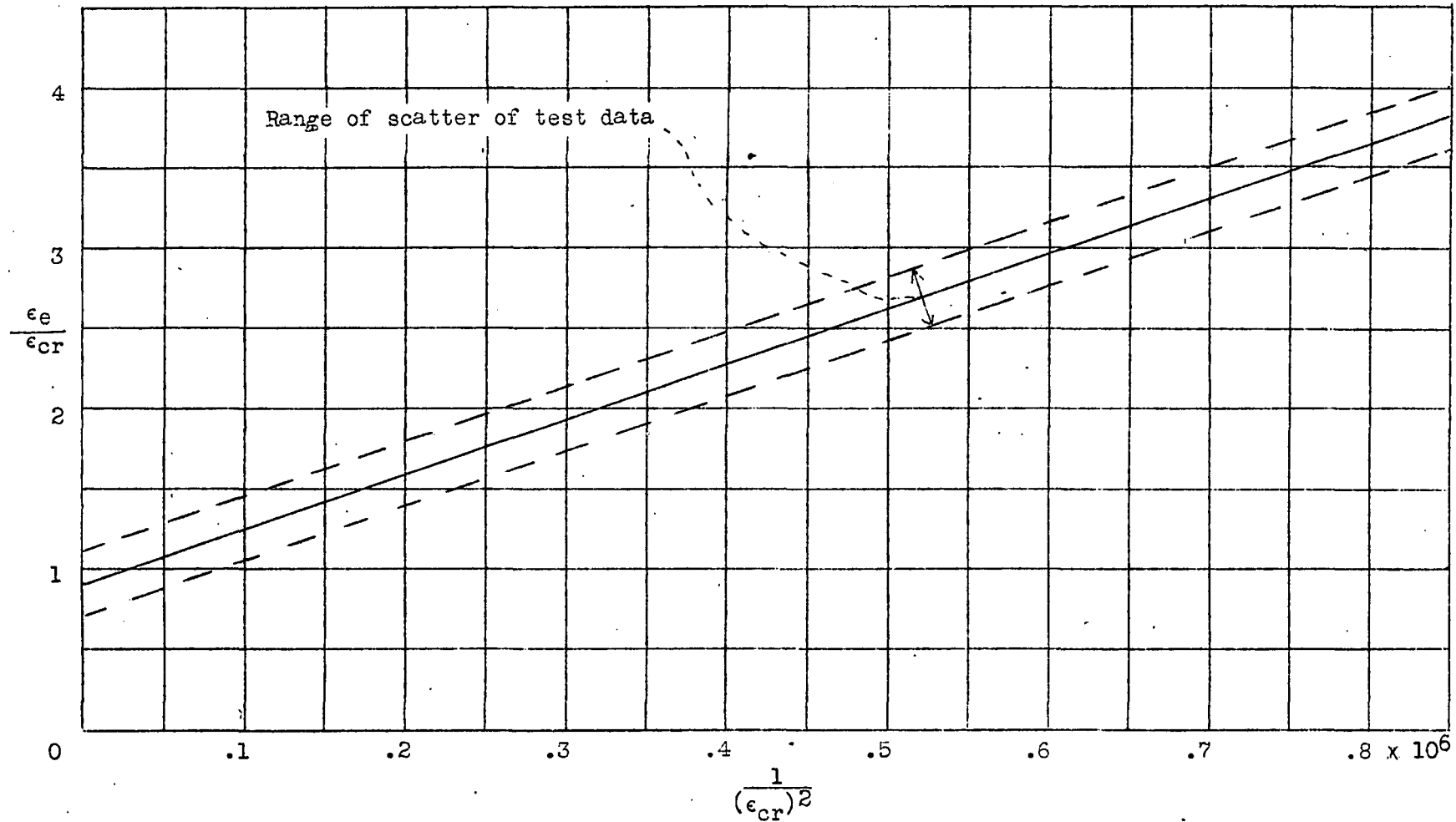
Fig. 13

Figure 14.- Variation of ϵ_e/ϵ_{cr} with $1/(\epsilon_{cr})^2$ for poplar plywood with 15-percent moisture content.

Fig. 14
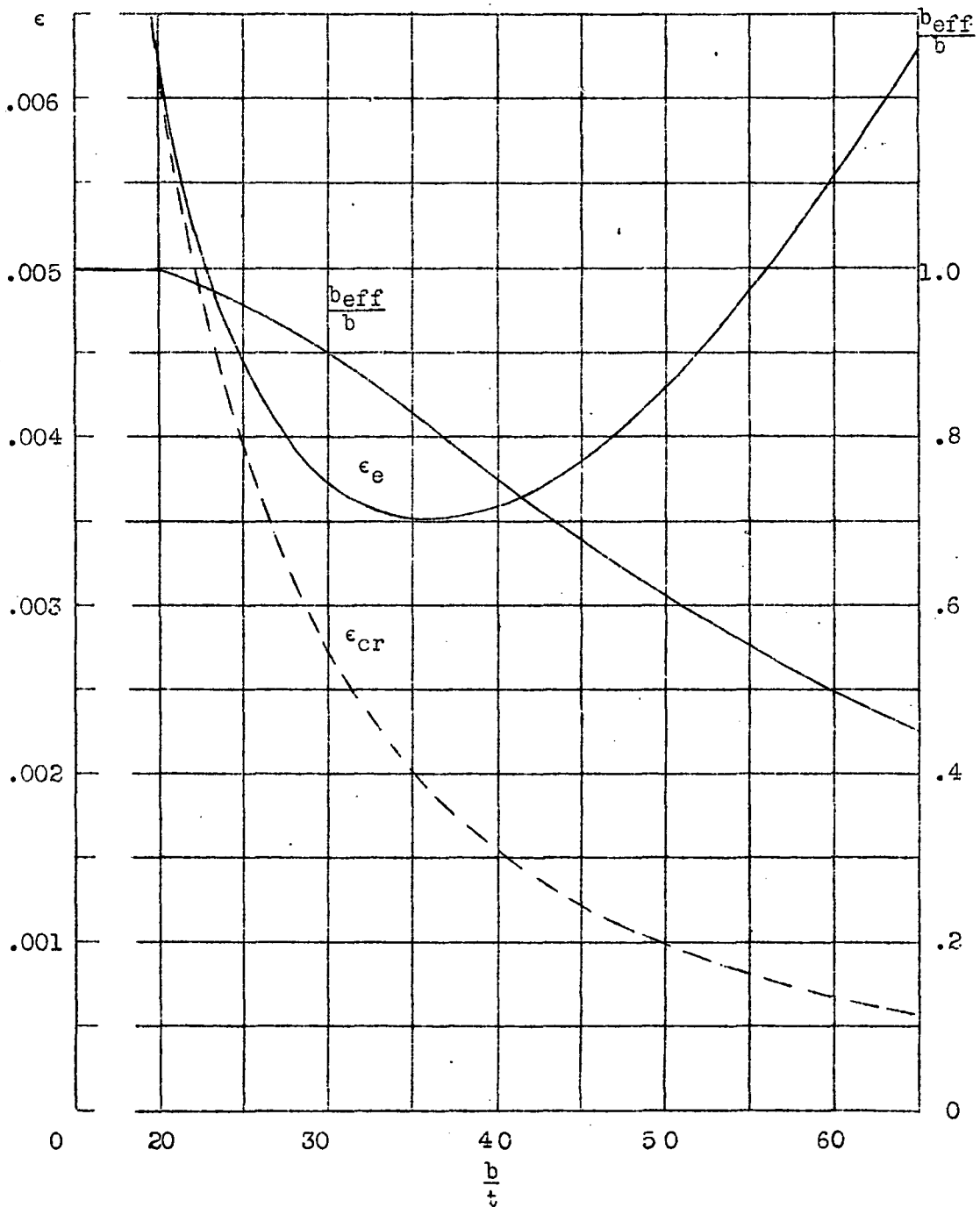
Figure 15.- Variation of ϵ_e, ϵ_{cr}, and b_{eff}/b with b/t for poplar plywood. Curves for ϵ_e and b_{eff}/b adjusted to 15-percent moisture content. Curve for b_{eff}/b to be used for calculation of separation load only.