INVESTIGATION OF DESIGN CRITERIA OF STIFFENED WOODEN PANELS

Thesis by

Lt. Comdr. W. E. Sweeney, U. S. N.

F/L E. P. Bridgland, R. C. A. F.

In Partial Fulfillment of the Requirements
for the Professional Degree in Aeronautical Engineering

California Institute of Technology
Pasadena, California

1943

ACKNOWLEDGMENT

The authors wish to express their gratitude to Dr. E. E. Sechler and Dr. L. G. Dunn of California Institute of Technology, for their many helpful suggestions and assistance in carrying out the research. Also they wish to thank the Fletcher Aviation Corporation, in particular Mr. L. W. Mosley, for supplying the wooden panels which were tested.

TABLE OF CONTENTS

SUBJECT		PAGE
	Summary	4
I	Introduction	5
II	Development of Research	
	1. Test Procedure	8
	2. Reduction Procedure	11
III	Discussion of Results	14
IV	Summary of Results	17
V	References	18
VI	Sample Calculations	19
VII	Index of Figures	21
VIII	Index of Photographs	22
IX	Summary of Data	23

SUMMARY

The aim of this research was to find design data for the stiffened plywood panels supplied by the Fletcher Aviation Company.

The tests included stiffened panel tests, unstiffened panel tests, and short column tests to find the physical properties of the material.

The results of these tests, show that the ultimate compression stress which the specimen will resist is of function of the percentage stiffener area compared to the total panel area, and the L/ρ ratio of the panel.

Predicted ultimate stresses from the curves developed show sufficiently good agreement with actual test, that they may be used for design purposes with allowance for descrepancies in material and workmanship.

INTRODUCTION

With the present war time emphasis on aircraft production and its consequent shortage of metal material, attention is directed toward the utilization of wood, plywood, and plastics in manufacturing planes. Since research in metal has developed materials very satisfactory for aircraft production, we find that wood for use in this field has not been fully investigated. The ANC Handbook on Wood Aircraft Structures, presents many theoretical formulae that should be used with caution until more data is available to corroborate or refute the formulae presented. Our aim was to investigate the design criteria of stiffened wooden panels.

Reference No. 2 includes the results of various tests made by the Fletcher Company on birch plywood and spruce stiffeners. Only a very few tests were made on stiffened plywood panels under compression. Also the data on wooden panel tests performed at Galcit by Mr. Chu and Denison were available. It was agreed that the Fletcher Aircraft Company would construct stiffened plywood panels of various lengths, stiffener sizes, and stiffener spacings, to be tested under compression, in order to determine, if possible, the effect of the above variables on the strength of the plywood panels. Also panels of various curvatures were included in the program. However, time permitted the construction and test of only a small part of the original program.

All panels tested were made of birch plywood with spruce stiffeners. The panel thickness was one-eighth of an inch which consisted of two plys glued together. The grain of the plywood ran at an angle of 25 degrees to the vertical, and the grain direction of the two ply was crossed so that the resultant angle between the grain directions of the two plys at any cross-section was 50° . The vertical direction as noted above is called with the grain, and all tests in compression were made on this axis. The panel is the strongest when tested with the grain, and expands the most across the grain.

No attempt was made to test perfect panels, because small panels always have some degree of warping. Attempts were made to hold the panel straight during tests and to load the panels as evenly as possible. The smaller the panels the greater the initial warping and thus could a greater scatter in results be expected for the smaller stiffener sizes.

The panels tested were numbered according to vertical length of panel, spacing between stiffeners, number of stiffeners, and size of stiffeners. Thus in examining the results of any panel test such as panel test No. 18631, one can ascertain from the number that the panel is 18 inches long, 6 inches spacing between stiffeners, 3 stiffeners, and size No. 1, which is the largest size. The panels tested for this report included those of three lengths, 6 inches, 12 inches, and 18 inches. The spacing between stiffeners was either 5 or 6 inches. The number of stiffeners in any panel was either 2 or 3. For each length of panel and stiffener spacing, a group of five panels of the different stiffener sizes was tested. These groups of five were not complete for the 5 inch stiffener spacing panels, because time was not available to allow for shifting test set-up, since a redesign of Huggenberger attachment is needed when spacing of stiffeners is below 4-1/2 inches.

The machine used for testing is shown in photograph No. 1, and is a Southwark 300,000 lb. machine. Control and accuracy allowable by this machine is excellent.

Information desired from the tests included mesurement of elongation as load was applied, critical stress, ultimate stress, variation of strength panels with length and stiffener reinforcements, effective width of panel with stiffener columns, and the correlation of test results with available information in ANC-5.

II DEVELOPMENT OF RESEARCH

A. Test Procedure

Prior to the commencement of the actual testing, preliminary tests were made to develop a suitable method. A description of these preliminary tests, along with a discussion of their advantages and disadvantages is included in this section for the reference of anyone who continues with this project. The discussion of the development will be divided into three sections.

1. Method of loading
2. Method of measuring deflection
3. Method of applying load.

While the first two of these items were developed together, it is considered well to discuss them separately for the sake of clearness. A satisfactory solution of the third item was never found, but the effect and limitation on the tests will be discussed.

1. Method of loading.

The first method of loading was to place the specimen between the two steel plates which are shown in photograph No. 4. The bottom plate rested on the platen of the testing machine and could be adjusted by putting shims underneath it. The upper plate was attached to the moving cross-head by means of two steel studs which passed through the hole in the center of the cross-head and was bolted to a plate which rested on the top of the cross-head. The face plates were then aligned by running a dial gauge between them to assure that they were parallel. The end panels of the specimens were held straight by means of the metal tubes which were clamped on the outside edges. These tubes offered no torsional restraint and took no compression, so that they merely prevented buckling.

Difficulty was encountered in keeping the specimens flat while putting them in the machine, due to their initial warping. The first attempt to overcome this was to clamp them between two "two-by-fours" which were bolted together. The specimen was then put under an initial load and the "two-by-fours" removed. Then the end tubes and the huggenbergers were attached to the specimen. This method had the following disadvantages:

a. The "two-by-fours" made it difficult to set the specimen perpendicular to the face plates.

b. A large initial load was required to prevent the specimens from warping. In some cases, it was impossible to prevent the end panels from warping.

c. In the event of unequal loading, all gauges and end restraint had to be removed and the two-by-fours put on before the load could be released so that shims could be inserted under the specimen.

The final method of loading comprised the design of end damps shown in photo No. 3. The clamps were made of 1/4" steel plate with slots milled in them to go around the stiffeners. While these clamps introduced a certain amount of end restraint, it was considered preferable to have a constant end restraint rather than no restraint with uneven panel loading.

2. Method of measuring deflection.

Throughout the whole project, two deflections were measured; first the overall deflection of the panel, that is the movement of the cross-head and secondly the unit deflection of the stiffener. The first measurement was only used as an indication of buckling during the test, except for the case where "E" was measured for the spruce stiffeners, and the unit deflection was calculated from the dial gauge as well as the Huggenbergers. The unit deflection was the more difficult to obtain. The first method which was tried consisted of fastening a dial gauge at one point on the stiffener and putting a bracket at another point so that the dial gauge registered the deflection of the stiffener between these two points. As the axis of the dial gauge was about one and one-half inches from the neutral axis of the stiffener, any bending magnified the dial gauge reading so as to make the axial deflection undertain.

Another method being preferable, Huggenberger extensometers were tried. As the panels then under consideration had four inch stiffener spacing it was impossible to mount the Huggenbergers in the conventional manner, so the method shown in photograph No. 4 was tried. This method suffered from the same bending errors as the first method, although an average Huggenberger reading gave better results than the dial gauge.

It was then considered desirable to mount the Huggenbergers in the conventional manner shown in photograph No. 2. This limited the minimum spacing between the edges of the stiffeners to four and one-half inches. This method was used for all of the stiffened panels.

The method used to measure axial deflection of the non-stiffened panels is shown in photograph No. 3. In addition to measuring the axial deflection, the lateral deflection was measured by the two-dial gauges shown in photograph No. 3.

The elastic modulus of both the spruce and plywood was found by using Huggenbergers on short columns to measure the axial deflection. The plywood column was made up of eight thicknesses of plywood glued together. The axial deflection was also measured by the dial gauge on the cross-head.

3. Method of Applying Load.

The load was applied in equal increments, the size of the increment depending on the size of the specimen. It was observed that the rate of loading has a large effect on the value of the ultimate stress. Ref. 2, page 1.214 Specs. 17 and 20 show an increase in ultimate stress of approximately 20% due to an increase in rate of loading. Throughout the tests it was impossible to keep a steady rate of loading because of the time required to read the Huggenbergers. However, a slow and nearly constant rate of loading was maintained during loading of increments.

B. Reduction Procedure.

1. Stiffened Panel Tests.

In these tests the following data was recorded:

a. Load

b. Total deflection

c. Unit deflection of stiffener.

Figs. 12 - 30 were developed in the following manner:

1. The average Huggenberger reading was multiplied by the average Huggenberger constant to get the stiffener strain.

2. The stiffener stress was computed from the stiffener strain and the modulus of elasticity found from test.

3. The stiffener load was computed from stiffener area including the plywood adjacent to the column and the stiffener stress.

4. The sheet load was computed by subtracting the stiffener load from the total load.

5. The sheet load and total load were plotted against stiffener strain on figures 12 - 30.

The results obtained for the critical stress of the unstiffened panels, together with the results of the stiffened panel tests showed that the effective width method used for metal panels was not applicable. Therefore, another method of working up the design data was necessary. The method suggested was to find the ultimate stress as a function of the percent reinforcement of the panel by the stiffeners. This relationship is shown in Figs. 7 and 8. Three curves are plotted, one for each length of panel. From these curves and the type of failure which occurred, it became apparent that the ultimate stress was also a function of the L/ρ of the panel. These curves also show good agreement with Ref. 2.

In order to show the ultimate stress as a function of A_S/A_T and L/ρ, Fig. 2 was plotted giving lines of constant ultimate stress as a function of the two variables. From Fig. 2 the data was cross-plotted onto figure 1 to give the ultimate stress as a function of L/ρ for constant A_S/A_T. This gives design data which may be applied to this type of plywood panel. The table in the summary of data shows the percentage difference between the predicted values and the test values for the ultimate stress. Figure 1a shows the percent agreement of actual stress with stress predicted from Figure 1.

2. Unstiffened Panel Tests.

The following data was recorded

a. Load

b. Axial deflection

c. Lateral deflection

The axial deflection divided by the load was plotted against axial deflection. The value of critical buckling stress was obtained from the slope of this curve. The results of these tests are included in the data.

3. E Tests.

The following data were recorded

a. Load

b. Total axial deflection

c. Unit axial deflection

d. Lateral deflection (plywood tests only)

The stress strain curves were developed in the following manner:

1. The strain was computed by the following methods.

   a. The average Huggenberger reading was multiplied by the average Huggenberger constant.

   b. The total axial deflection was divided by the length of the specimen.

2. The stress was computed dividing the load by the cross-sectional area of the stiffener.

Then the stress strain curves were plotted.

Spruce - Fig. 11

Plywood - Figs. 9 - 10

The average slopes of these curves give the value of "E".

III DISCUSSION OF RESULTS

Since we found that the ultimate stress of the plywood panel unstiffened was stronger than the ultimate stress of the spruce stiffeners, our results were not calculated along the conventional assumption of effective panel widths acting with the stiffeners. Reference (1), the ANC Handbook, lists its results from the effective width analysis only, so we could not compare our results with any available data.

Fig. (1) represents one method of predicting ultimate stiffened panel stresses by knowing the geometrical characteristics of the panel, that is L/ρ, A_S - stiffener area, and A_T - total area of stiffeners and sheet. These lines were cross plotted from figure (2), where ultimate stress lines were plotted through the average results of all panels tested. Fig. 1(a) shows the percent agreement between test results, and that predicted by figure (1).

Fig. (3) contains the resultant of the plots shown in figures (4), (5), and (6). The slope of the ultimate stress vs. L/ρ lines is fairly constant, and checks with the slope of the lines in figure (1).

Figures (8) and (9) show the relationship between percent reinforcement represented by A_S/A_T and ultimate stress of the panels tested for each different length of panel, 6, 12, and 18 inch heights. From these lines we can note that the top of the line or curve was not reached. This means that further tests of panels, which contain a higher percentage of stiffener area, should show the most effective stiffener area for any given panel. Since the panels buckled or failed when the stiffeners failed, the data presented would lead to the surmise that the lines could be extended to the ultimate stress of spruce stiffeners about 5,000 lbs./sq.in., and the most effective percent reinforcement would be about 60 percent.

Column compression tests were made on plywood specimens, inch square by 6 inch length. These columns were made up of 8 layers of 1/8 inch ply, each layer separated by glue. The results of the tests shown in figures (9) and (10) gave us an E of 1,100,000 for this birch plywood. Attempts were also made to get Poisson's Ratio for the plywood. The results were uniform in that great expansion was measured in the direction across the grain, in the plane of the panel widths. Also compression or necking down was noticed in all tests of elongation normal to the panel widths. These tests are not the only instances where contraction normal to the width of the panel has been noticed. This plywood is so constructed that its greatest strength is with the grain and its greatest expansion is in the direction across the grain. Apparently so much expansion takes place across the grain in the plane of the panel that the thickness of the plywood panel is decreased.

In figure (11) is shown the results of tests on spruce stiffeners. These tests resulted in the E for this type spruce as being equal to 1,450,000.

Figures (12) through (30) include the test results of all the panel tests. The tests show a plot of load in pounds versus elongation in ten thousandths. Also the load taken by panel sheet was calculated and plotted versus elongation. Some of the non-uniformity in results can be laid to the initial buckling present in the plywood panels, before testing. In some cases where the loading was not quite uniform, one panel section would fail first, hastening the total failure of the entire panel. These cases are shown on the data sheet where the percent scatter from that predicted is quite large.

In an attempt to find the critical buckling stress of this plywood, tests were made on unstiffened panels, the results being shown by figures (31) through (34). As shown on the data sheet the critical stress for all panels of width 6 inches varied with length of the specimen. According to theory all panels of the same width between supports should have the same critical stress. However, the irregularities in the panel construction and the initial stresses present in the panels due to warping, made a variation in results most likely. The longer the panel, the more likely there was to be premature bending. The 12 inch width panel should have one-fourth the critical stress of the 6 inch panel, and shows close agreement. Due to the limited tests made and the difficulty of testing long plywood panels due to bending, no definite critical stress was found.

As was noted during the testing of all panels, after buckling starts, the ultimate load that the panel will take depends on the speed of loading. In the tests listed, the loading was performed in 4 or 5 hundred pound increments, and then stops were made for readings. No definite rate of loading was made, other than the definite stops, so that no part of the irregularity in ultimate loads can be traced to this item.

IV SUMMARY OF RESULTS

A method for predicting the ultimate load and ultimate buckling stress from the knowledge of the geometrical properties of the panel was derived for this type of plywood and stiffener. The modulus of elasticity for the birch plywood and for the spruce stiffeners was found to be 1,100,000 and 1,450,000 respectively, both in psi

Since only a small portion of the original test program was completed, many items were left for future research. Poisson's ratio should prove an interesting study since there was necking down in evidence in one direction in the compression tests. Increase in percent reinforcement should give higher ultimate stresses. A definite critical buckling stress was not determined from the limited tests performed, but the effect of length of specimen was noted. An investigation into the effect of rate of loading on the ultimate values was not performed. The design criteria for curved panels contains interest for further research.

V REFERENCES

1. SECHLER & DUNN, Airplane Structural Analysis and Design.

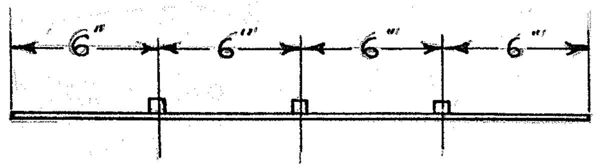
2. Fletcher Aviation Corporation, Report No. 20, Structural Tests.

3. ANC Hand book on the Design of Wood Aircraft Structures. (Restricted)

4. Wood Aircraft Fabrication Manual. (Restricted)

VI SAMPLE CALCULATIONS

Panel: No. 6634 - Fig. 13



Data: Length - 6"

Stiffener Spacing - 6"

No. of Stiffeners - 3

Stiffener Size - 1/2" x 1/2"

SPECIMEN No. 6634

(1) Load	(2)	(3)	(4)	(5)	(6)	(7)	(8) Average Diff.	(9) E x 10^4	(10) σ_{ST}	(11) P_{ST}	(12) P_{SH}
	Huggenberger Readings										
0	40.0	40.5	36.5	37.5	42.0	41.0	0	0	0	0	0
1000	39.0	38.5	35.5	35.5	41.0	39.0	1.5	2.51	364	342	658
2000	36.0	35.0	34.0	34.0	39.5	38.0	3.5	5.86	850	800	1200
3000	33.5	32.0	33.0	33.0	38.5	36.5	5.2	8.7	1260	1180	1820
4000	31.5	30.0	32.0	31.5	37.0	35.0	6.8	11.4	1650	1550	2450
5000	30.0	28.0	31.0	30.5	36.0	34.0	8.0	13.4	1940	1820	3180
6000	28.5	27.0	30.0	29.5	34.5	32.0	9.3	15.6	2260	2120	3880
7000	27.0	25.0	29.0	28.0	32.5	30.5	10.9	18.3	2660	2500	4500
8000	25.0	23.5	28.0	27.0	31.0	29.0	12.3	20.6	2990	28.0	5190
9000	23.5	21.5	27.0	25.5	29.5	27.0	13.9	23.3	3380	3180	5820
10000	21.0	20.0	25.5	24.5	28.0	25.5	15.5	26.0	3770	3550	6450
11000	28.5	16.5	24.0	23.0	26.0	23.0	17.7	29.6	4300	4040	6960
12000	-	-	23.0	22.0	25.0	22.0	21.2	35.5	5150	4840	7160
12750		- - - - - Ultimate									

(1) Load measured on machine

(2)-(7) Huggenberger readings

(8) Average difference of Huggenberger readings

(9) Strain = (8) x Huggenberger constant

(10) Stiffener stress = (9) x E.

(11) Stiffener load = (10) x A_{ST}

(12) Sheet load = (1) - (11)

1. Percent Reinforcement.

Sheet Area $A_{SH} = 24 \times 1/8 = 3.0$ sq. in.

Stiffener Area $A_{ST} = 3 \times 1/2 \times 1/2 = .75$ sq.in.

Total Area A_T = 3.75 sq.in.

Percent Reinforcement $\frac{A_S}{A_T} = \frac{0.75}{3.75} = .200$

2. Determination of L/ρ .

(1) Neutral Axis

$$Q = 24 \times 1/8 \times 1/16 - 3 \times 1/2 \times 1/2 \times 1/4$$

$$= .187 - .187 = 0$$

$$\bar{y} = \frac{Q}{A} = \frac{0}{3.75} = 0$$

(2) $I = I \qquad = A\ (\bar{x})^2$

$$= \frac{24}{3} \times (1/8)^3 + 3 \times 1/2 \times 1/3 \times (1/2)^3$$

$$= \frac{1}{64} + \frac{1}{16} = .0156 + .0625 = .0781 \text{ in.}^4$$

$$\rho^2 = \frac{I}{A} = \frac{.0781}{3.75} = .0208$$

$$\rho = \quad .0208 = .145$$

$$L/\rho = \frac{6}{0.145} = 41.5$$

VII INDEX OF FIGURES

TITLE	FIGURE
Ultimate Stress vs. L/ρ for constant A_S/A_T	(1)
Constant ultimate Stress Lines for L/ρ and A_S/A_T	(2)
Ultimate Stress vs. L/ρ of Panels Tested	(3) - (6)
Ultimate Stress vs. Percent Reinforcement	(7) - (8)
"E" Tests - Plywood Columns	(9) - (10)
"E" Tests - Spruce Stiffeners	(11)
Panel Tests	(12) - (30)
Unstiffened Panel Tests	(31) - (34)

VIII INDEX OF PHOTOGRAPHS

I - General View

II - Stiffened Panel Test

III - Unstiffened Panel Test

IV - Original Panel Test

SUMMARY OF DATA

Test Panel	STIFFENERS Length	Spacing	Number	Size	$\frac{L}{P}$	Ultimate Load	AREAS A_T	A_{S_T}	$\frac{A_S}{A_T}$	Ult.	Predicted Ult.	Percent Scatter
6621	6	6	2	3/4 x 1	18	14,550	3.75	1.69	.4	3880	3980	+ 2.58
6622	6	6	2	3/4 x 3/4	27	12,100	3.37	1.31	.332	3590	3650	+ 1.67
6623	6	6	2	1/2 x 3/4	27.3	8,820	3.00	.875	.25	2940	3320	+12.9
6624	6	6	2	1/2 x 1/2	42.5	7,640	2.70	.625	.182	2780	2890	+ 4.0
6625	6	6	2	1/4 x 1/2	55	5,600	2.50	.312	.10	2240	2430	+ 8.5
12621	12	6	2	3/4 x 1	36	12,600	3.75	1.69	.4	3360	3780	+12.5
12622	12	6	2	3/4 x 3/4	52.7	10,800	3.37	1.31	.332	3200	3380	+ 5.6
12623	12	6	2	1/2 x 3/4	55	8,000	3.00	.875	.25	2670	3040	+13.8
12624	12	6	2	1/2 x 1/2	85	6,980	2.70	.625	.182	2580	2440	- 5.4
12625	12	6	2	1/4 x 1/2	110	5,040	2.5	.312	.10	1910	1840	- 3.7
18621	18	6	2	3/4 x 1	54	11,600	3.75	1.69	.4	3100	3600	+16
18622	18	6	2	3/4 x 3/4	80.5	10,680	3.37	1.31	.332	3160	3070	- 2.8
18623	18	6	2	1/2 x 3/4	82	8,750	3.00	.875	.25	2920	2750	- 5.8
18624	18	6	2	1/2 x 1/2	127.5	5,250	2.70	.625	.182	1945	1980	+ 1.8
18625	18	6	2	1/4 x 1/2	165	3,600	2.50	.312	.10	1440	1270	-12

SUMMARY OF DATA
(Continued)

Test Panel	STIFFENERS Length	Spacing	Number	Size	$\frac{L}{P}$	Ultimate Load	AREAS A_T	A_{S_T}	$\frac{A_S}{A_T}$	Ult.	Predicted Ult.	Percent Scatter
6631	6	6	3	3/4 x 1	20	22,200	5.25	2.53	.429	4230	4100	- 3.1
6632	6	6	3	3/4 x 3/4	24	16,000	4.68	1.97	.36	3420	3760	+10.0
6633	6	6	3	1/2 x 3/4	26	13,800	4.12	1.31	.272	3350	3430	+ 2.4
6634	6	6	3	1/2 x 1/2	41	12,750	3.75	.94	.20	3300	2980	- 9.7
6635	6	6	3	1/4 x 1/2	51	9,980	3.38	.472	.111	2950	2520	-14.5
12631	12	6	3	3/4 x 1	35.3	21,000	5.25	2.53	.429	4000	3920	- 0.2
12632	12	6	3	3/4 x 3/4	48	18,000	4.68	1.97	.36	3840	3510	- 8.6
12633	12	6	3	1/2 x 3/4	52.5	13,150	4.12	1.31	.272	3180	3140	- 0.13
12634	12	6	3	1/2 x 1/2	83	8,940	3.75	.94	.20	2380	2530	+ 6.3
12635	12	6	3	1/4 x 1/2	102	7,200	3.38	.472	.11	2130	1980	- 7.0
18631	18	6	3	3/4 x 1	53	25,000	5.25	2.53	.429	4760	3720	-21
18632	18	6	3	3/4 x 3/4	72	16,050	4.68	1.97	.36	3420	3150	- 7.9
18633	18	6	3	1/2 x 3/4	79	13,000	4.12	1.31	.272	3150	2850	- 9.5
18634	18	6	3	1/2 x 1/2	123	5,810	3.75	.94	.20	1550	2120	+37
18635	18	6	3	1/4 x 1/2	153	5,150	3.38	.472	.11	1530	1440	- 5.9

SUMMARY OF DATA
(Continued)

Test Panel	STIFFENERS Length	Spacing	Number	Size	$\frac{L}{P}$	Ultimate Load	AREAS A_T	A_{S_T}	$\frac{A_S}{A_T}$	Ult.	Predicted Ult.	Percent Scatter
6523	6	5	2	1/2 x 3/4	26	9,600	2.63	.875	.285	3640	3490	- 4.1
6524	6	5	2	1/2 x 1/2	40.5	7,580	2.38	.625	.21	3180	3030	- 4.7
6525	6	5	2	1/4 x 1/2	51	5,000	2.12	.312	.118	2360	2550	+ 8.0
12523	12	5	2	1/2 x 3/4	52	8,700	2.63	.875	.285	3300	3210	- 0.27
12524	12	5	2	1/2 x 1/2	81	6,000	2.38	.625	.21	2520	2600	+ 0.32
12525	12	5	2	1/4 x 1/2	102	5,200	2.12	.312	.118	2450	2010	-18
18523	18	5	2	1/2 x 3/4	78.5	7,000	2.63	.875	.285	2660	2910	+ 9.4
18524	18	5	2	1/2 x 1/2	121	5,330	2.38	.625	.21	2240	2180	- 2.7
18525	18	5	2	1/4 x 1/2	153	4,380	2.12	.312	.118	2070	1480	-28

Results of Unstiffened Panel Tests

6" x 6" x 1/8"

Test	6	= 3680	#/in.^{2}
Test	7	= 3500	#/in.^{2}
Test	10	= 2960	#/in.^{2}

12" x 6" x 1/8"

Test	3	= 5330	#/in.^{2}
Test	12	= 5330	#/in.^{2}

18" x 6" x 1/8"

Test	5	= 3140	#/in.^{2}

12" x 12" x 1/8"

Test	13	= 1600	#/in.^{2}

Note: Size is designated by length x width x thickness.

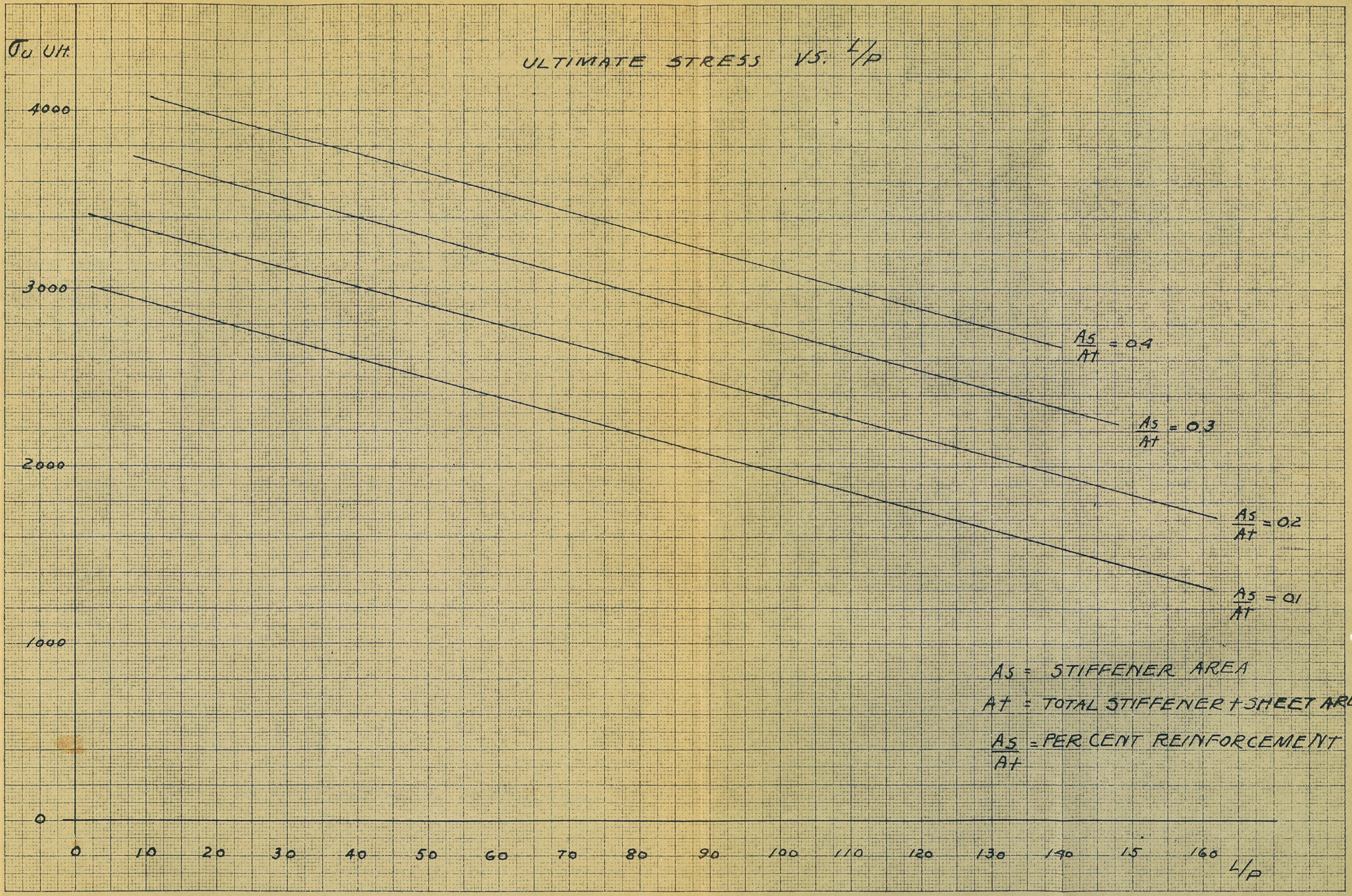

σu ult.
ULTIMATE STRESS VS. L/ρ
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
15
160
L/ρ
As/At = 0.4
As/At = 0.3
As/At = 0.2
As/At = 0.1
As = STIFFENER AREA
At = TOTAL STIFFENER + SHEET AREA
As/At = PER CENT REINFORCEMENT

Fig. 1

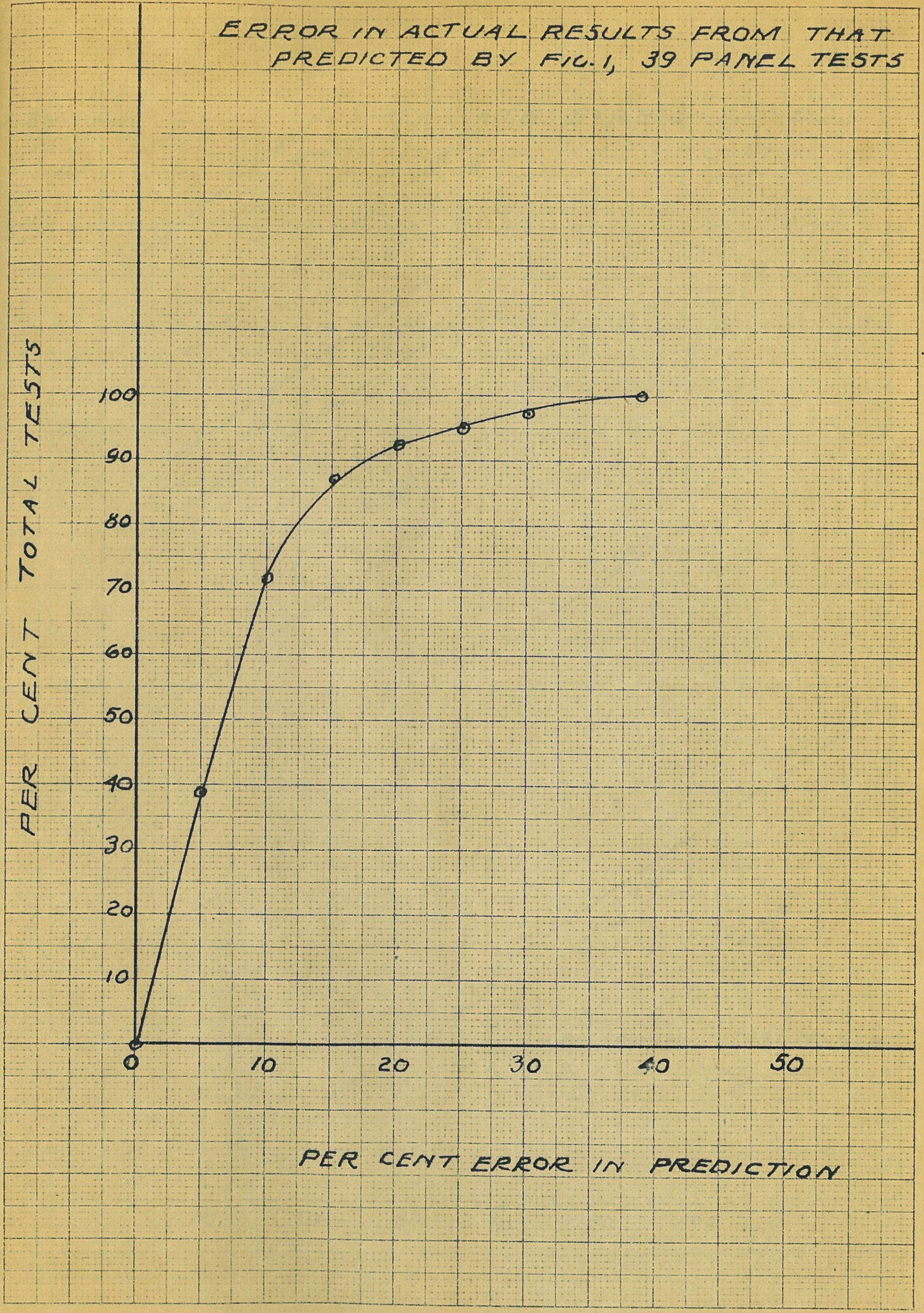

ERROR IN ACTUAL RESULTS FROM THAT PREDICTED BY FIG. 1, 39 PANEL TESTS
PER CENT TOTAL TESTS
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
PER CENT ERROR IN PREDICTION

Fig. 1(a)

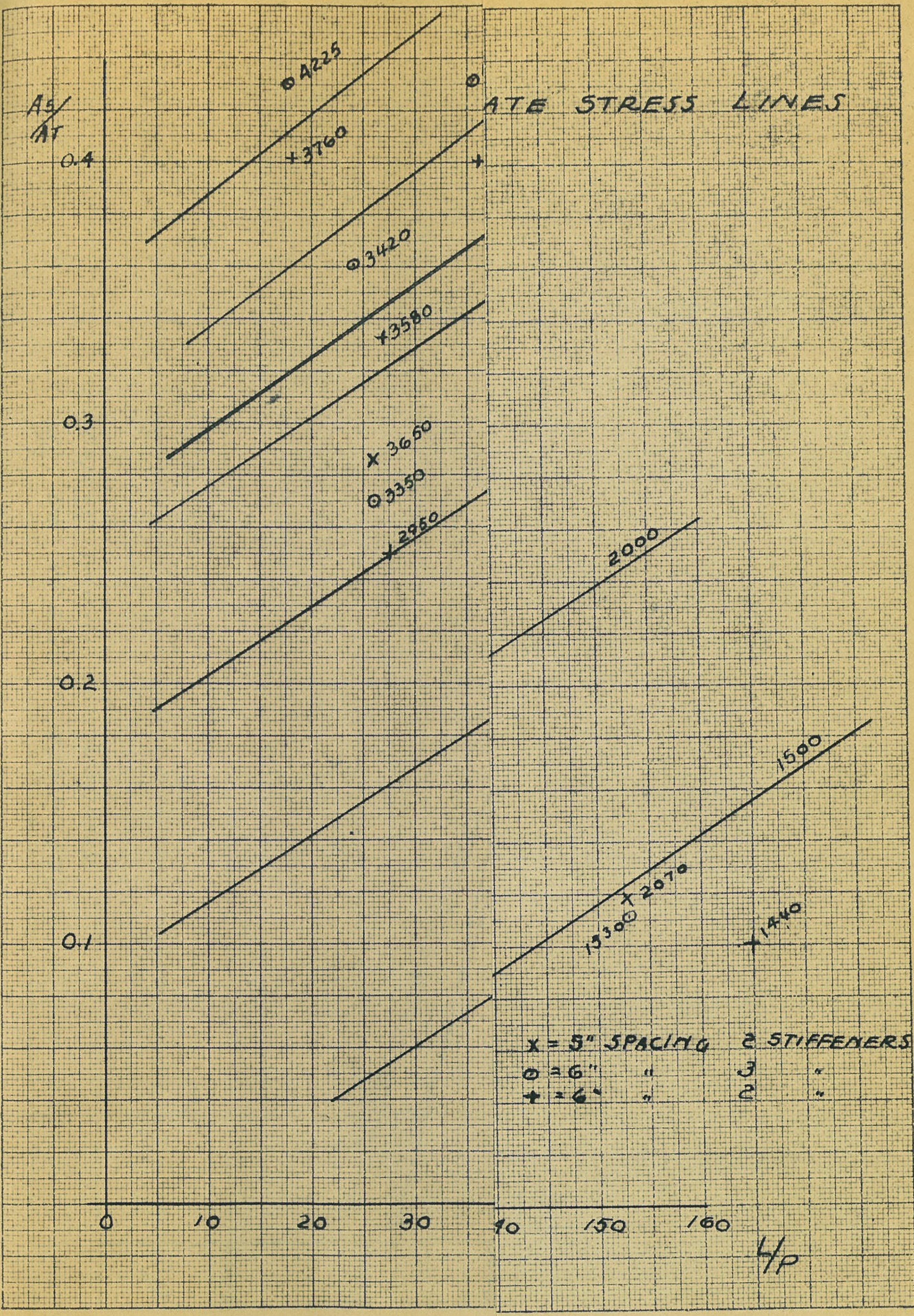

ATE STRESS LINES
As/At
0.4
0.3
0.2
0.1
o 4225
+ 3760
o 3420
+ 3580
x 3660
o 3350
x 2950
2000
1500
x 2070
15300
+ 1440
x = 5" SPACING 2 STIFFENERS
o = 6" " 3 "
+ = 6" " 2 "
0
10
20
30
40
150
160
L/P

Fig 2

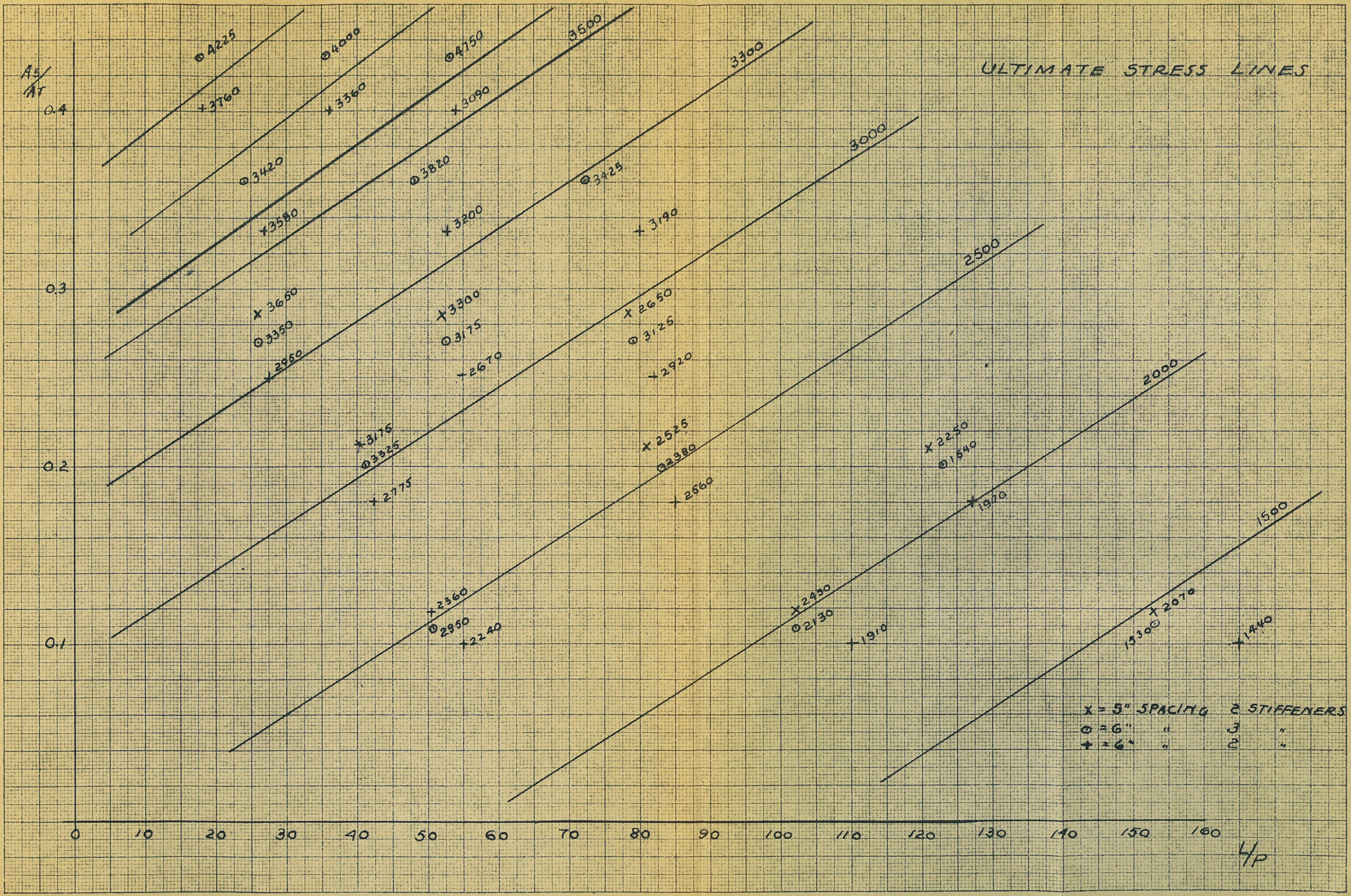

ULTIMATE STRESS LINES
As/At
0.4
0.3
0.2
0.1
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
L/P
3500
3300
3000
2500
2000
1500
X = 5" SPACING 2 STIFFENERS
⊙ = 6" " 3 "
+ = 6" " 2 "

Fig. 2

ULTIMATE STRESS vs L/P

Resultant of Panels Tested

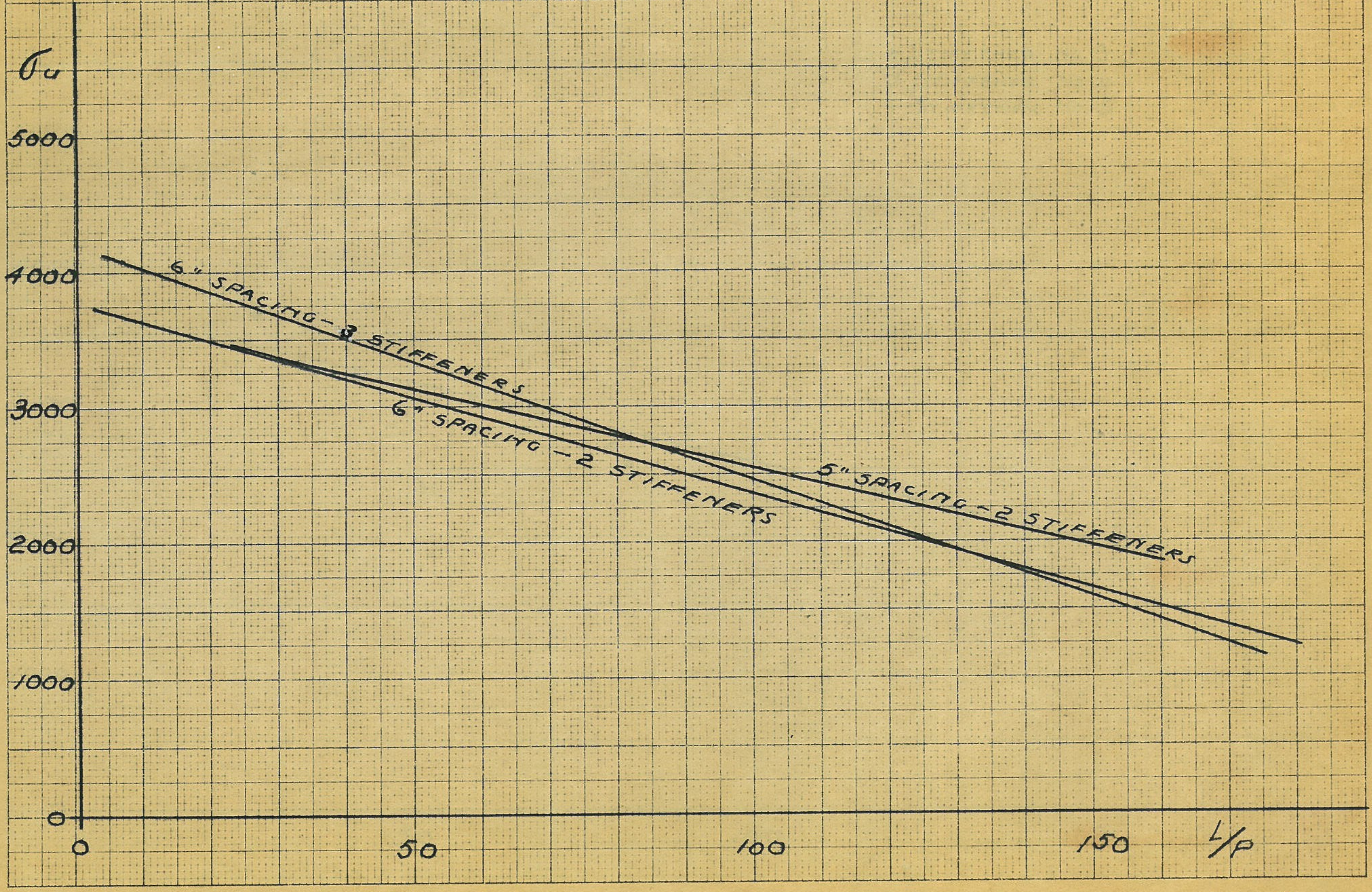
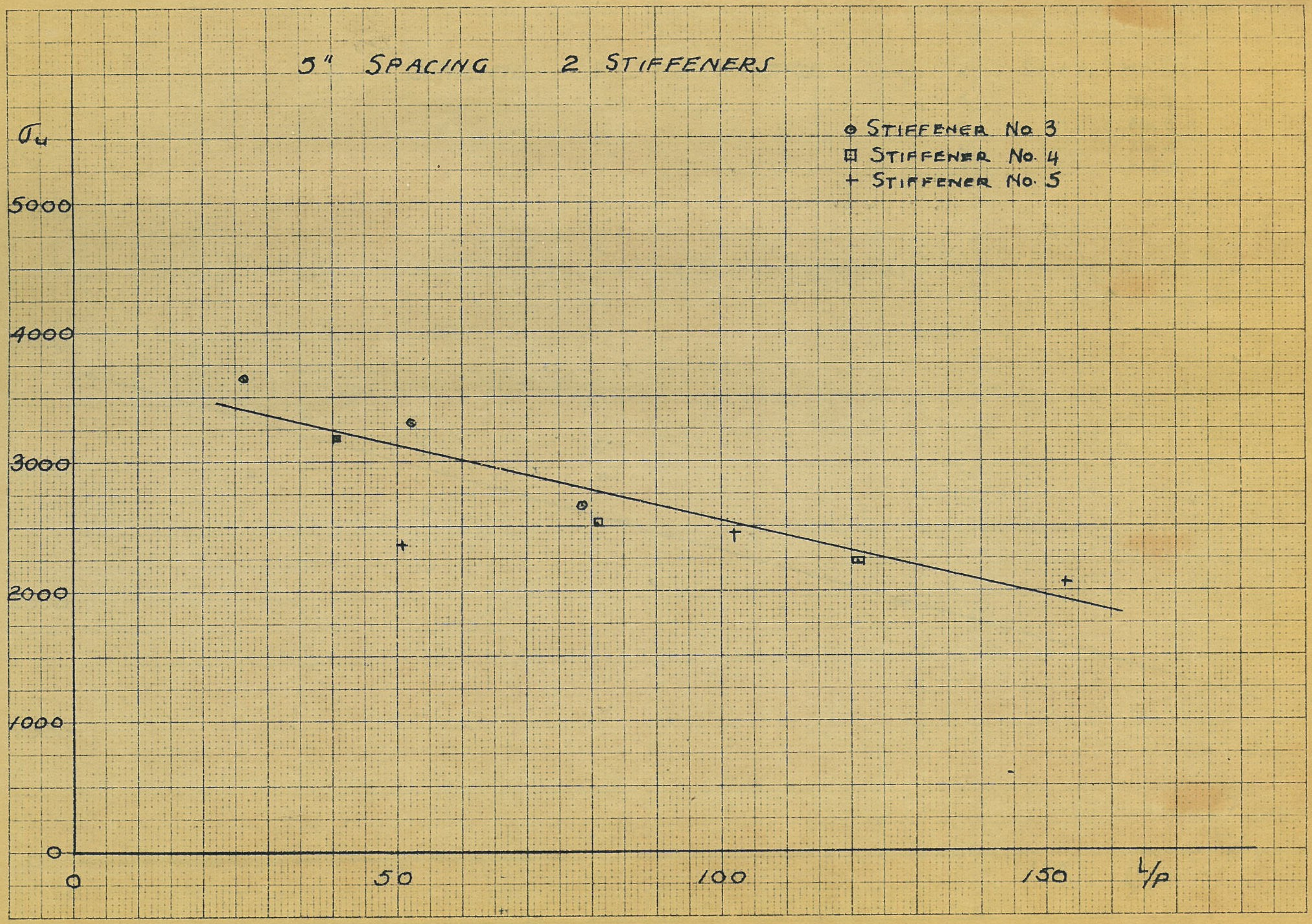


Fig. 3



5" SPACING 2 STIFFENERS
σu
⊙ STIFFENER No. 3
⊞ STIFFENER No. 4
+ STIFFENER No. 5
5000
4000
3000
2000
1000
0
0
50
100
150
L/ρ

Fig. 4

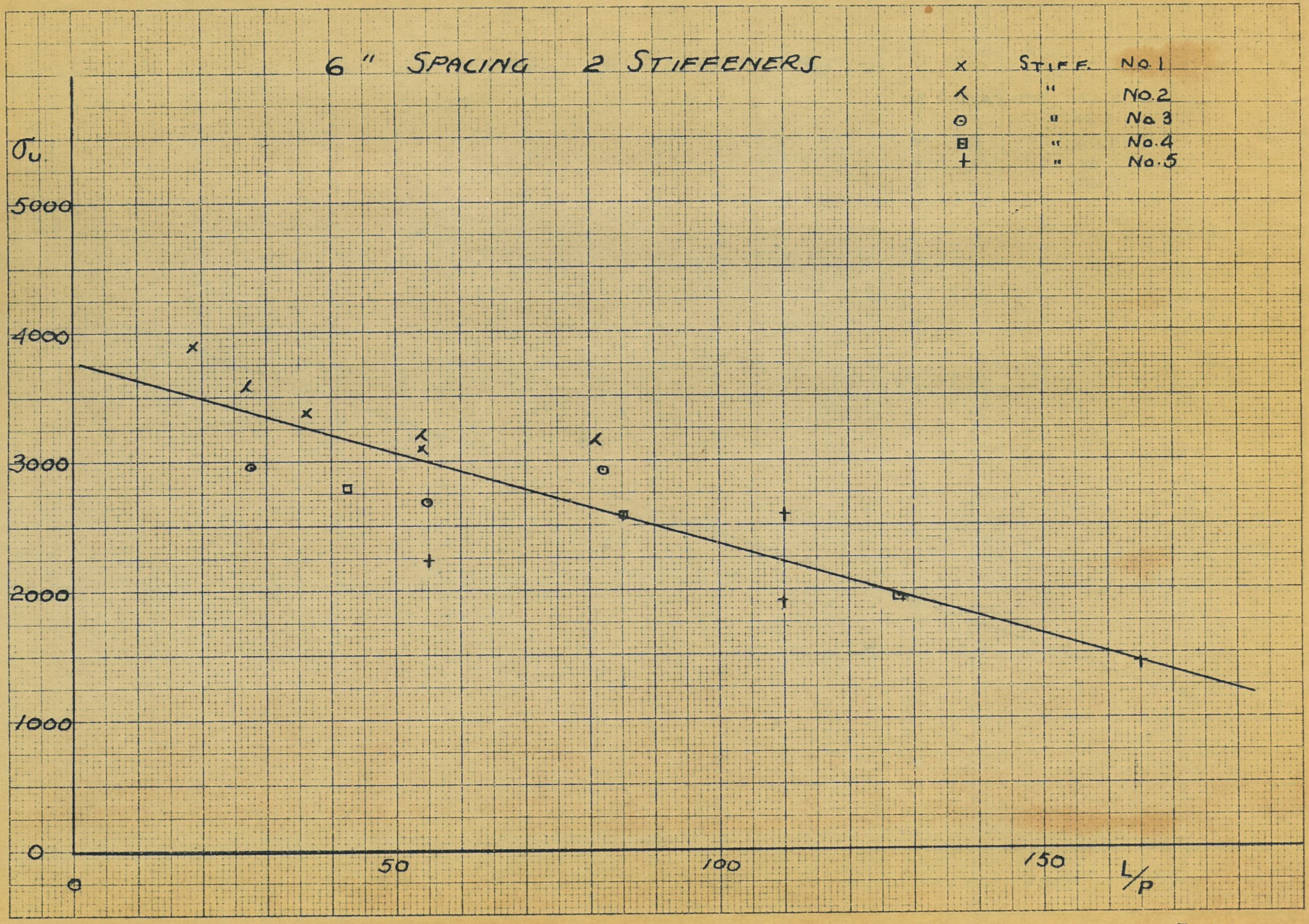

6" SPACING 2 STIFFENERS
x STIFF. No.1
" No.2
" No.3
" No.4
" No.5
σ_u
5000
4000
3000
2000
1000
0
0
50
100
150
L/P

Fig. 5

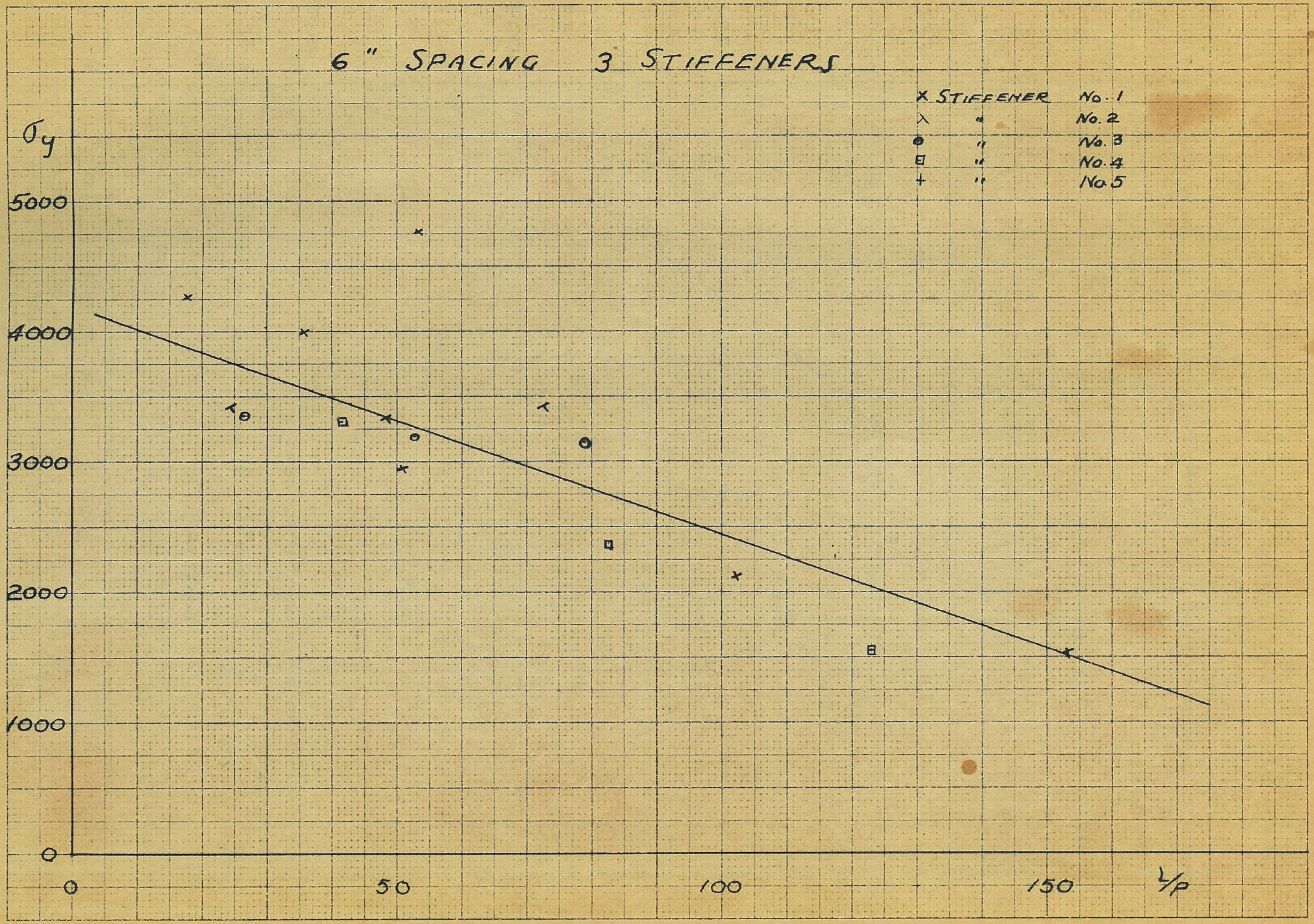

6" SPACING 3 STIFFENERS
× STIFFENER No. 1
λ " No. 2
● " No. 3
⊟ " No. 4
+ " No. 5
σy
5000
4000
3000
2000
1000
0
0
50
100
150
L/P

Fig. 6

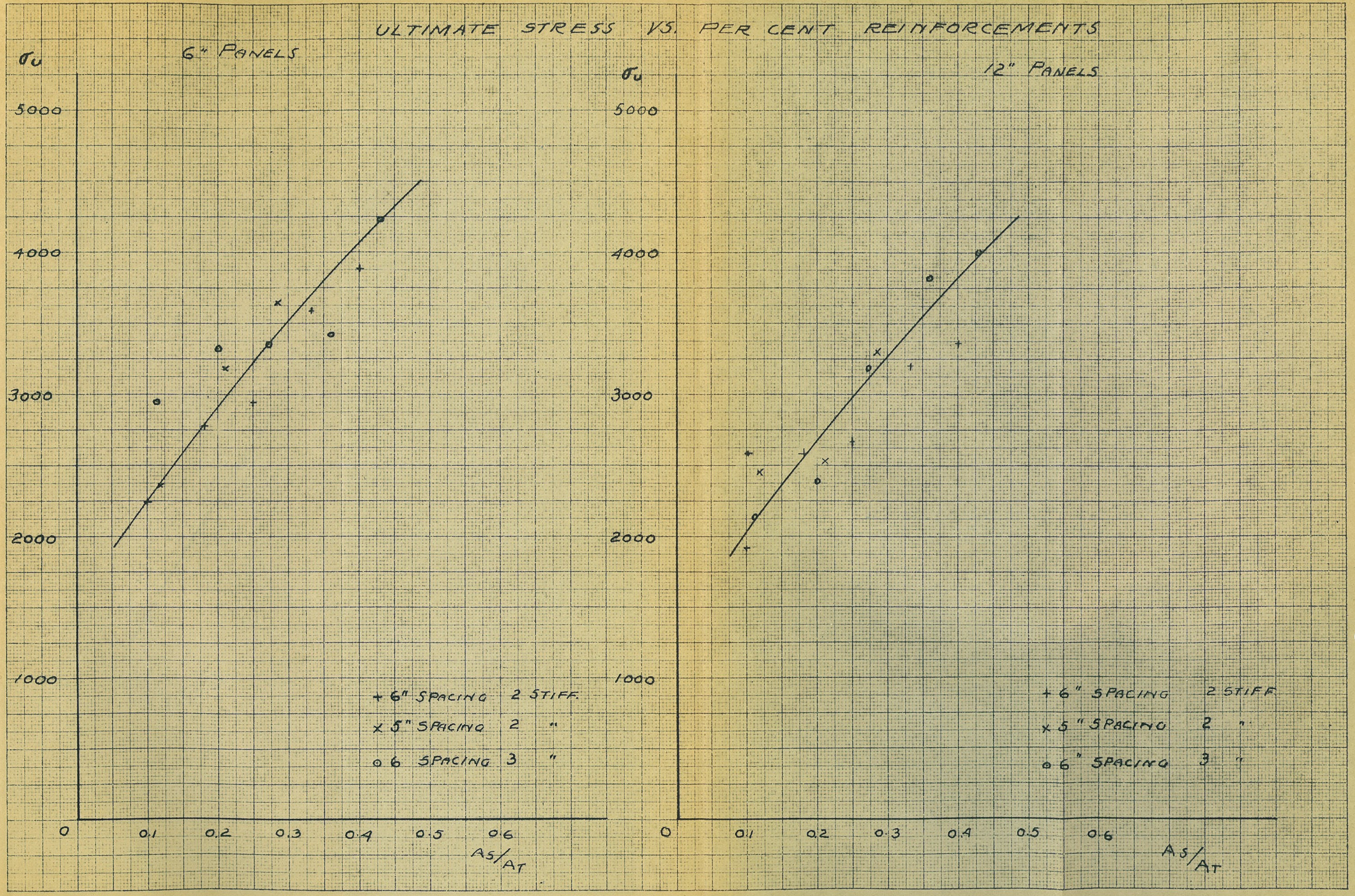
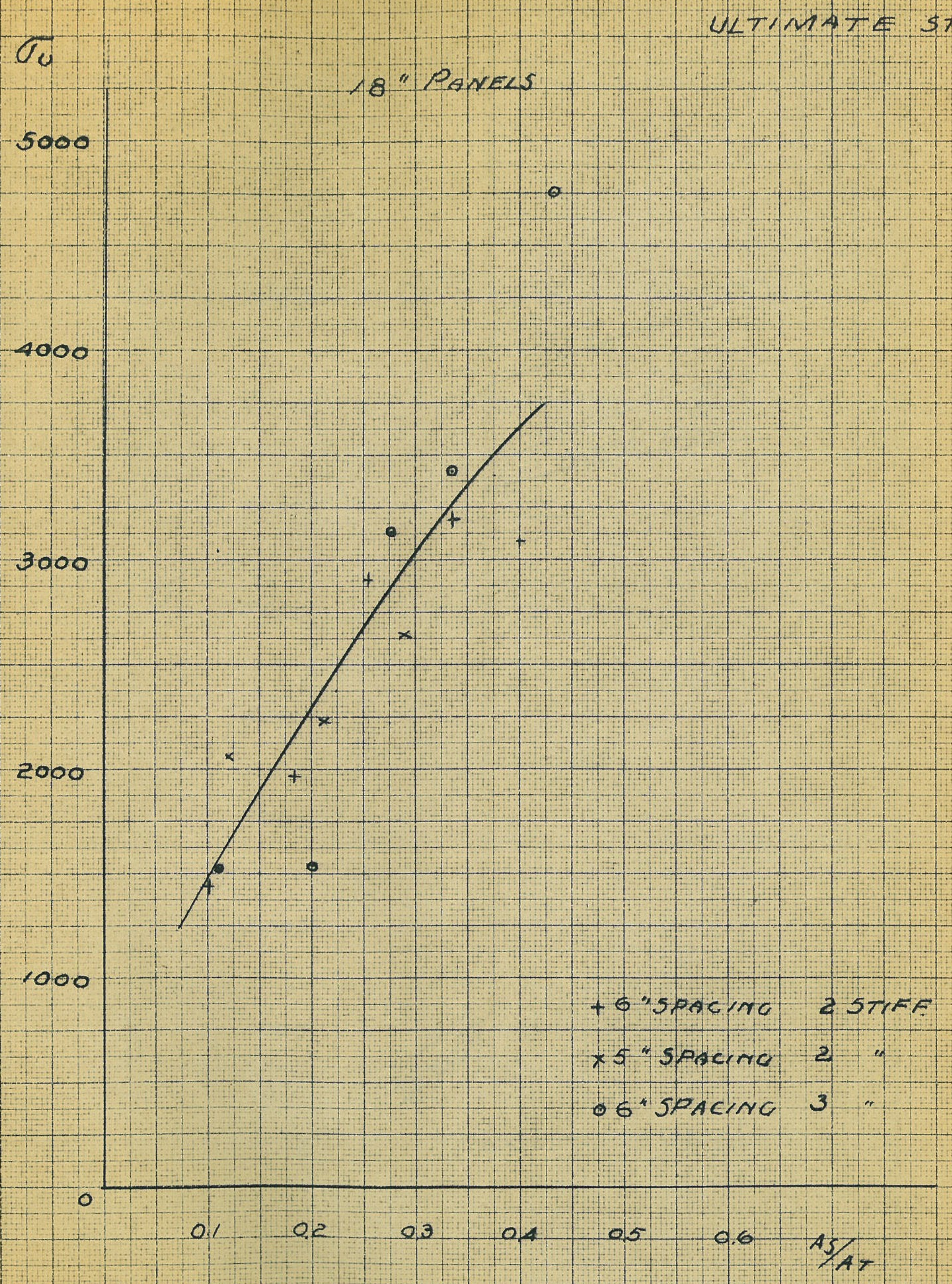

ULTIMATE STRESS VS. PER CENT REINFORCEMENTS
6" PANELS
12" PANELS
σu
5000
4000
3000
2000
1000
0
0.1
0.2
0.3
0.4
0.5
0.6
AS/AT
+ 6" SPACING 2 STIFF.
x 5" SPACING 2 "
o 6 SPACING 3 "

FIG. 7



ULTIMATE STRESS VS. PER CENT REINFORCEMENTS
18" PANELS
σU
5000
4000
3000
2000
1000
0
0.1
0.2
0.3
0.4
0.5
0.6
AS/AT
+ 6" SPACING 2 STIFF.
× 5" SPACING 2 "
⊙ 6" SPACING 3 "

Fig. 8

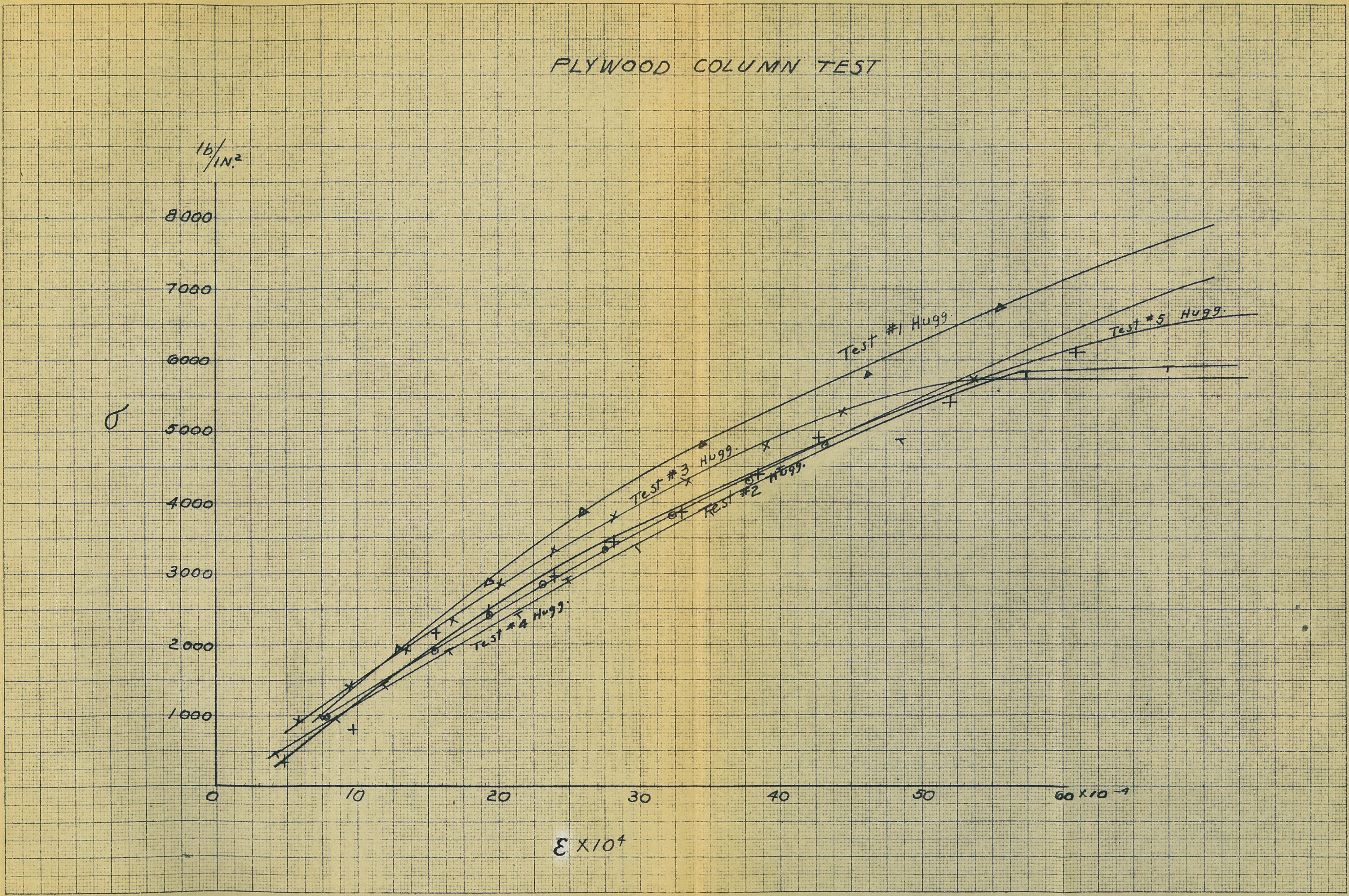

PLYWOOD COLUMN TEST
lb/IN.²
σ
8000
7000
6000
5000
4000
3000
2000
1000
0
10
20
30
40
50
60 x10⁻⁴
ε x10⁴
Test #1 Hugg.
Test #3 Hugg.
Test #2 Hugg.
Test #4 Hugg.
Test #5 Hugg.

Fig. 9

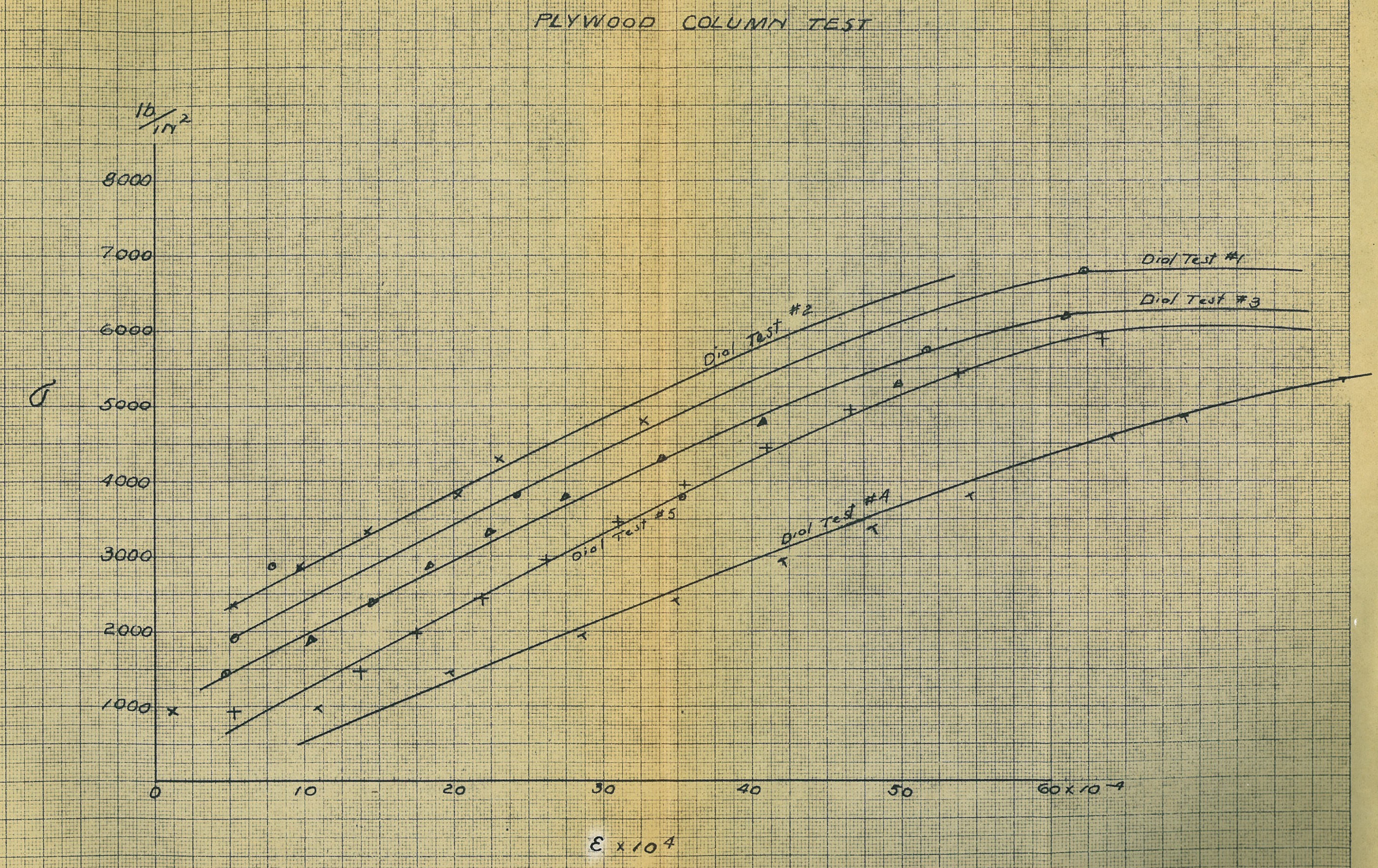
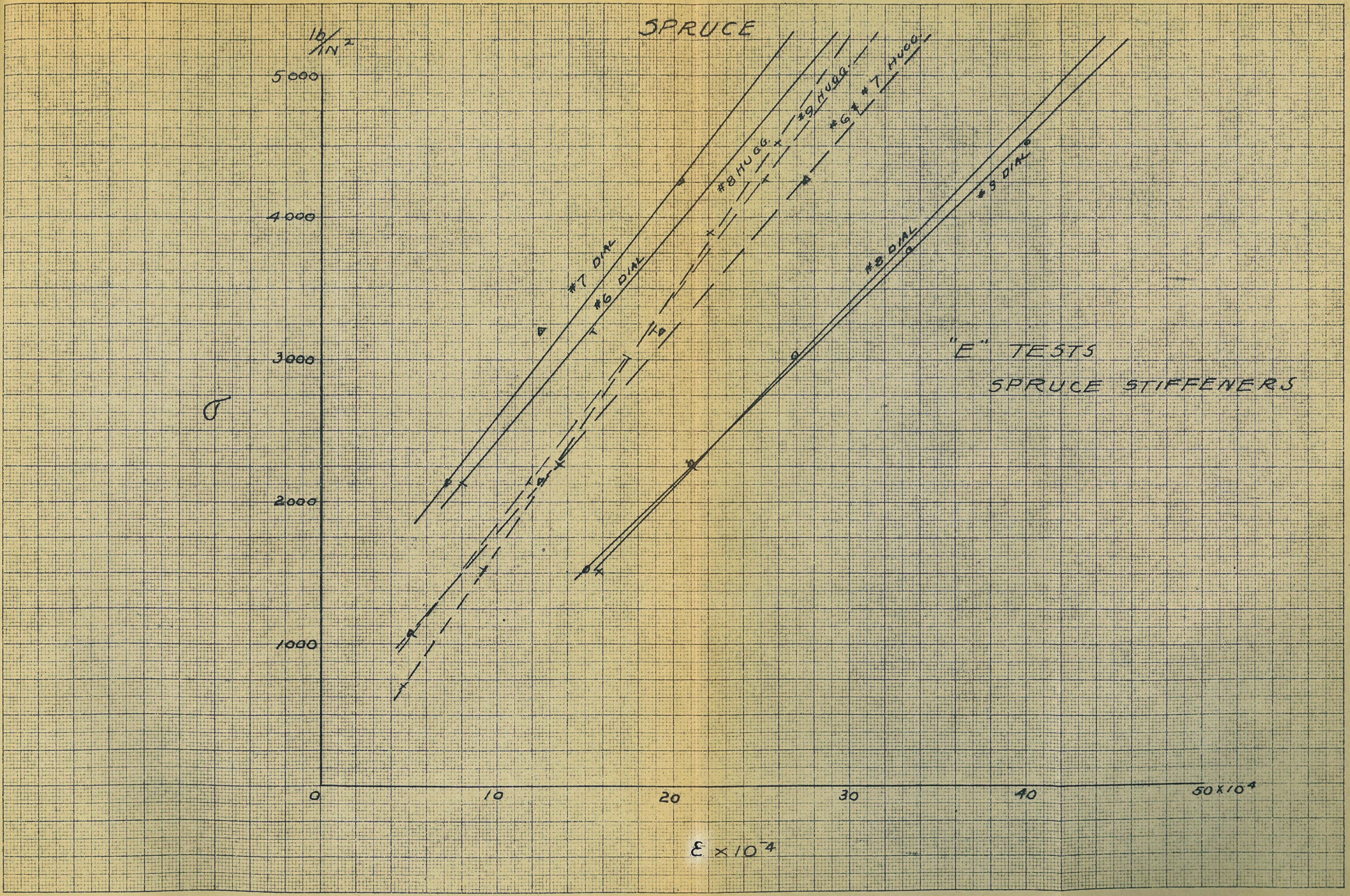
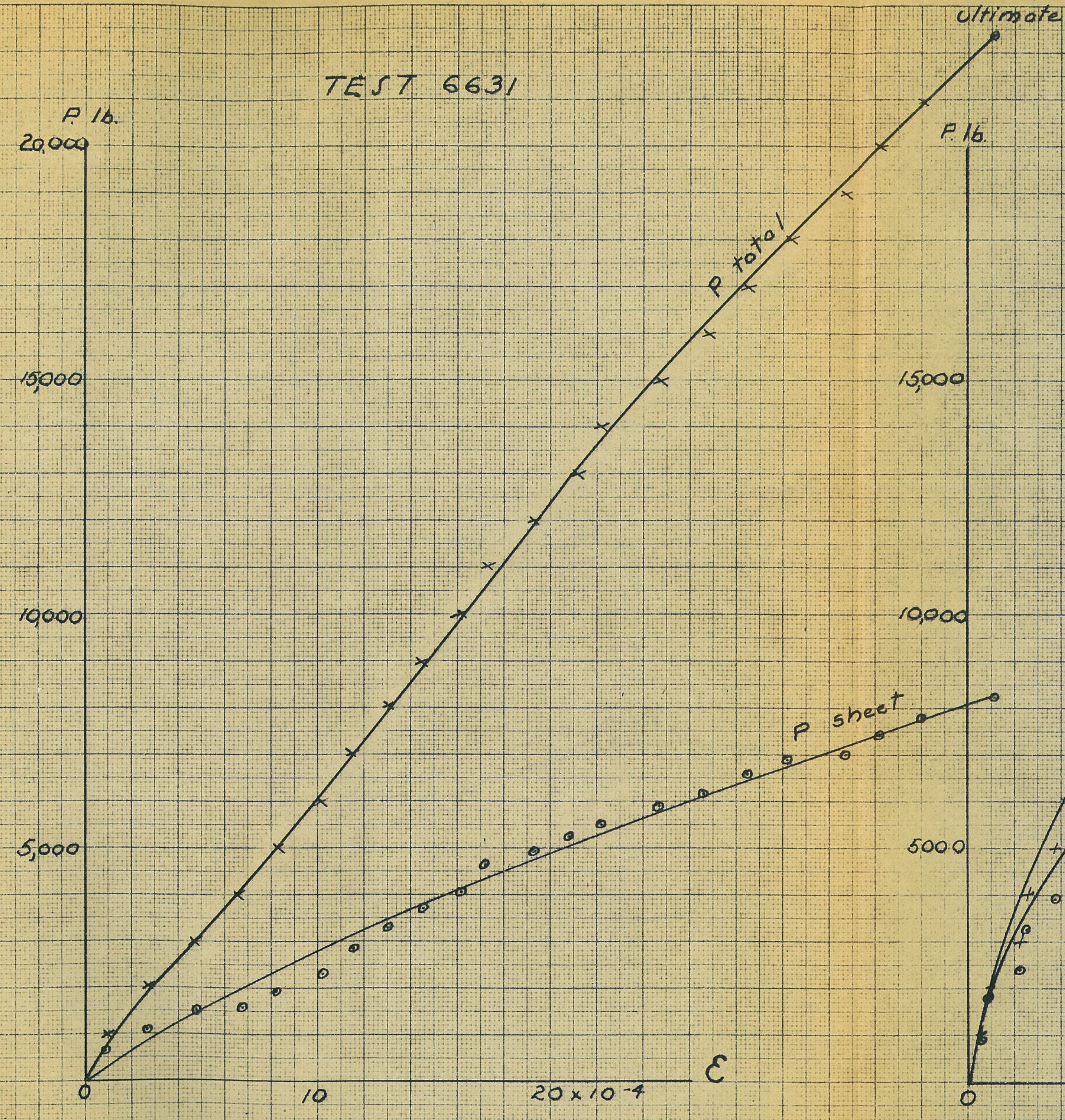

PLYWOOD COLUMN TEST
lb/in²
8000
7000
6000
5000
4000
3000
2000
1000
σ
0
10
20
30
40
50
60 x 10⁻⁴
ε x 10⁴
Dial Test #1
Dial Test #2
Dial Test #3
Dial Test #4
Dial Test #5

Fig. 10



SPRUCE
lb/IN²
5000
4000
3000
2000
1000
σ
0
10
20
30
40
50×10⁻⁴
ε × 10⁻⁴
#7 DIAL
#6 DIAL
#8 HUGG.
#9 HUGG.
#6 & #7 HUGG.
#8 DIAL
#9 DIAL
"E" TESTS
SPRUCE STIFFENERS

Fig. 11


TEST 6631
P lb.
20,000
15,000
10,000
5,000
0
10
20 x 10 -4
ε
P total
P sheet
ultimate

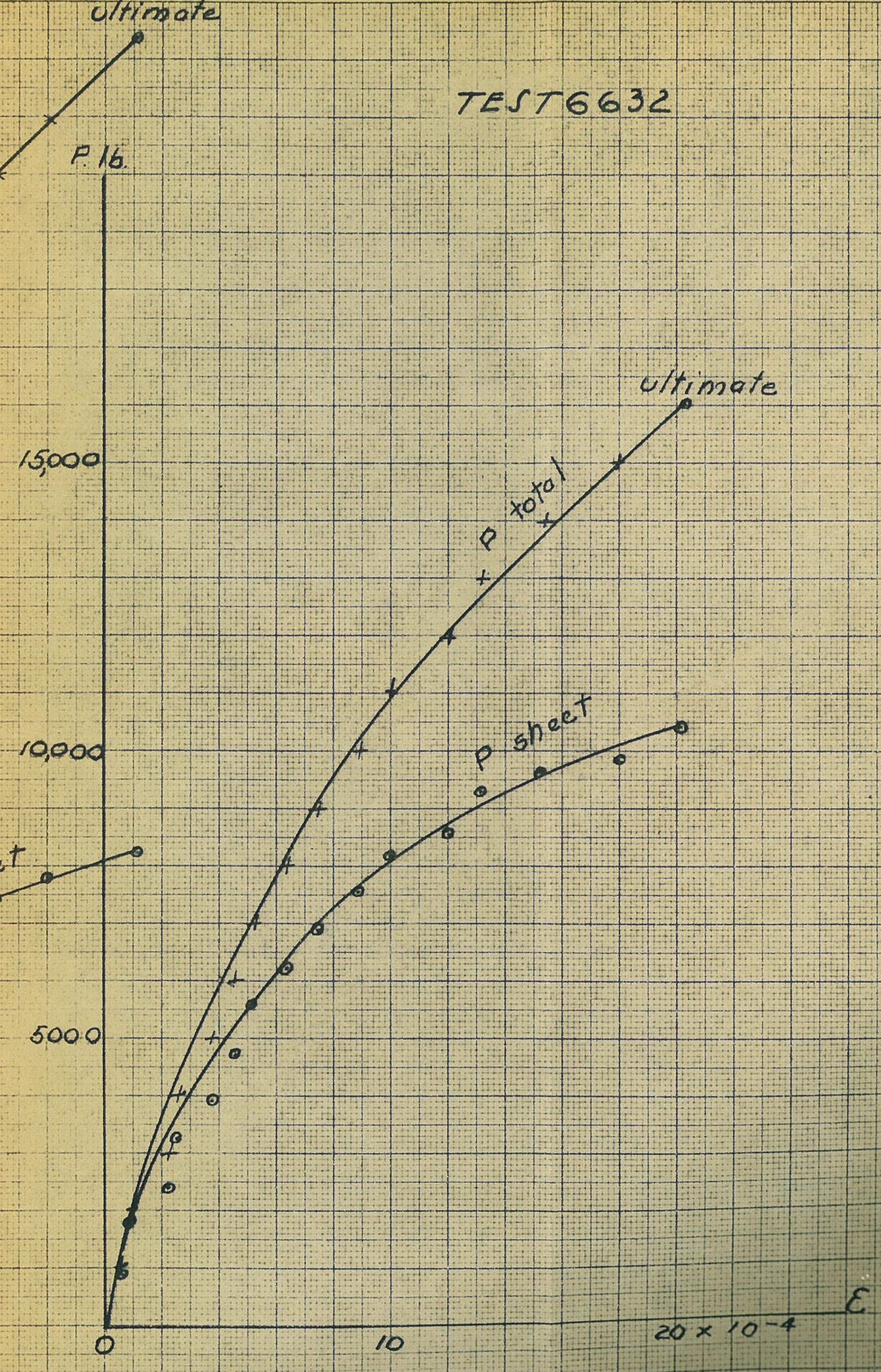

TEST 6632
P lb.
15,000
10,000
500.0
0
10
20 x 10 -4
ε
P total
P sheet
ultimate

Fig. 12

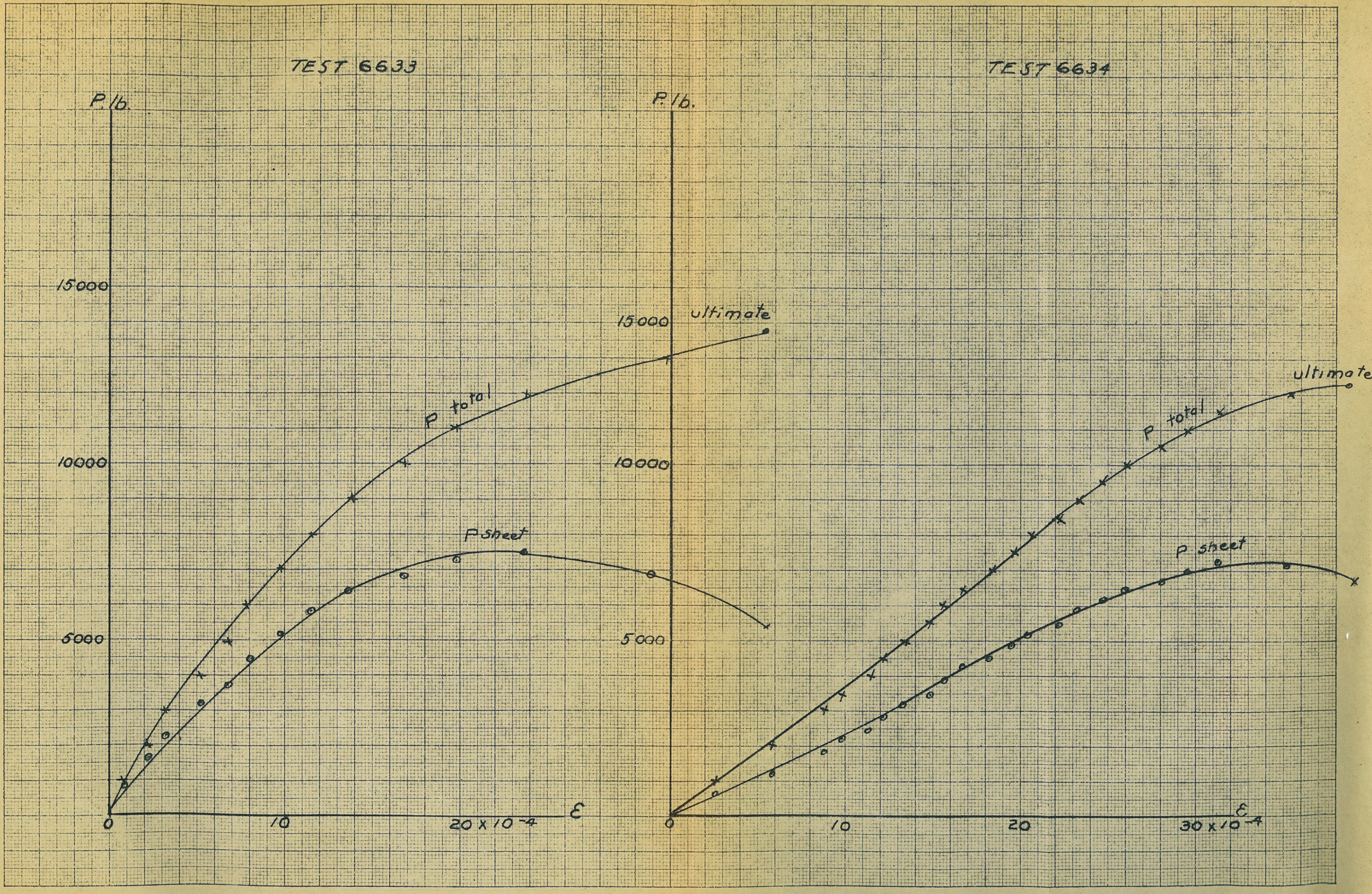
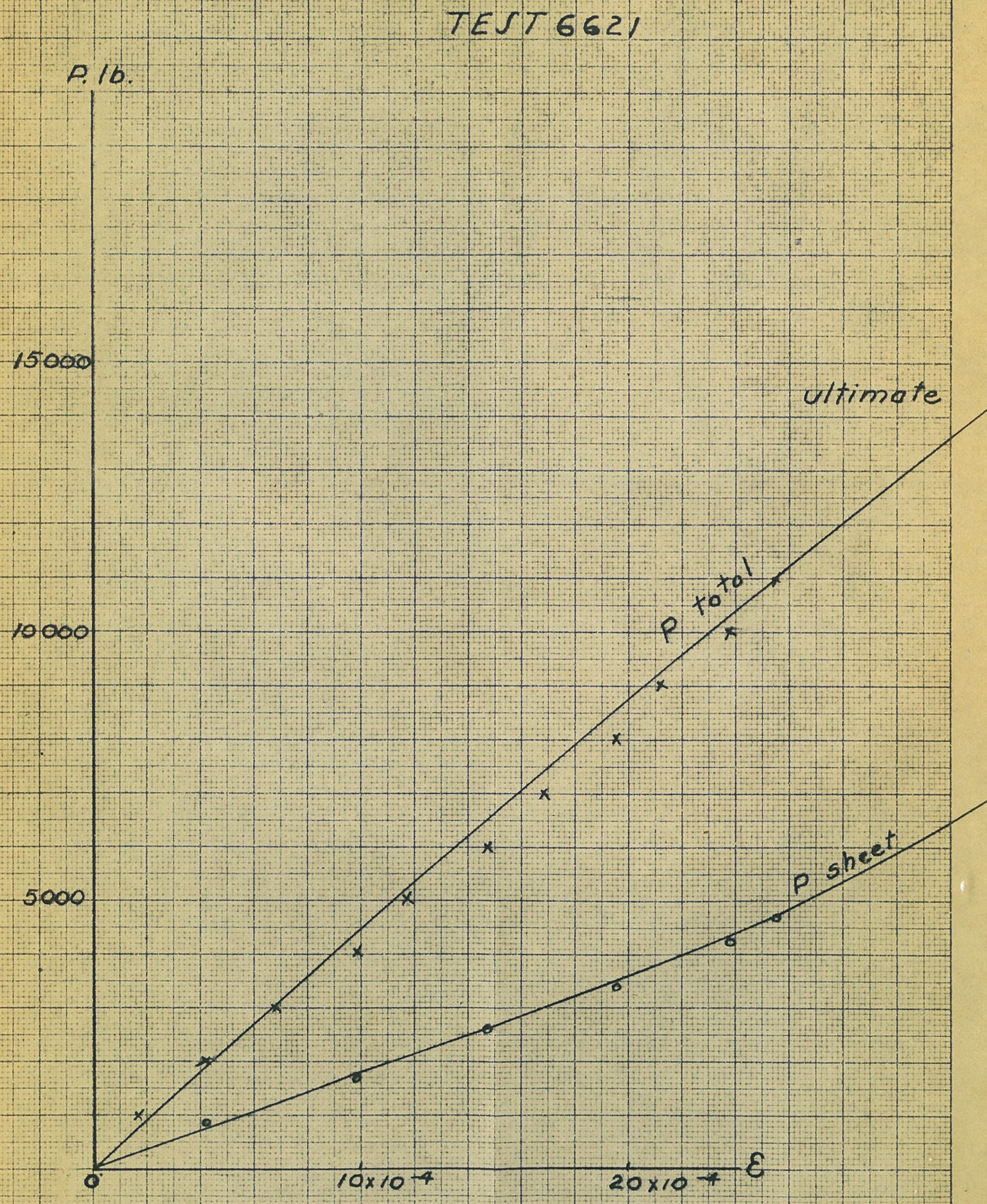
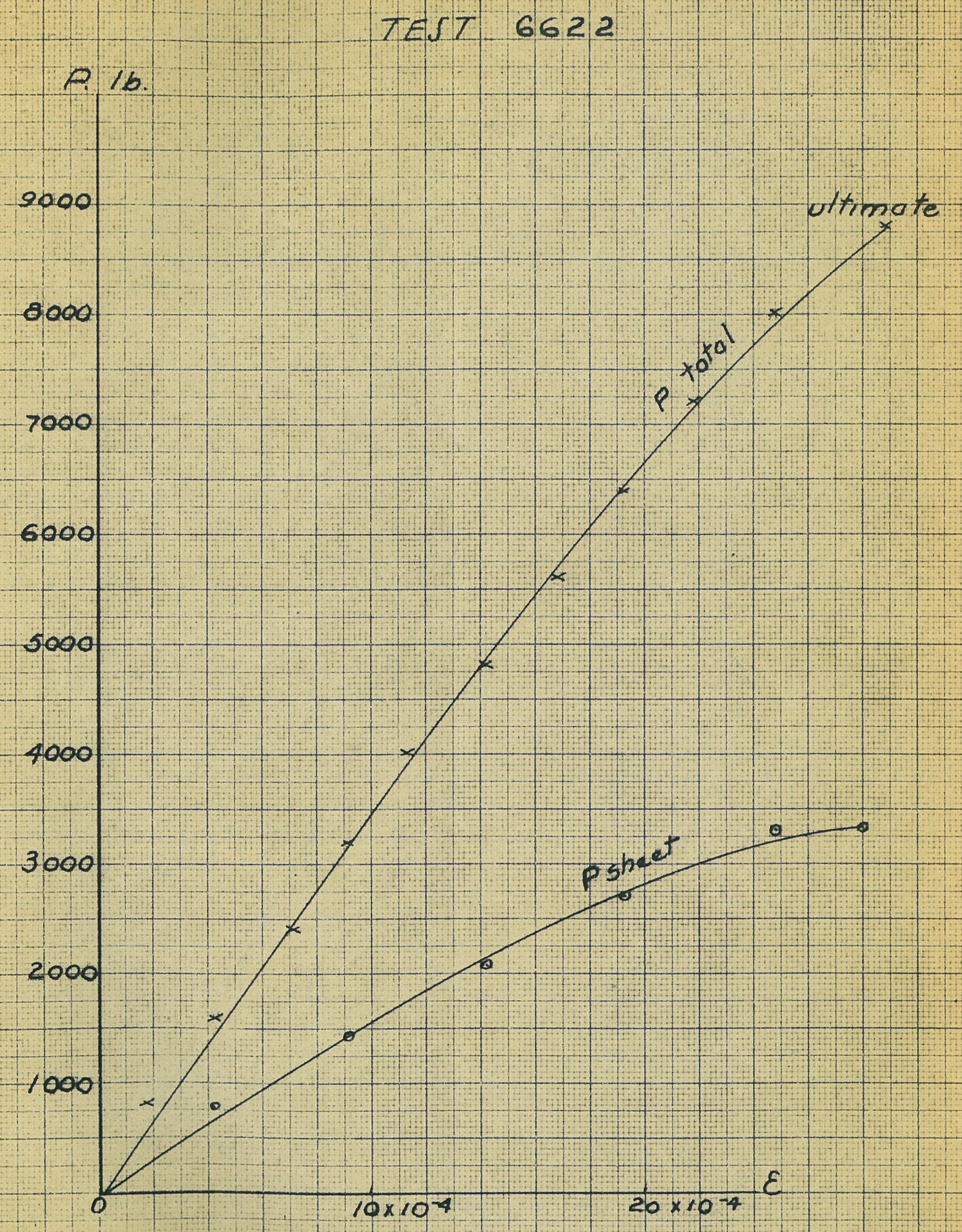

TEST 6633
P lb.
15000
10000
5000
0
10
20 x 10-4
ε
P total
P sheet
ultimate
TEST 6634
P lb.
15000
10000
5000
0
10
20
30 x 10-4
ε
P total
P sheet
ultimate

Fig. 13


TEST 6621
P. lb.
15000
10000
5000
0
10x10^-4
20x10^-4
ε
ultimate
P total
P sheet


TEST 6622
P. lb.
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
ultimate
P total
P sheet
10x10⁻⁴
20x10⁻⁴
ε

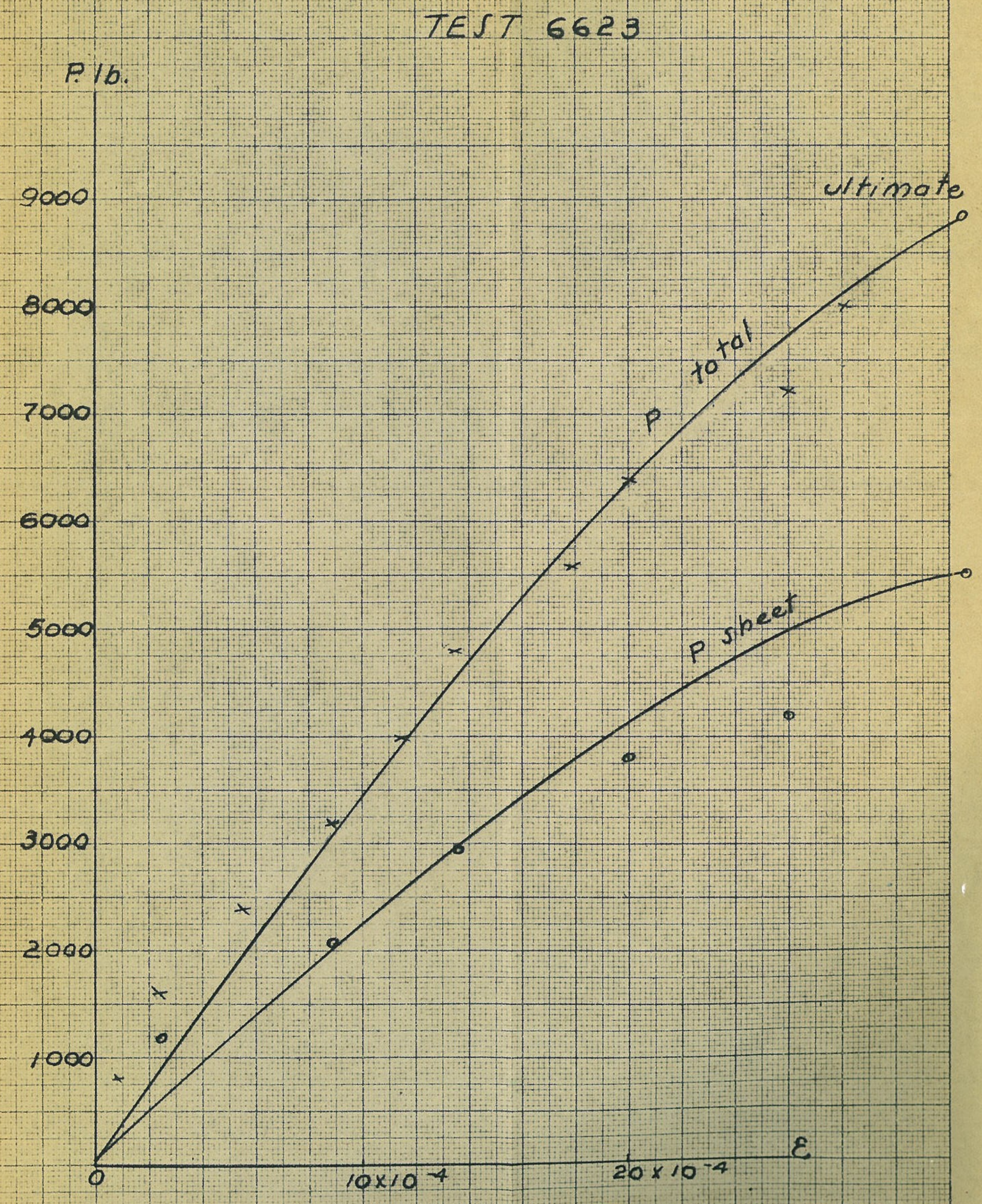
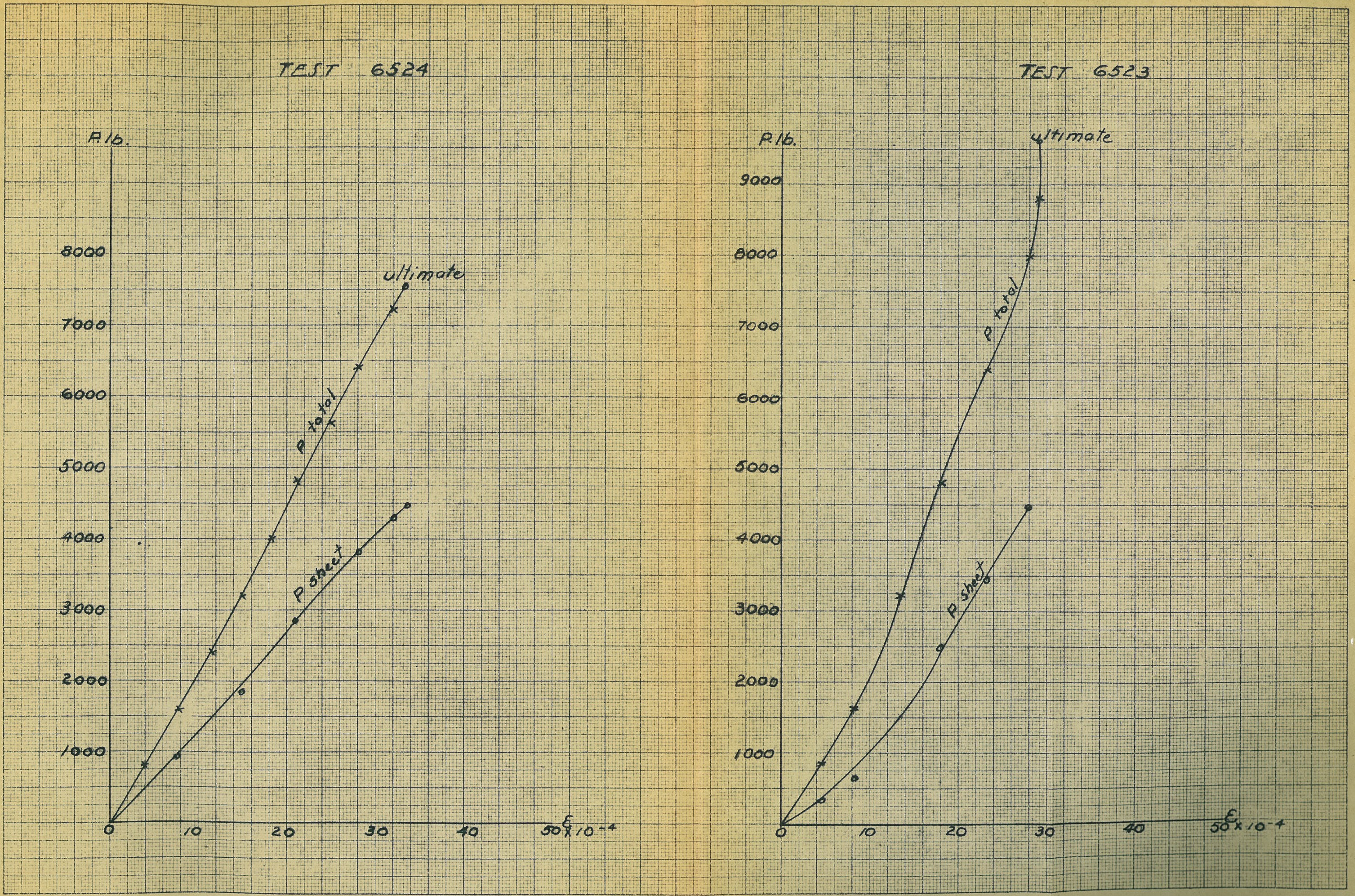
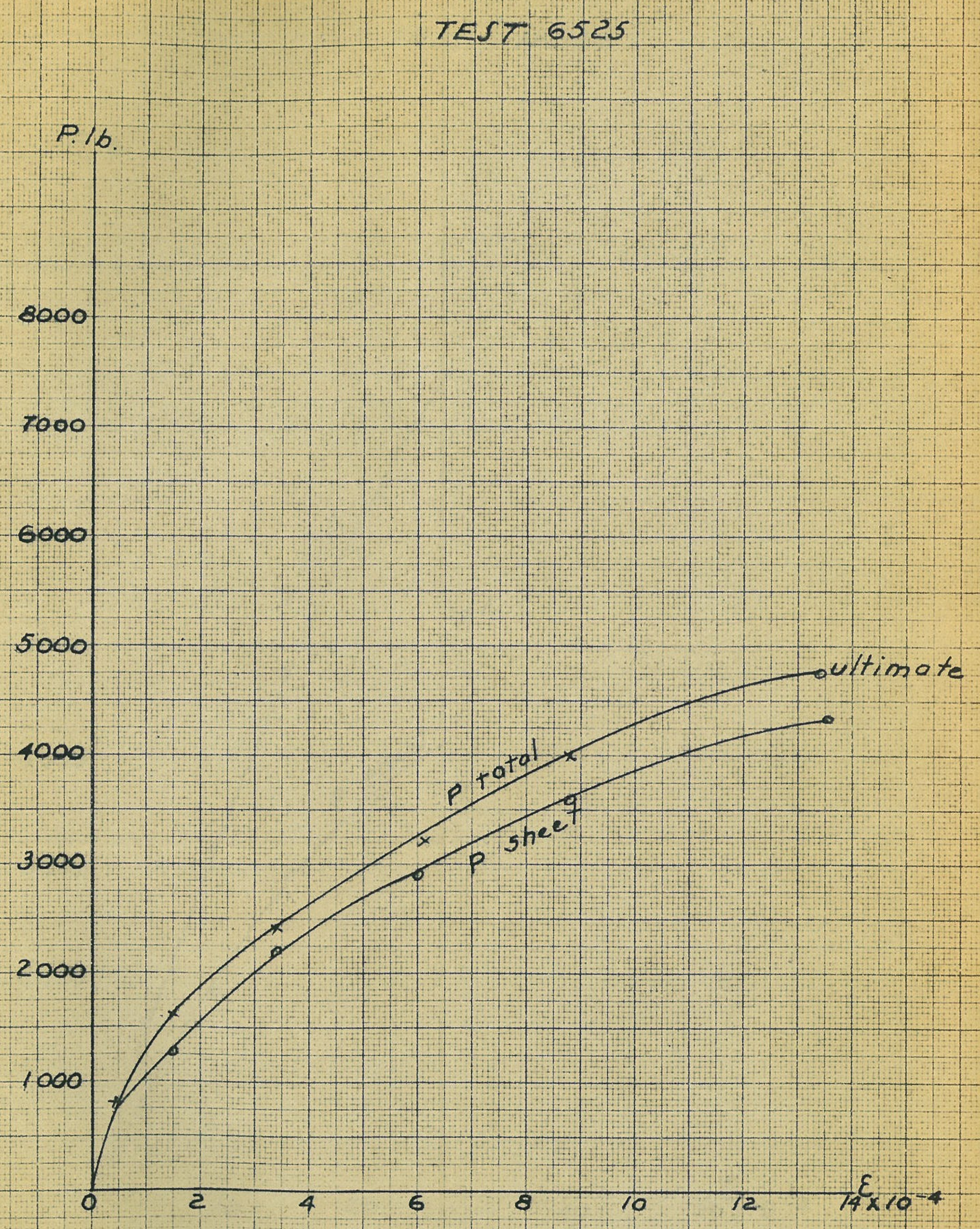

TEST 6623
P. lb.
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
ultimate
P total
P sheet
10x10⁻⁴
20x10⁻⁴
ε

Fig. 15



TEST 6524
P lb.
8000
7000
6000
5000
4000
3000
2000
1000
0
10
20
30
40
50 x 10⁻⁴
ultimate
P total
P sheet
TEST 6523
P lb.
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
10
20
30
40
50 x 10⁻⁴
ultimate
P total
P sheet

Fig. 16


TEST 6525
P lb.
8000
7000
6000
5000
4000
3000
2000
1000
0
2
4
6
8
10
12
14x10⁻⁴
ε
ultimate
P total
P sheet

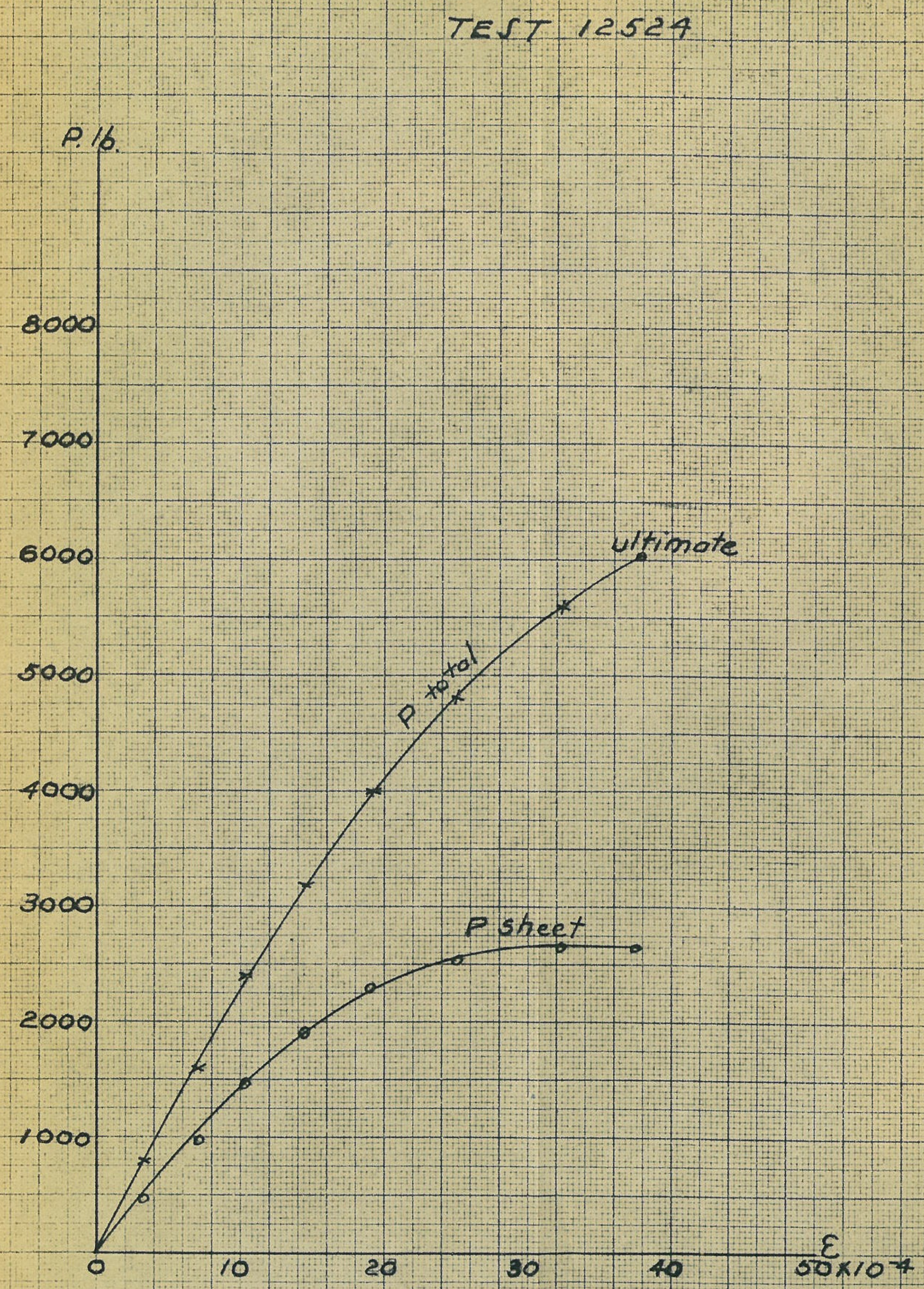
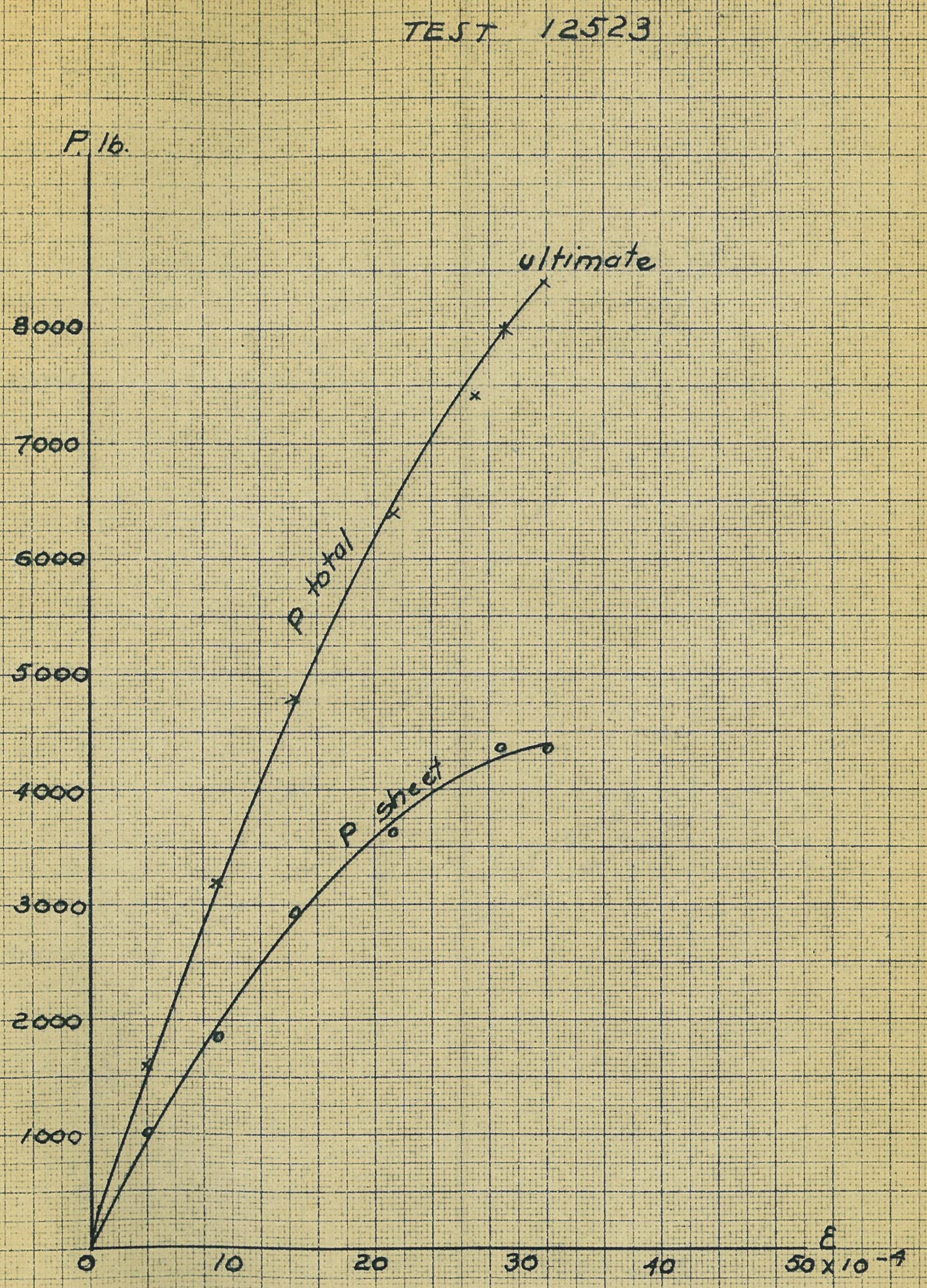

TEST 12524
P lb.
8000
7000
6000
5000
4000
3000
2000
1000
0
10
20
30
40
50x10⁻⁴
ε
ultimate
P total
P sheet

Fig. 17


TEST 12523
P. lb.
ultimate
P total
P sheet
8000
7000
6000
5000
4000
3000
2000
1000
0
10
20
30
40
50 x 10^-4
ε

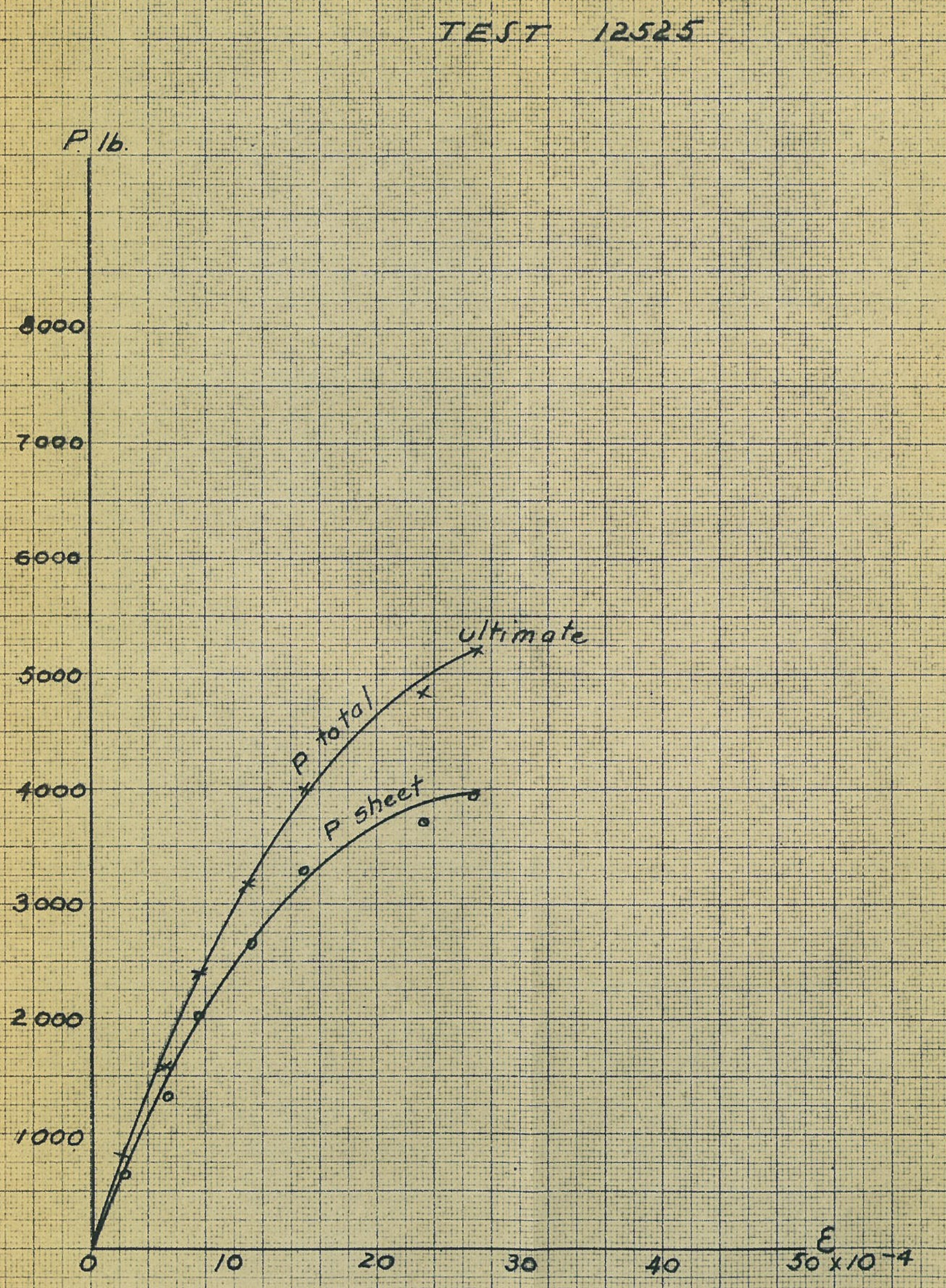
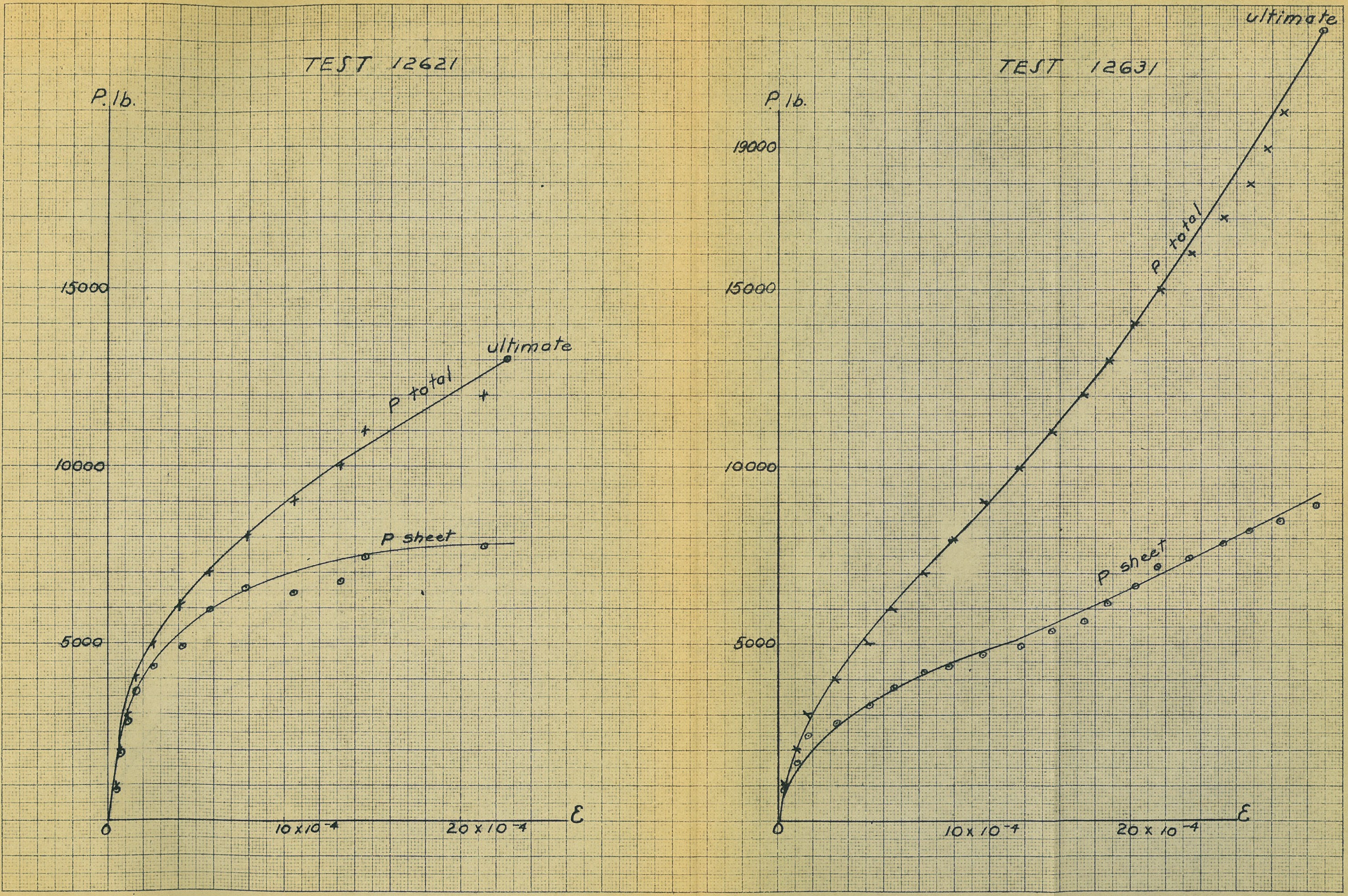

TEST 12525
P lb.
ultimate
P total
P sheet
8000
7000
6000
5000
4000
3000
2000
1000
0
10
20
30
40
50 x 10^-4
ε

Fig. 18



TEST 12621
P. lb.
15000
10000
5000
0
ultimate
P total
P sheet
10 x 10^-4
20 x 10^-4
ε
TEST 12631
P lb.
19000
15000
10000
5000
0
ultimate
P total
P sheet
10 x 10^-4
20 x 10^-4
ε

Fig. 19

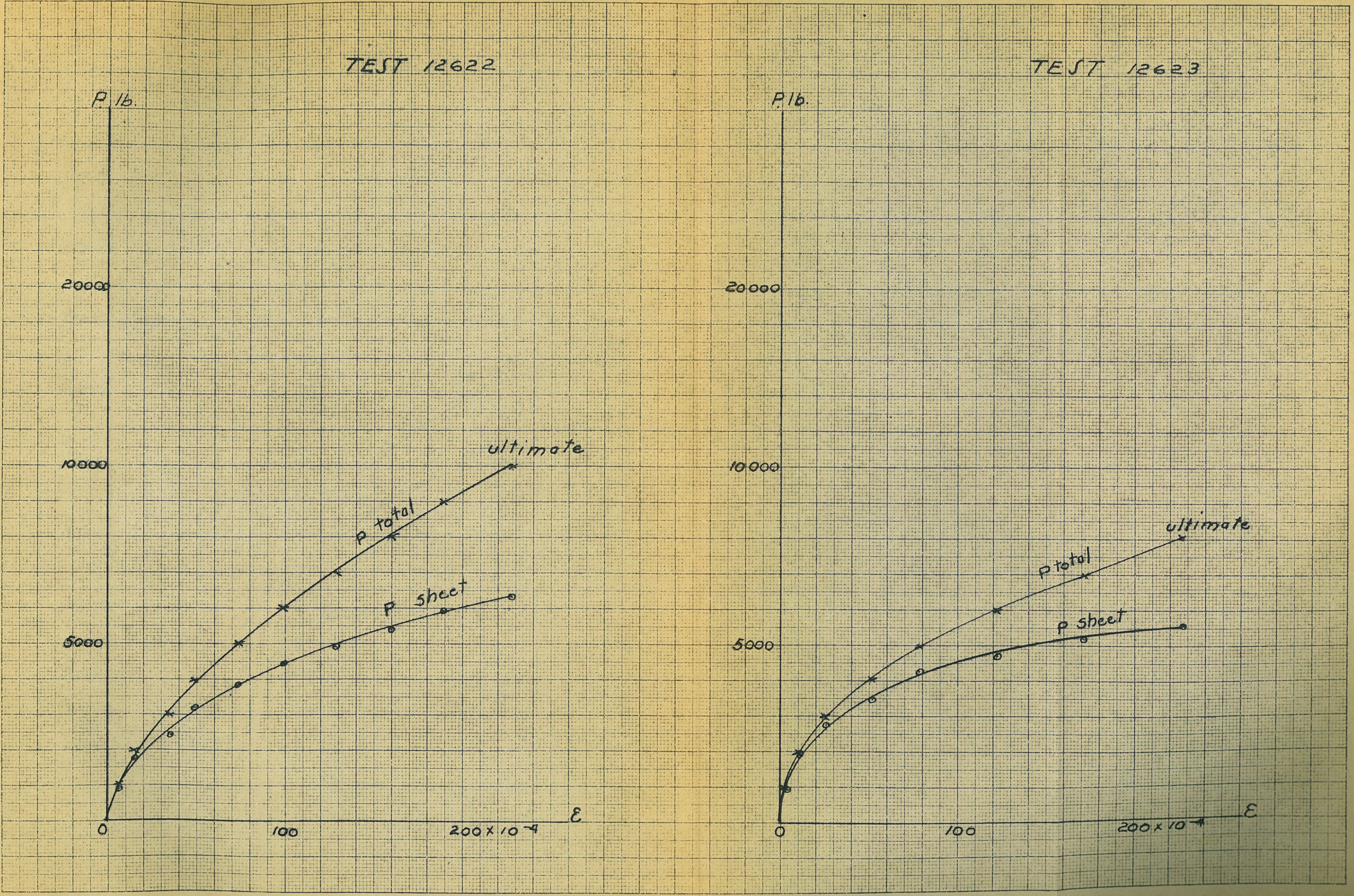

TEST 12622
P lb.
20000
10000
5000
0
100
200 x 10⁻⁴
ε
ultimate
P total
P sheet
TEST 12623
P lb.
20000
10000
5000
0
100
200 x 10⁻⁴
ε
ultimate
P total
P sheet

Fig. 20

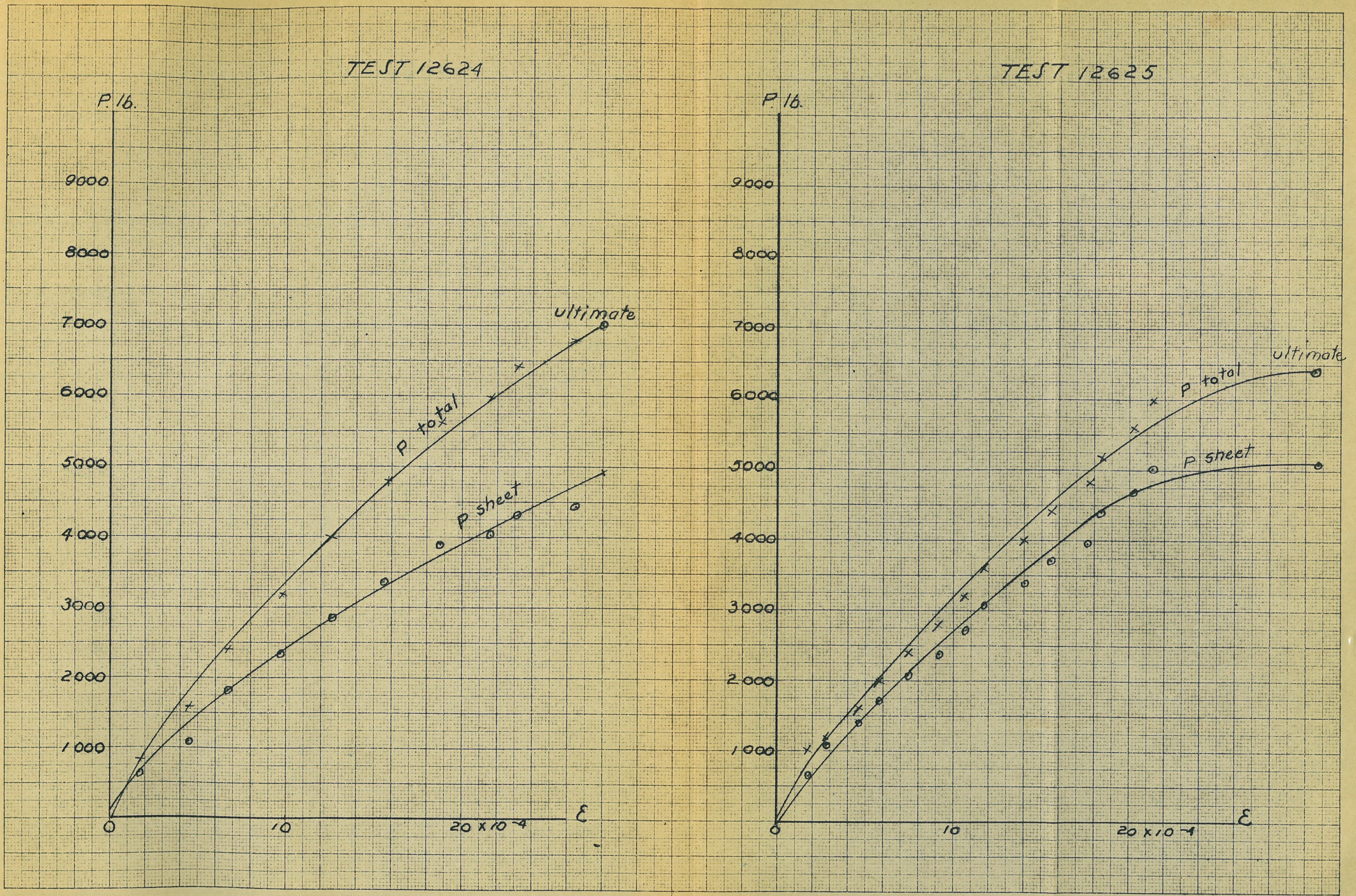

TEST 12624
P lb.
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
10
20 x 10⁻⁴
ε
ultimate
P total
P sheet
TEST 12625
P lb.
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
10
20 x 10⁻⁴
ε
ultimate
P total
P sheet

Fig. 21

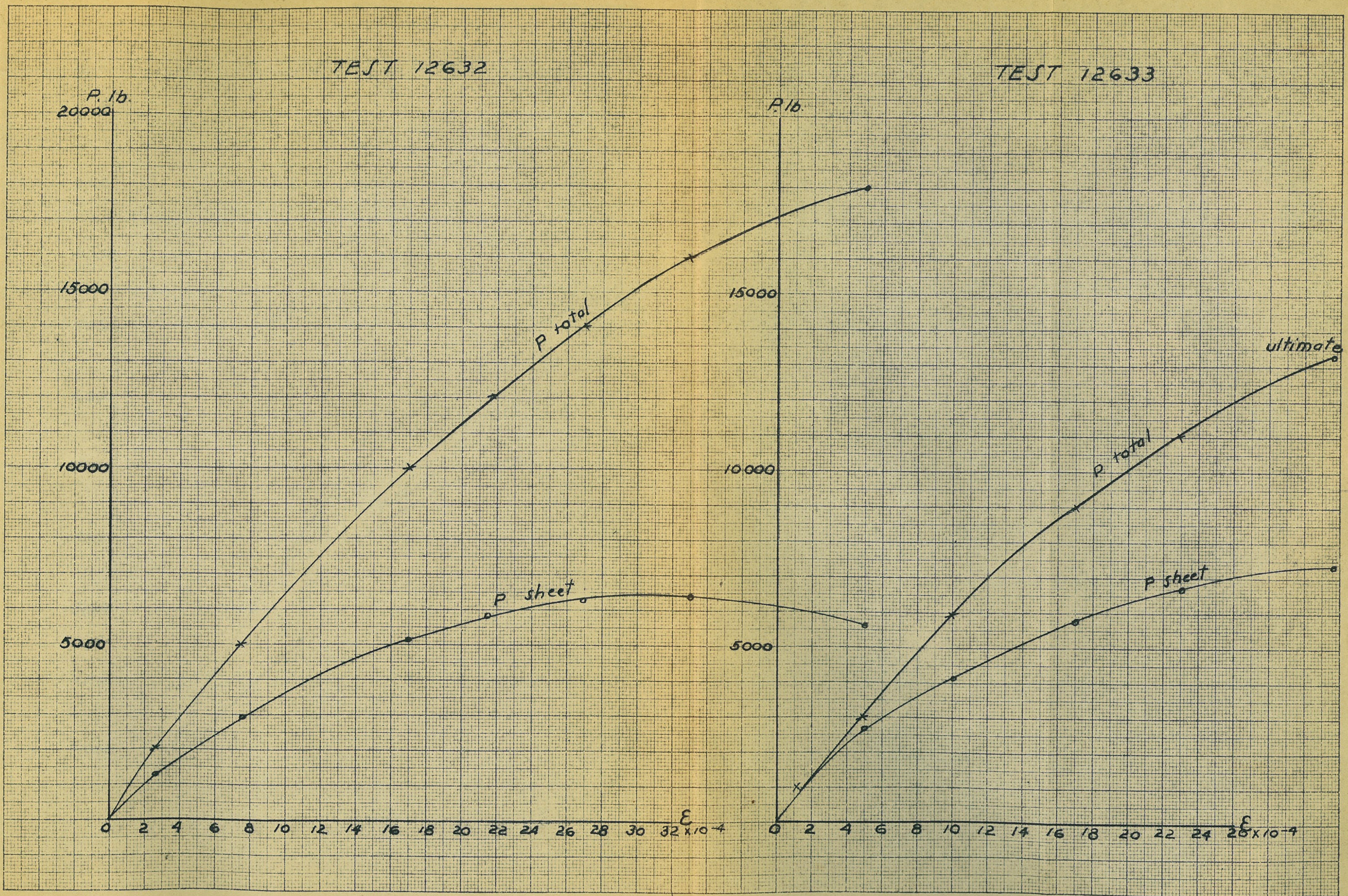
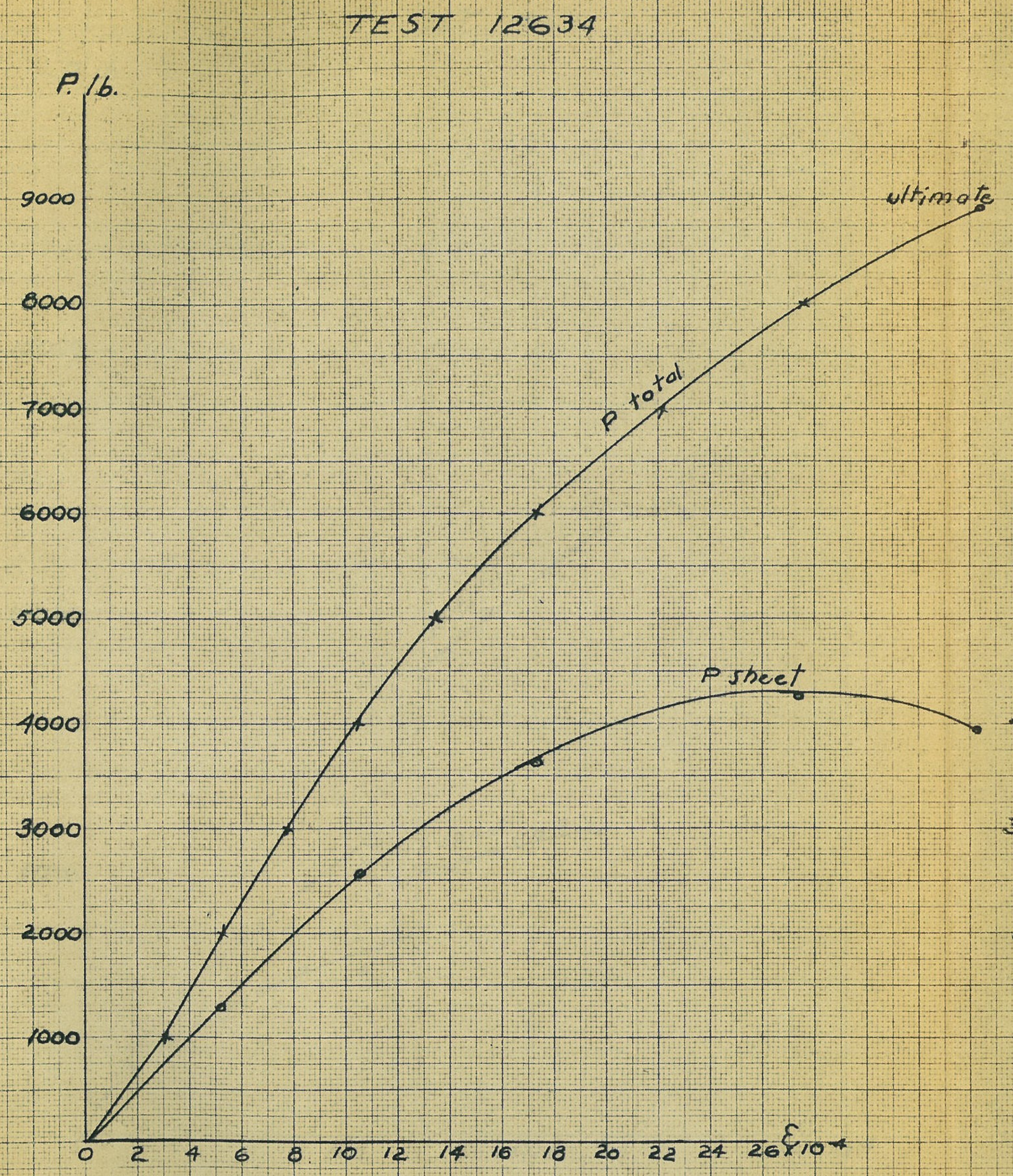

TEST 12632
P lb.
20000
15000
10000
5000
P total
P sheet
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 x10⁻⁴
ε
TEST 12633
P lb.
15000
10000
5000
ultimate
P total
P sheet
0 2 4 6 8 10 12 14 16 18 20 22 24 26 x10⁻⁴
ε

Fig. 23


TEST 12634
P. lb.
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
2
4
6
8
10
12
14
16
18
20
22
24
26x10⁻⁴
ε
ultimate
P total
P sheet

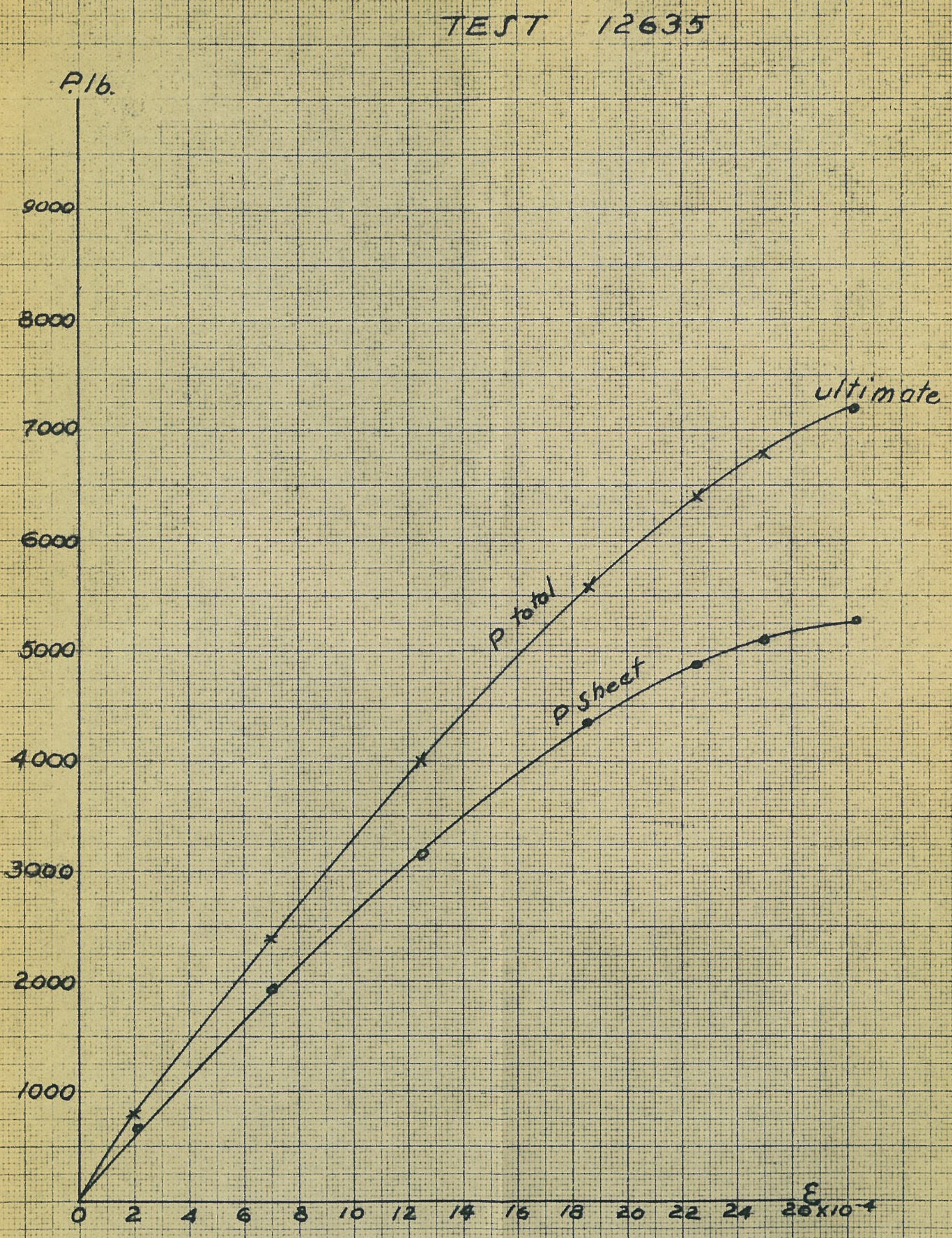
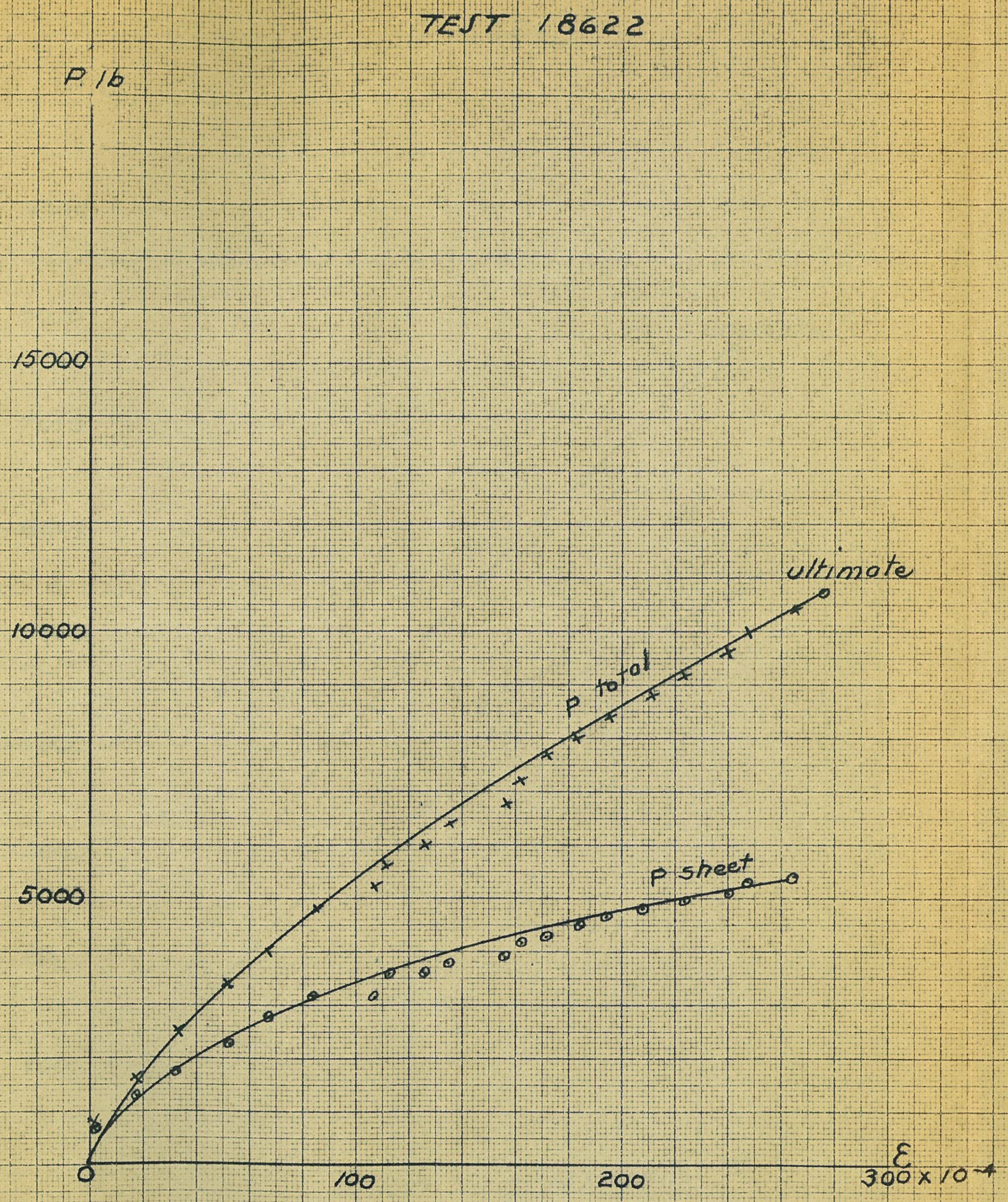

TEST 12635
P. lb.
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
2
4
6
8
10
12
14
16
18
20
22
24
26x10⁻⁴
ε
ultimate
P total
P sheet

Fig. 23


TEST 18622
P lb
15000
10000
5000
0
100
200
300 x 10⁻⁴
ε
ultimate
P total
P sheet

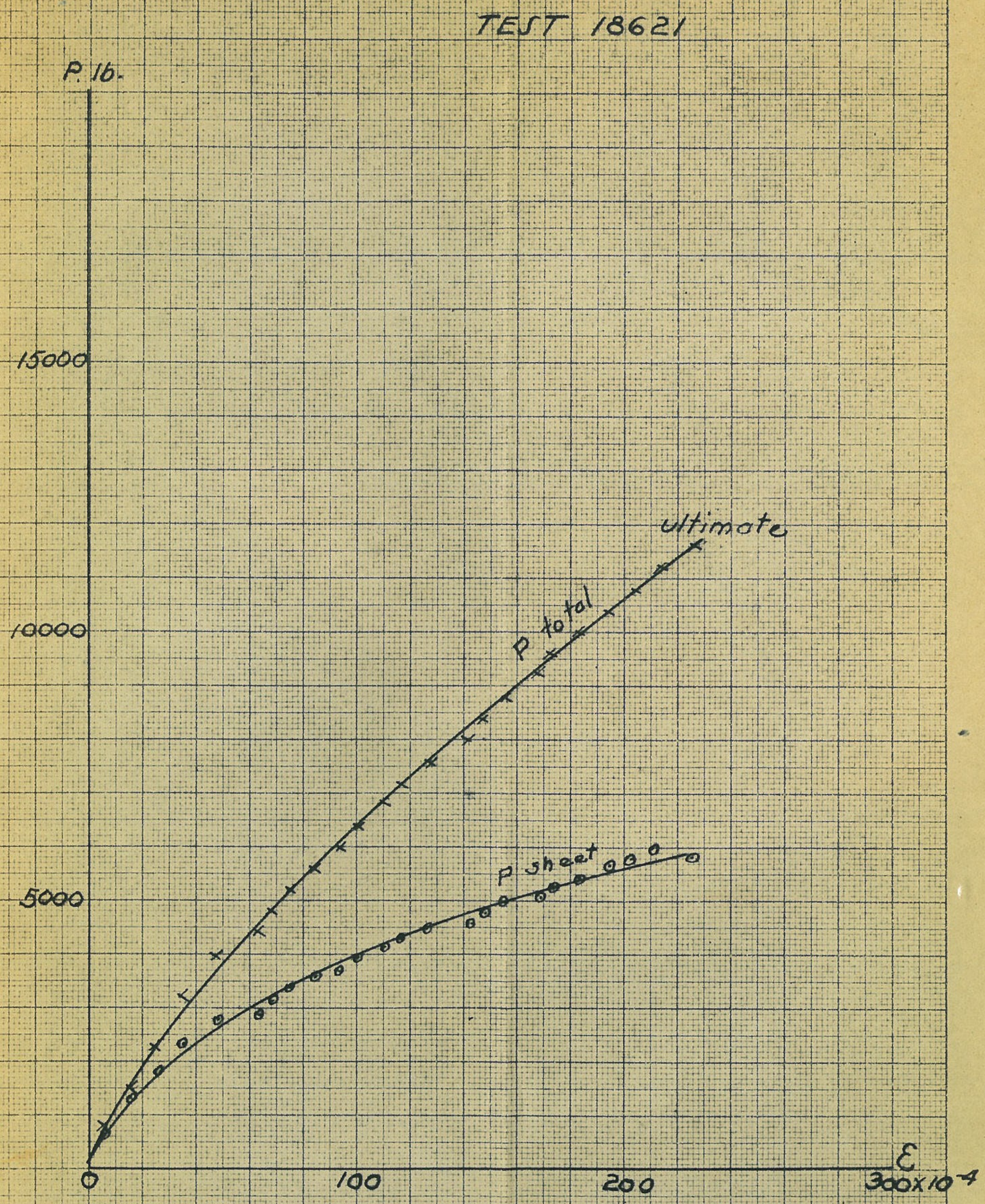
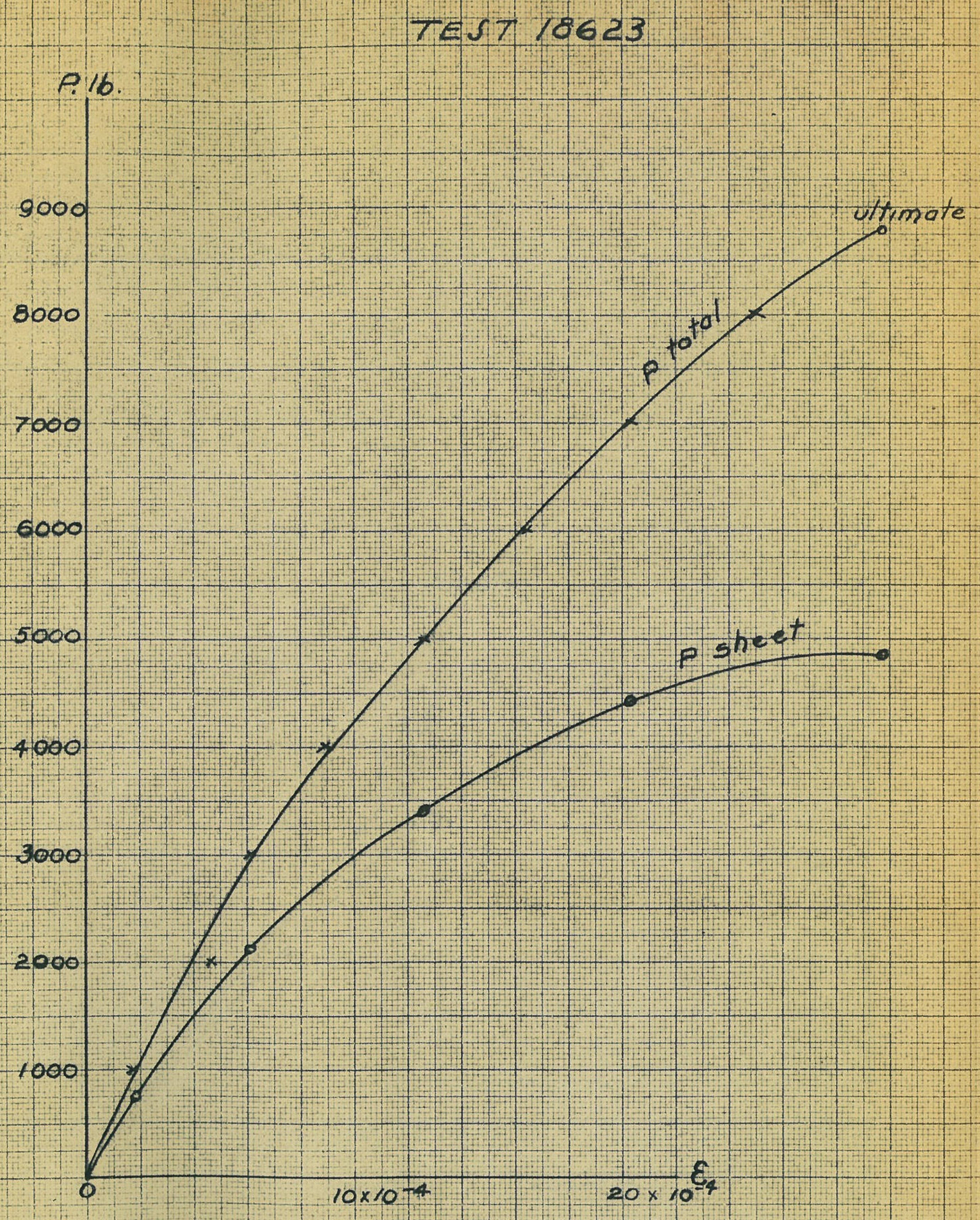

TEST 18621
P lb.
15000
10000
5000
0
100
200
300x10⁻⁴
ε
ultimate
P total
P sheet

Fig. 24


TEST 18623
P. lb.
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
10 x 10^-4
20 x 10^-4
ε
ultimate
P total
P sheet

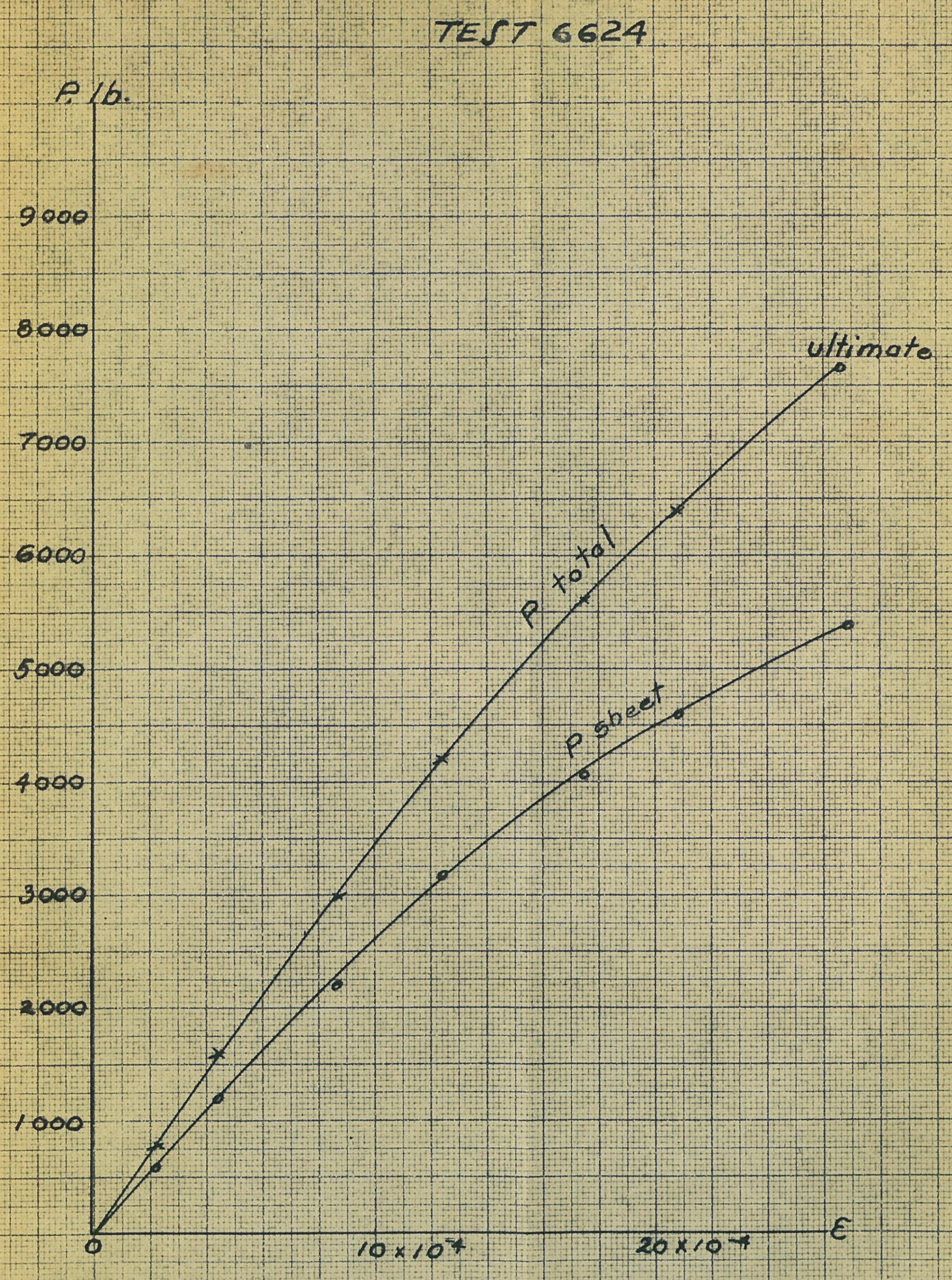

TEST 6624
P. lb.
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
10 x 10^-4
20 x 10^-4
ε
ultimate
P total
P sheet

Fig 25

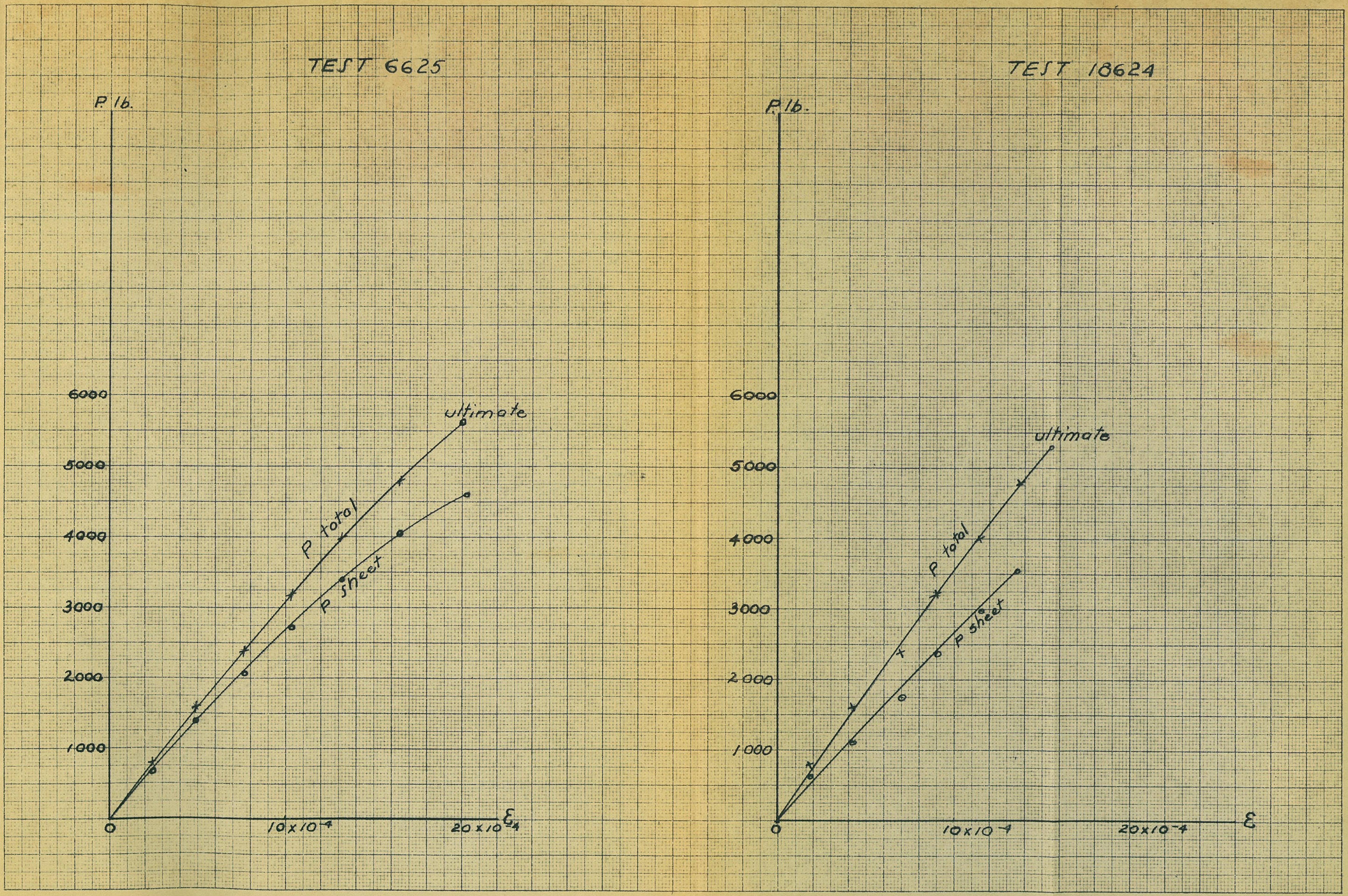
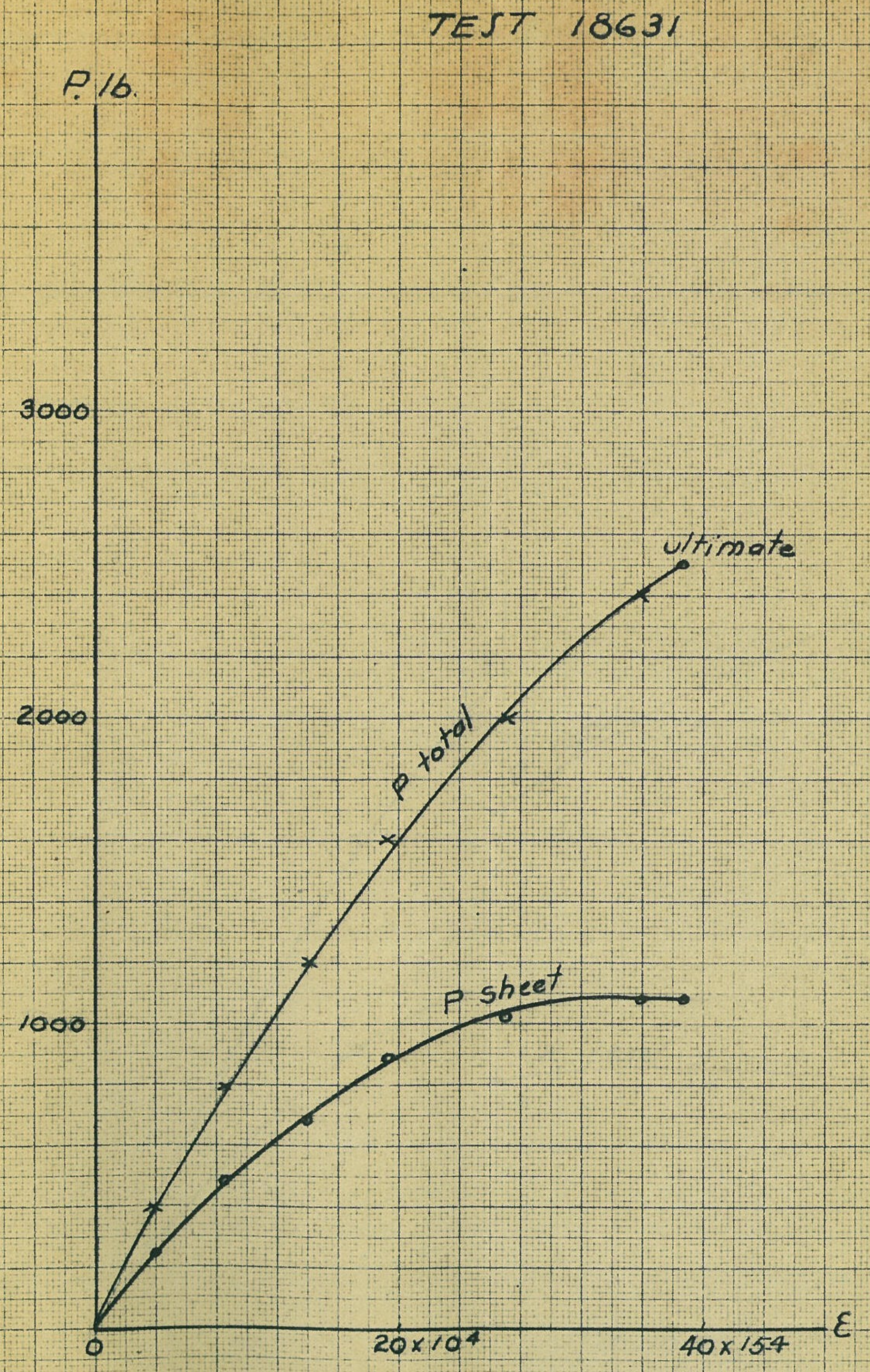
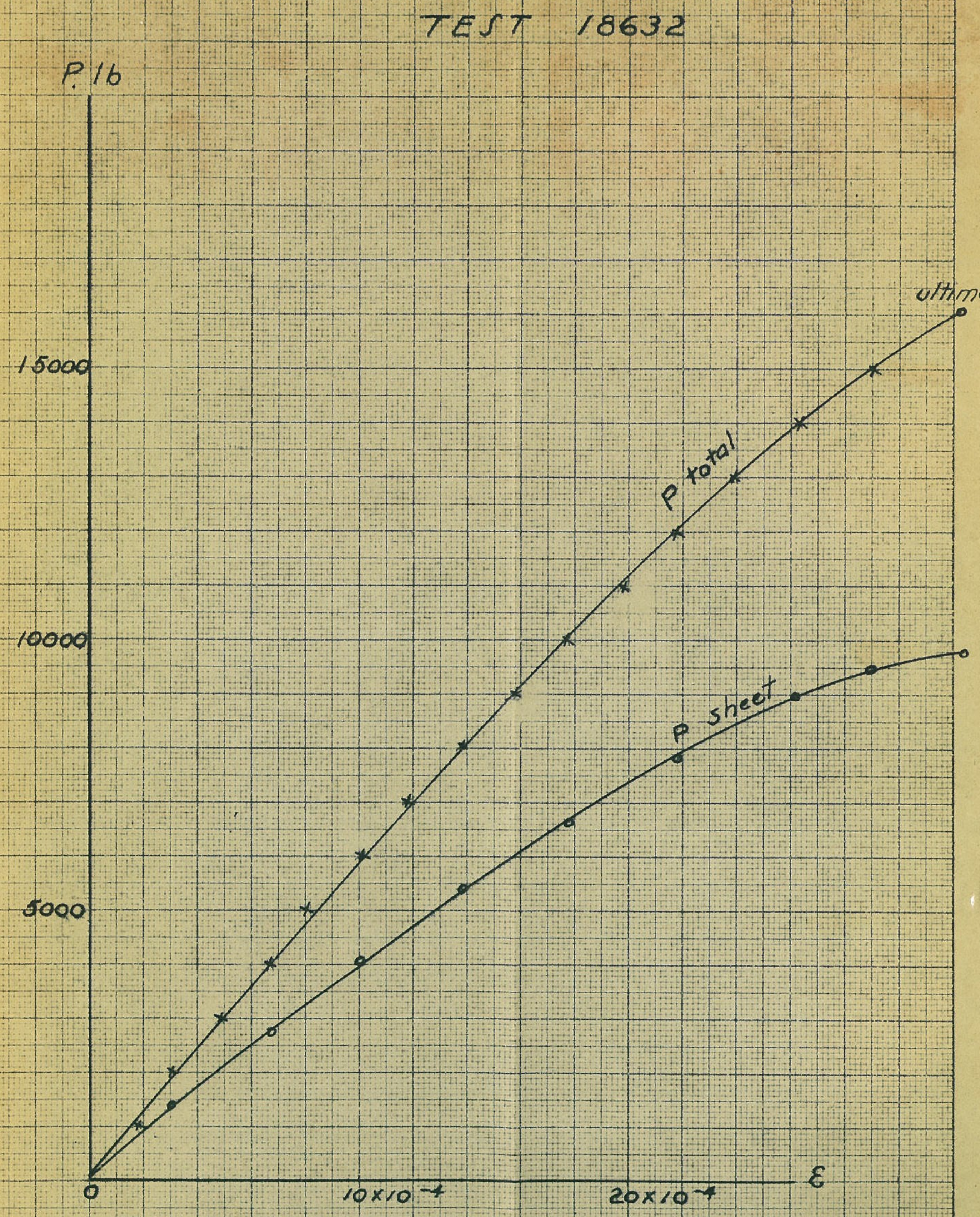

TEST 6625
P lb.
6000
5000
4000
3000
2000
1000
0
10 x 10⁻⁴
20 x 10⁻⁴
ε
ultimate
P total
P sheet
TEST 18624
P lb.
6000
5000
4000
3000
2000
1000
0
10 x 10⁻⁴
20 x 10⁻⁴
ε
ultimate
P total
P sheet

Fig. 2c



TEST 18631
P. lb.
3000
2000
1000
0
ultimate
P total
P sheet
20x10⁴
40x154
ε



TEST 18632
P. lb
15000
10000
5000
0
ultimate
P total
P sheet
10x10⁻⁴
20x10⁻⁴
ε

Fig. 27

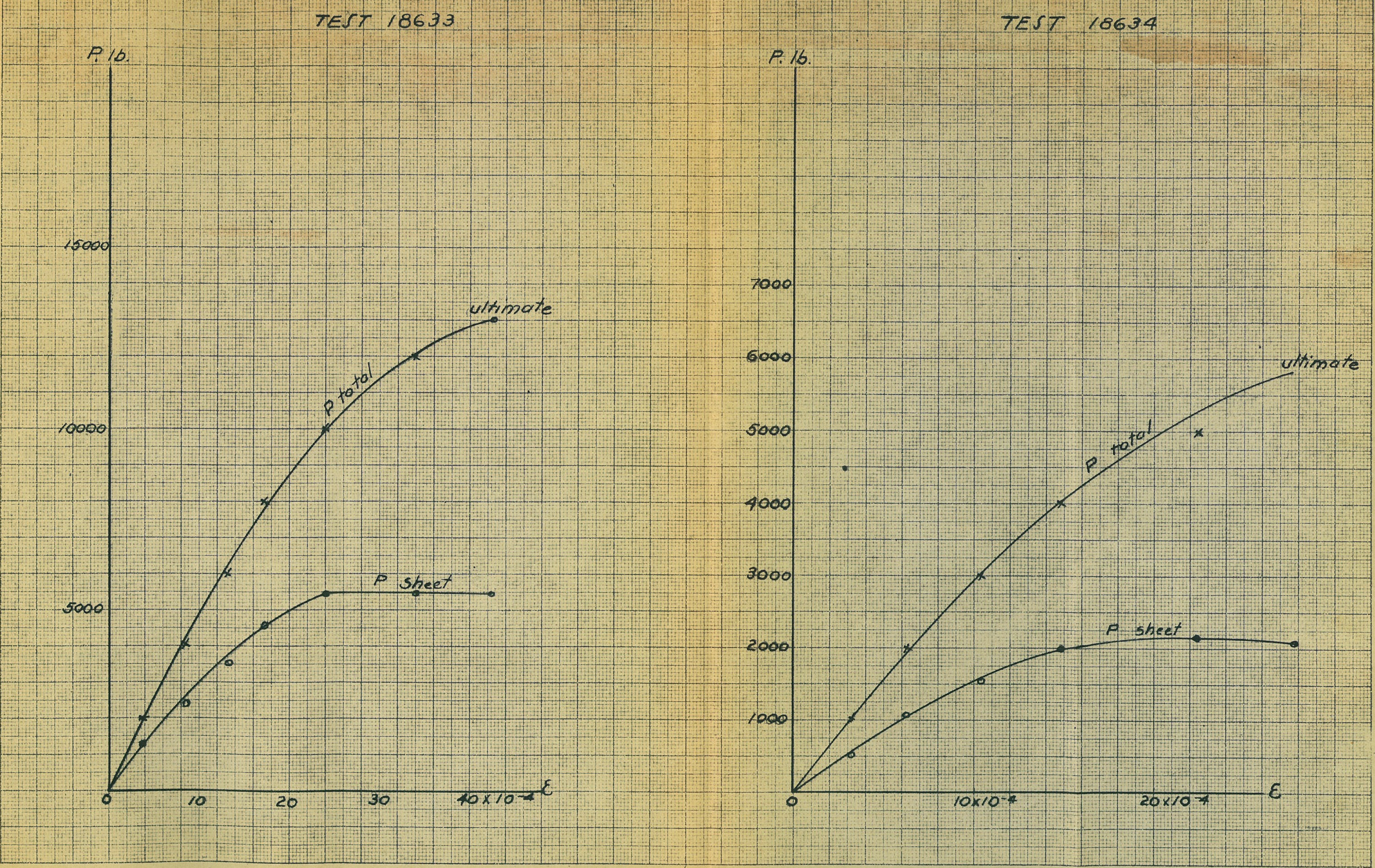
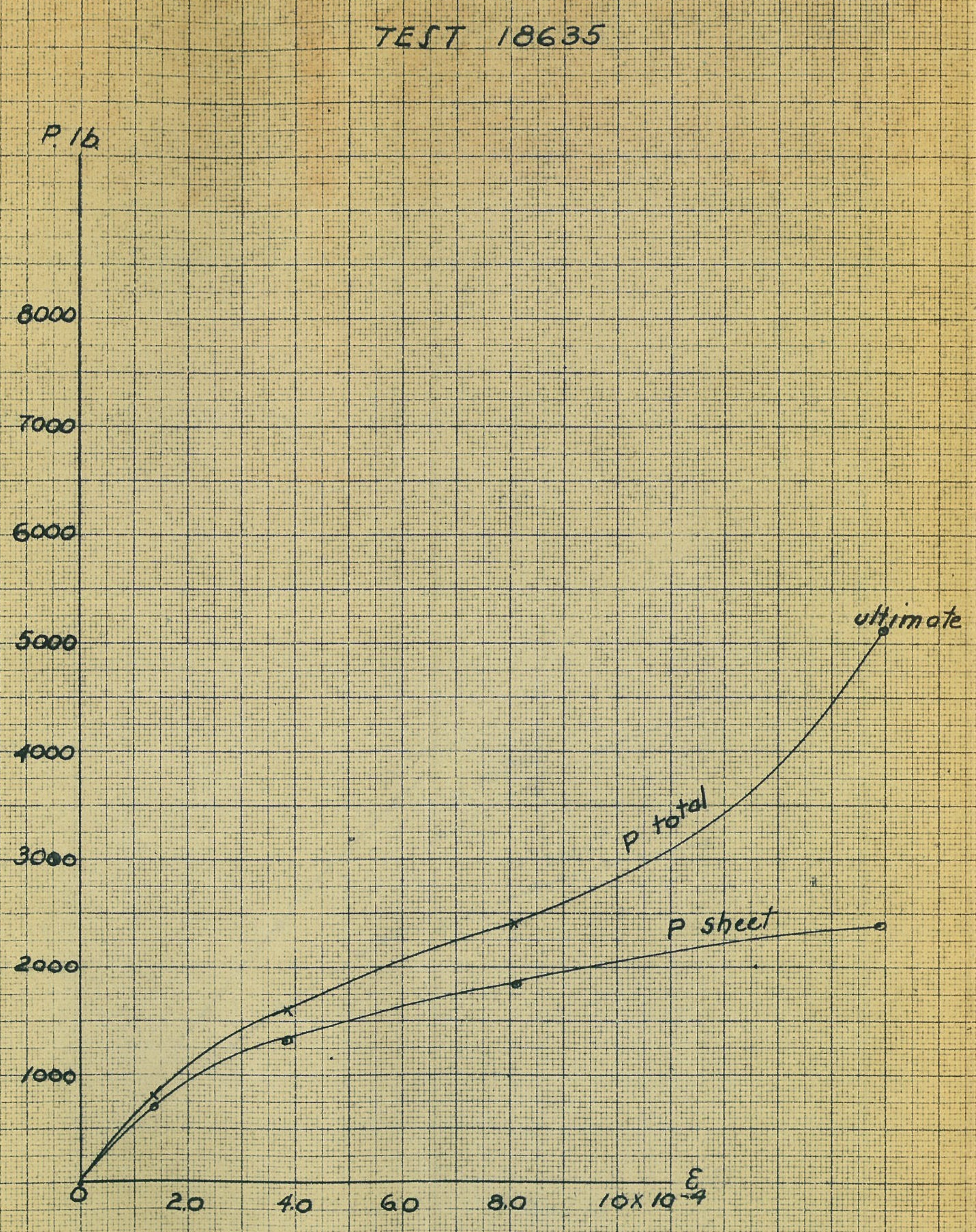

TEST 18633
P. lb.
15000
10000
5000
0
10
20
30
40 x 10⁻⁴
ε
ultimate
P total
P sheet
TEST 18634
P. lb.
7000
6000
5000
4000
3000
2000
1000
0
10x10⁻⁴
20x10⁻⁴
ε
ultimate
P total
P sheet

Fig. 28


TEST 18635
P. lb.
8000
7000
6000
5000
4000
3000
2000
1000
0
2.0
4.0
6.0
8.0
10 X 10^-4
ε
ultimate
P total
P sheet

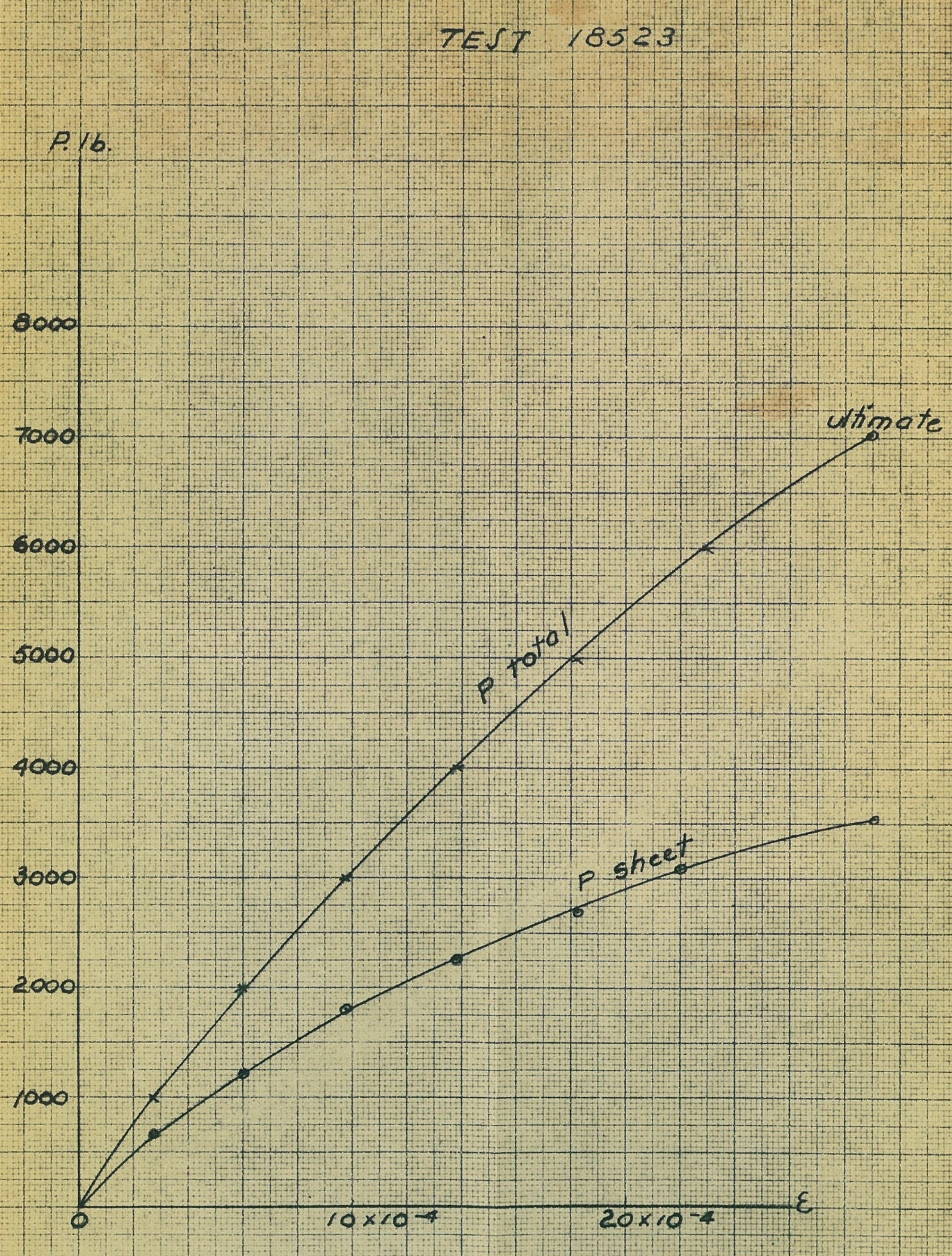

TEST 18523
P. lb.
8000
7000
6000
5000
4000
3000
2000
1000
0
10 X 10^-4
20 X 10^-4
ε
ultimate
P total
P sheet

Fig. 30

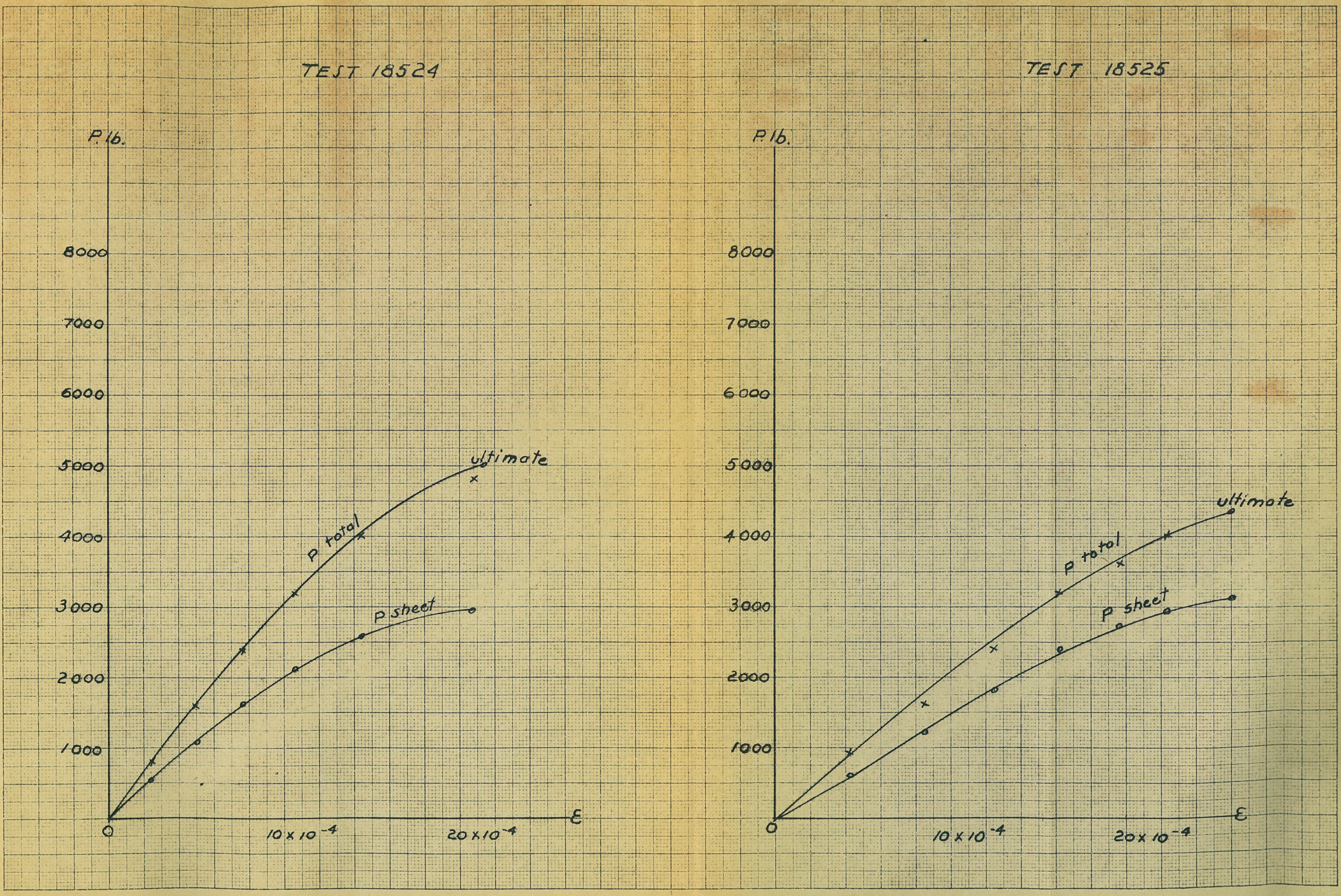

TEST 18524
P lb.
8000
7000
6000
5000
4000
3000
2000
1000
0
10 x 10^-4
20 x 10^-4
ε
ultimate
P total
P sheet
TEST 18525
P lb.
8000
7000
6000
5000
4000
3000
2000
1000
0
10 x 10^-4
20 x 10^-4
ε
ultimate
P total
P sheet

Fig. 30

UNSTIFFENED PANEL TESTS

Panels 6" x 6" x 1/8"

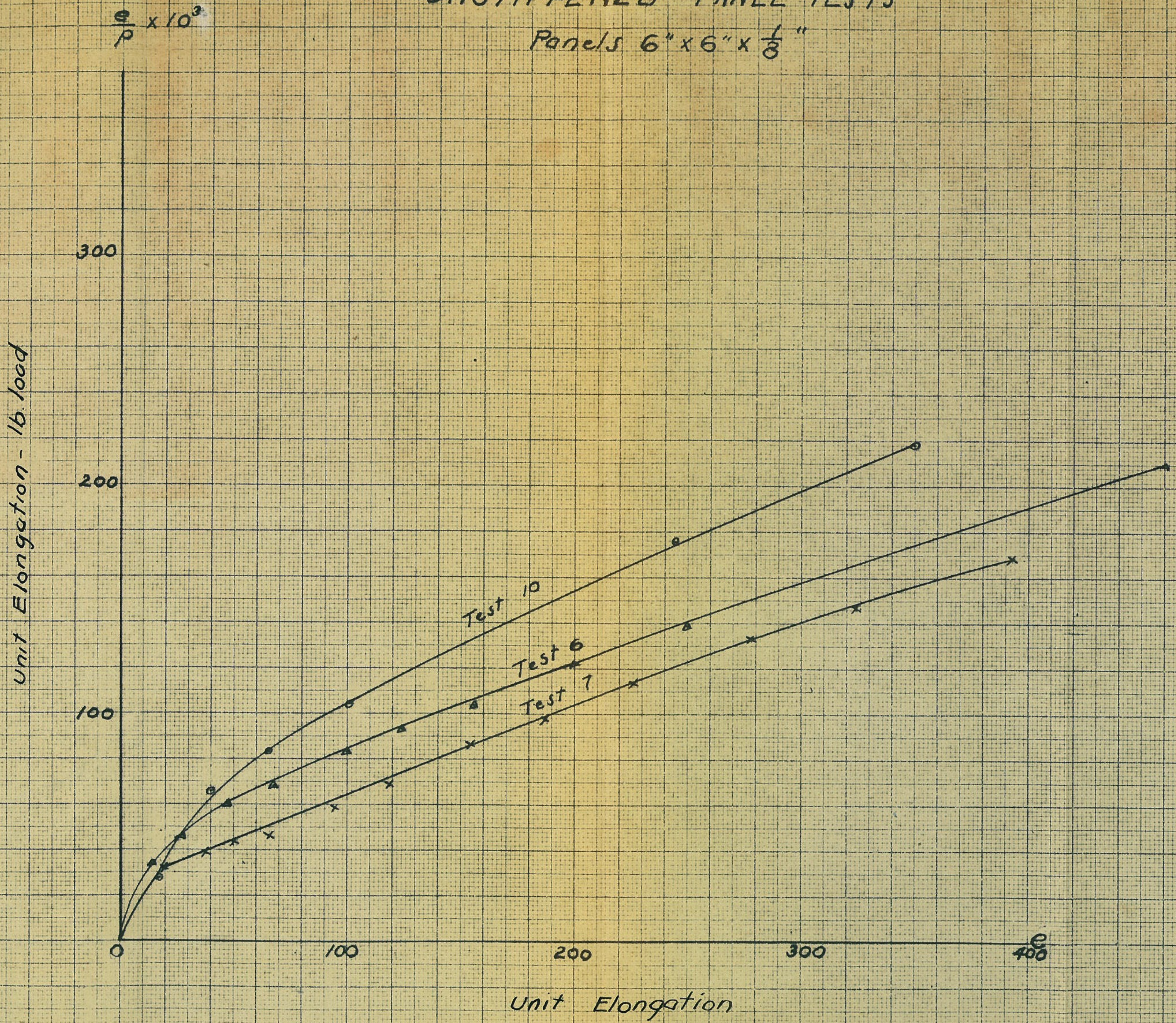


Fig. 31

UNSTIFFENED PANEL TESTS

PANELS 12" x 12" x $\frac{1}{8}$"

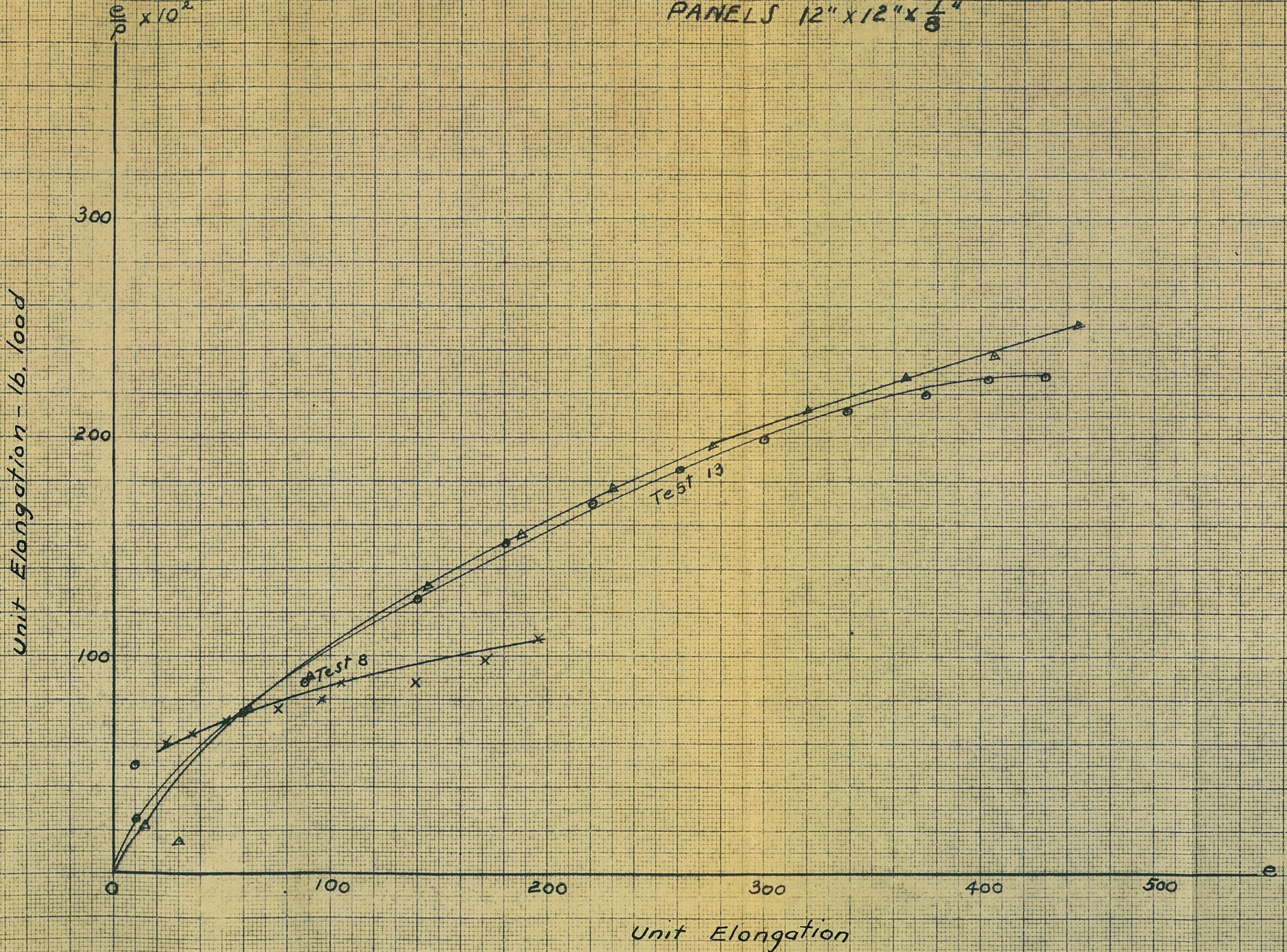


Fig. 32

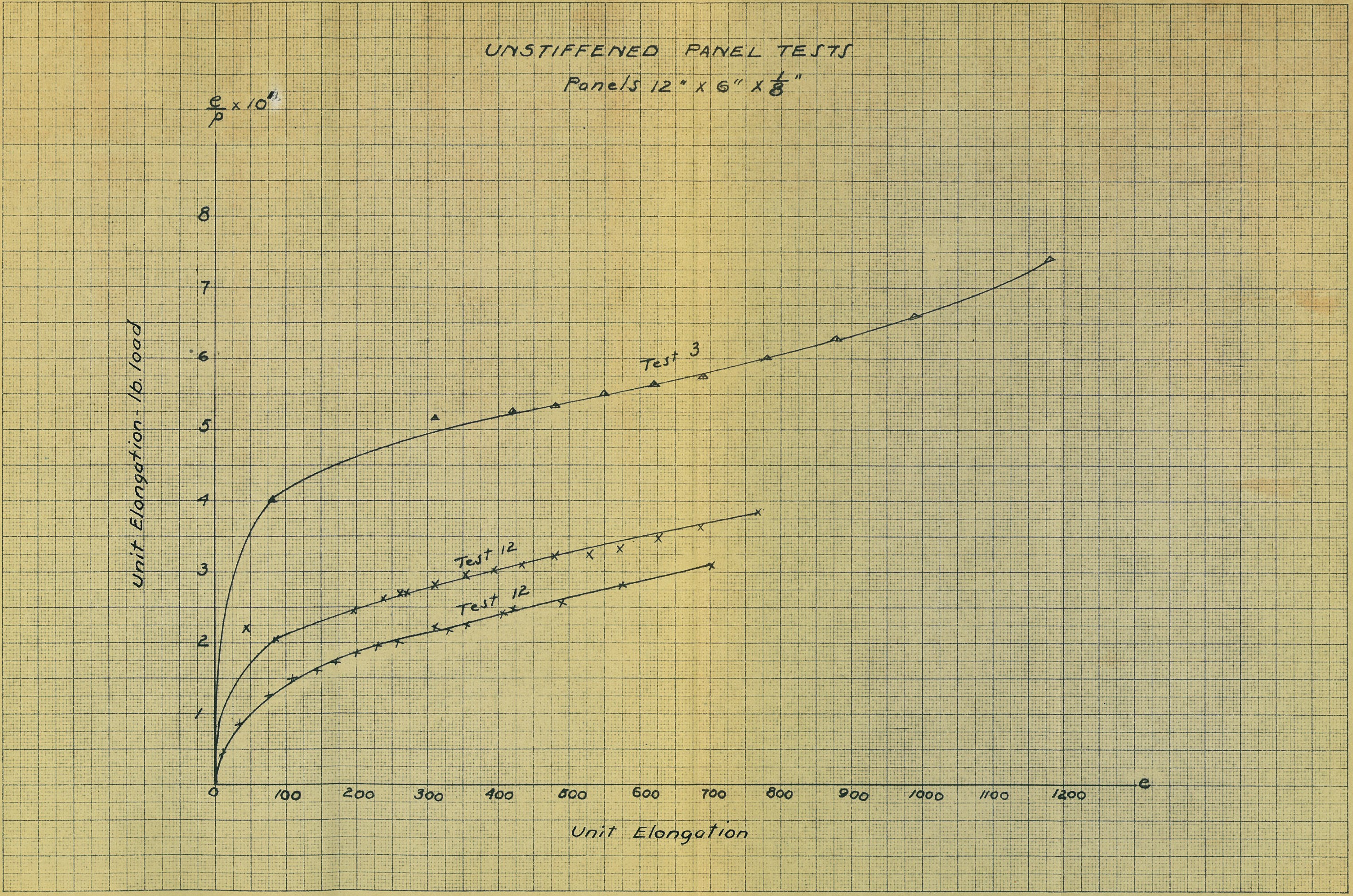

UNSTIFFENED PANEL TESTS
Panels 12" x 6" x 1/8"
e/p x 10^6
Unit Elongation - lb. load
8
7
6
5
4
3
2
1
0
Test 3
Test 12
Test 12
100
200
300
400
500
600
700
800
900
1000
1100
1200
e
Unit Elongation

Fig. 33

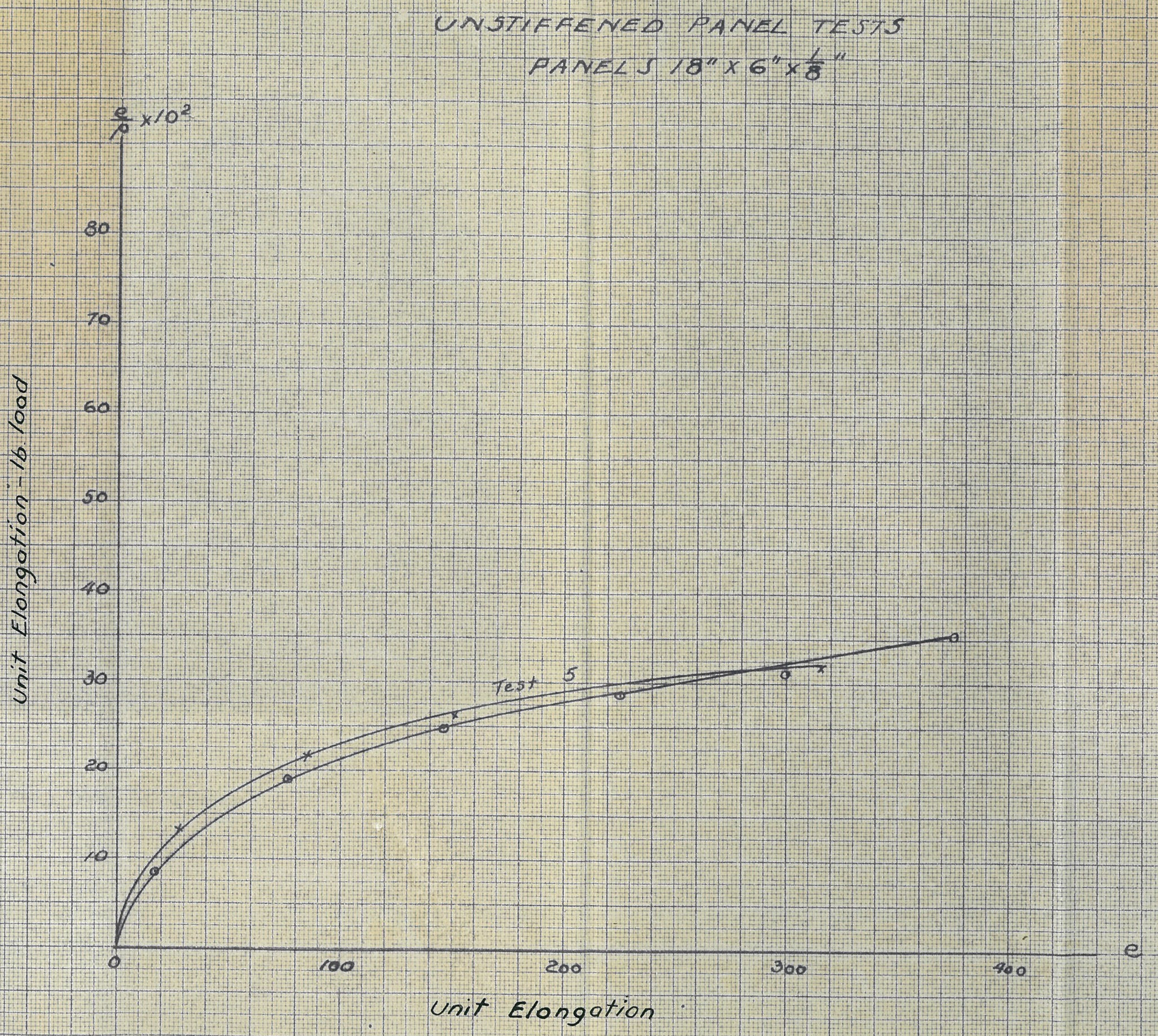

UNSTIFFENED PANEL TESTS
PANELS 18" x 6" x 1/8"
e/p x10²
Unit Elongation - lb load
80
70
60
50
40
30
20
10
0
100
200
300
400
e
Test 5
Unit Elongation

Fig. 34

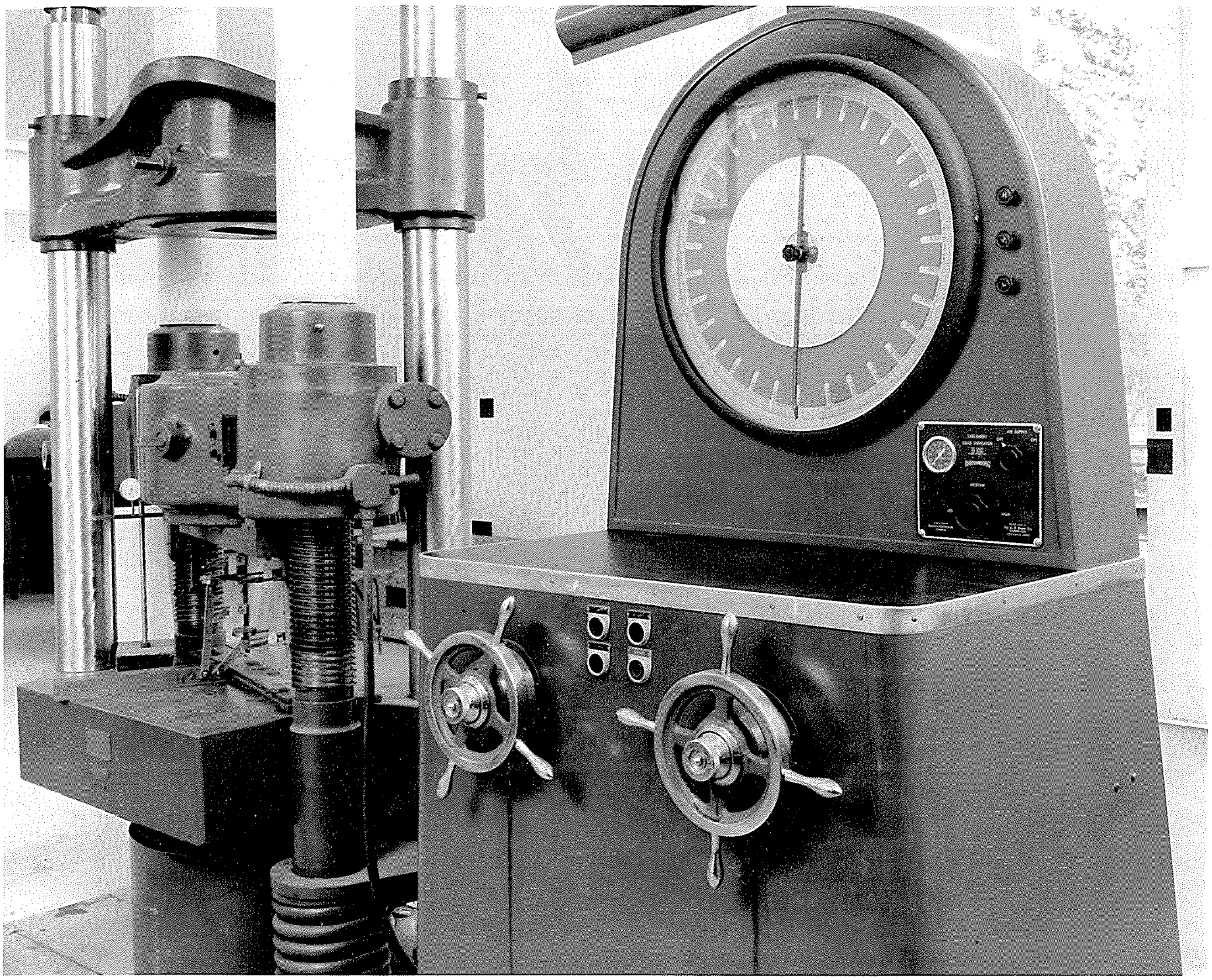


FIG. 1 GENERAL VIEW OF MACHINE

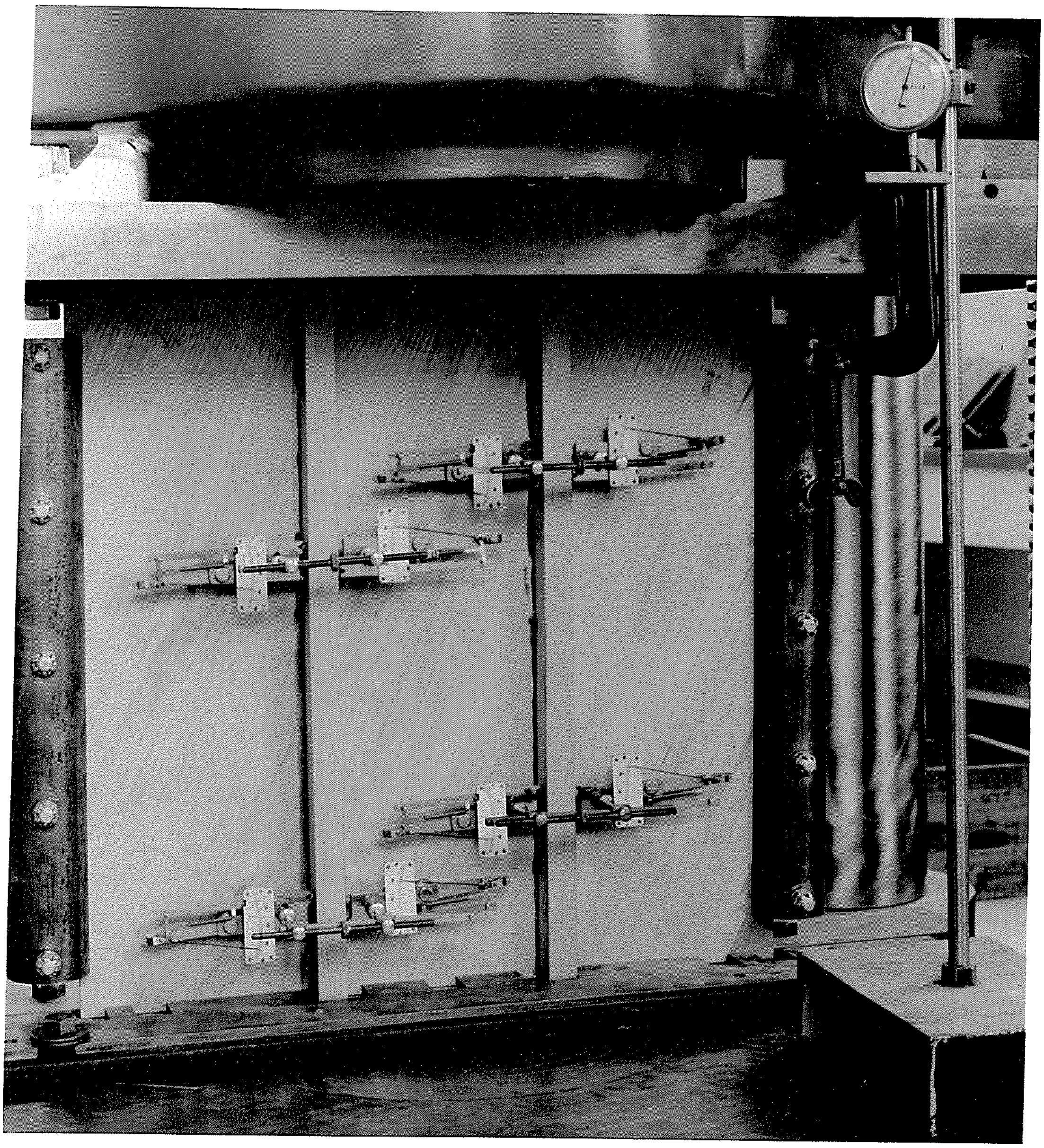


FIG. 2 STIFFENED PANEL TEST

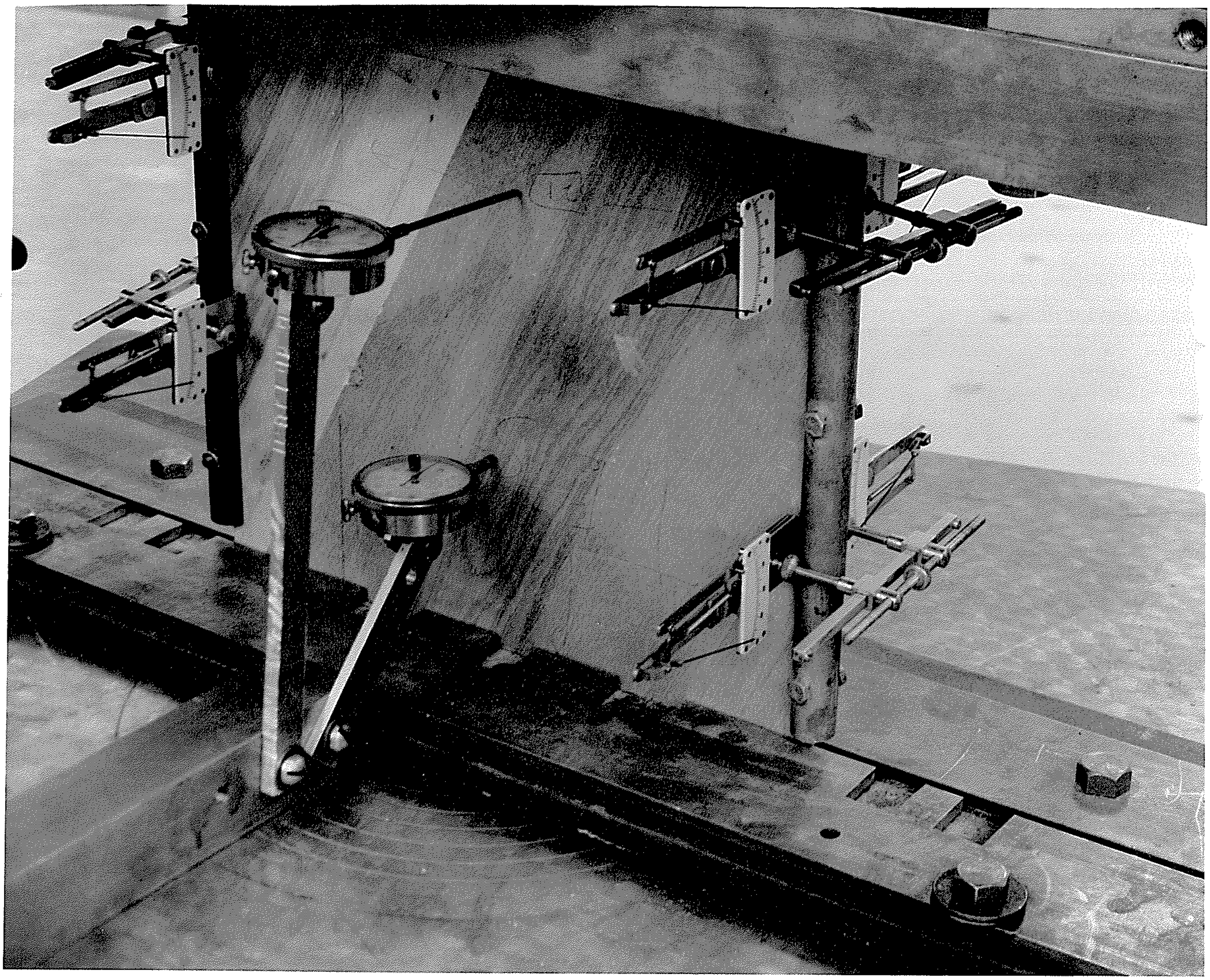


FIG. 3 UNSTIFFENED PANEL TEST

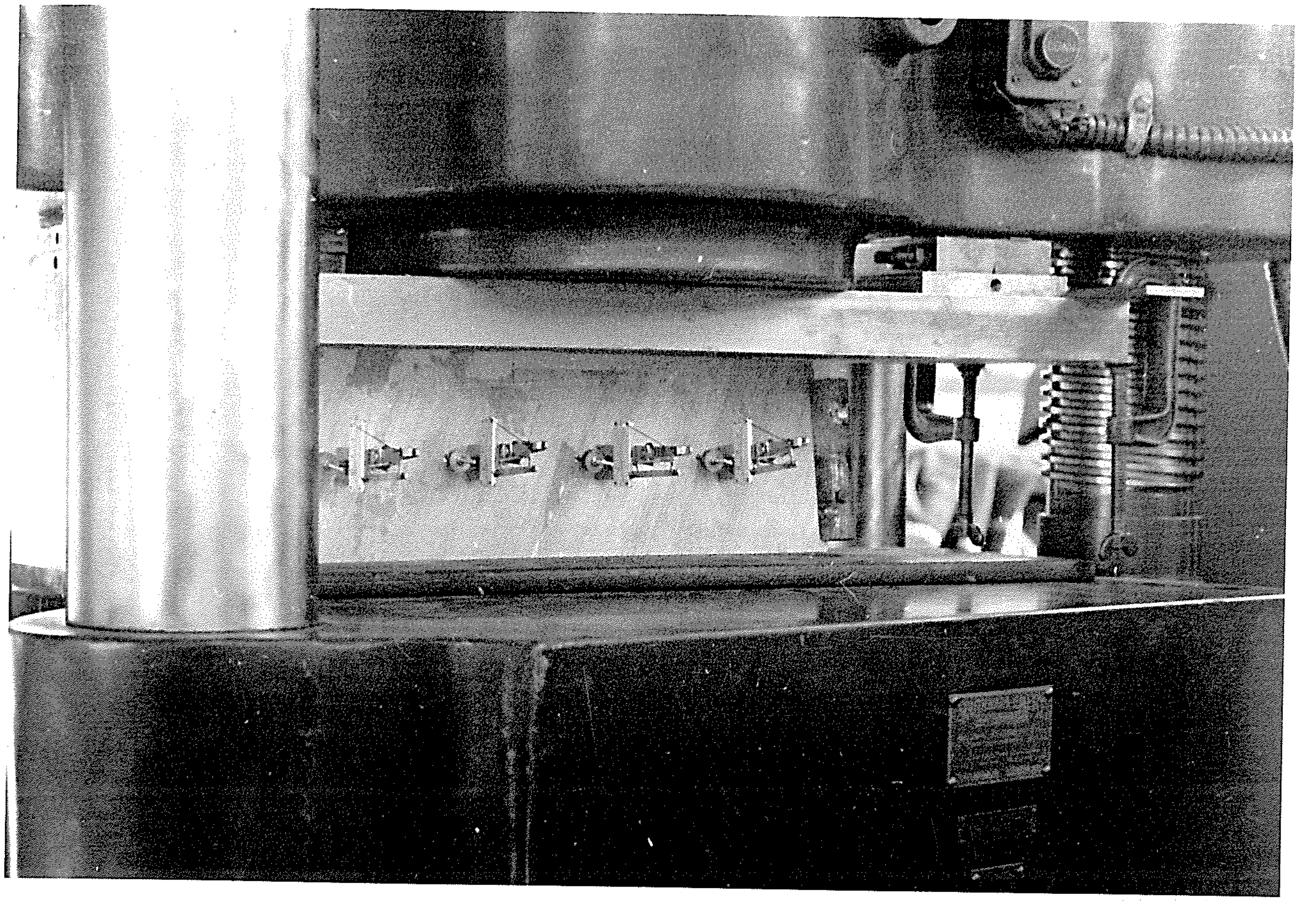


FIG. 4 ORIGINAL PANEL TEST