A CORRELATION OF REPEATED TENSION IMPACT TESTS WITH OTHER TENSION TESTS OF OF 17ST DURALUMIN

Thesis

by

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SUMMARY

The strain distribution after repeated tension impacts along the length of several differently dimensioned specimens of 17ST Duralumin is determined for various energies per blow.

An attempt is made to determine a relationship between the energy available per blow, the dimensions of the specimen, and the number of blows required to cause failure of the specimen by repeated tension impacts.

A relationship is determined between the percent total elongation and the length-to-diameter ratio.

A relationship is determined between the energy per unit volume required to cause failure and the length-to-diameter ratio under static tension, dynamic tension, and repeated tension impact conditions.

A "Modulus of Destructiveness" is proposed for 17ST duralumin.

A method is presented for predicting the number of repeated tension impact blows necessary to cause failure of a part.

INTRODUCTION

Previous repeated tension impact investigations at the Guggenheim Aeronautical Laboratory, California Institute of Technology, have been made with three types of testing machine, namely Tinius Olsen-Izod, Matsumura, and falling carriage.

The falling carriage machine, designed by Coates and Beardsley (see ref. b) at the GALCIT, has been least used in these investigations. Olsen and Brown (see ref. d), the only investigators previously using it, reported the machine unsuitable for impact test velocities above six feet per second due to bending of the specimens.

The present authors modified the falling carriage machine to overcome the difficulty of specimen bending, and used this machine exclusively for tension impact tests.

Basically the machine (see figs. 1-a and 1-b) consists of a carriage which slides on vertical guides, its fall being stopped by a heavy anvil. Rebound of the carriage is prevented by two catches on the anvil. One end of a test specimen is screwed into the bottom of the carriage, and to the other end of the specimen is screwed a weight. The carriage is raised to a set height and let fall. It is stopped by the anvil which has a central hole through it. The weight on the specimen continues to fall through this hole after the carriage is stopped, exerting a tension impact blow on the specimen.

The height of fall of the carriage and the magnitude of the weight attached to the specimen determine the energy of the blow. Thus velocity of impact and available energy of impact may be varied independently of each other.

The carriage is raised by a trip hook attached to a motor driven endless chain. The hook is tripped by a cam, allowing the carriage to fall. Three such hooks are mounted on the chain, giving a rate of about five blows per minute when operated continuously. To prevent shock on pick up of the carriage, coil springs are inserted in the lifting element on the carriage.

Bending of the specimen was encountered in preliminary tests conducted by the authors, due to horizontal vibration of the weight after the carriage struck the anvil. To prevent this bending a ball and socket fixture was designed to mount on the bottom of the carriage (see fig. 1-c). The specimen is screwed into the ball element. To absorb rebound motion of the specimen and attached weight after fall, a rubber damping pad is mounted above the ball element which is flat on top.

The velocity of impact for all tests was maintained at 13.32 feet per second. Equipment was mounted on the testing machine for determining the acceleration of fall of the carriage. This equipment, employing an interrupted spark coil, provided a record of the position of the carriage at every thirtieth of a second of time during its fall. The result of repeated measurements by this means showed the acceleration of the carriage to be no measureable amount different from the acceleration of gravity. Hence the energy per blow was taken as the weight times the height of fall.

Load weights used in the tests included the following:

17.922 lbs.

11.923 "

7.923 lbs.

3.930 "

2.430 "

0.629 "

Any weight contributed to the impact energy by the specimen itself has been neglected in this investigation. The weight of the specimens used ranged from one-half to one and one-half ounces for the different sizes. The proportion of the specimen weight actually contributing to the tension impact blow is a questionable matter; even if all the specimen weight is considered as so acting, the quanti y is negligible for the load weights used.

Six types of specimens (see Fig. 2) were used. These types are as follows:

Type designation	Test section length	Test section diameter
A	1.00 in.	0.300 in.
B	4.00 "	0.300 in.
C	8.00 "	0.300 in.
D	2.83 "	0.300 in.
E	2.83 "	0.178 in.
F	4.00 "	0.253 in.

The material of all specimens was 17 ST duralumin. After machining, specimens were polished to remove machining marks.

Fine scribe lines were placed at every tenth of an inch of length on the surface of the specimen by means of a razor blade. For placing the scribe lines a machine known as a comparator was used, having a screw driven head which moved the razor blade mount. The comparator was also used to measure the elongations of the specimens, with a microscope mounted on the comparator head. Readings were taken from a micrometer connected to the screw shaft. Accuracy of results is believed to be within one-thousandth of an inch.

Two types of test other than repeated tension impact test were made for purposes of comparison. These were dynamic tension and static tension tests. The dynamic tension tests were carried out by the Impact Laboratory, California Institute of Technology, and consisted of breaking a specimen in tension by a single blow at a specified velocity of impact and recording the stress values versus time. From these data, a stress-strain curve for the specimen was obtained.

STRAIN DISTRIBUTION

The strain distribution on each of the specimens tested is shown graphically in Figs. 3 to 37 inclusive. The "a" curve of each figure shows the actual strain distribution or the unit elongation in each tenth of an inch. The "b" curve of each figure shows the total elongation up to each point in question and is really an integral curve of the corresponding "a" curve.

For plotting the total elongation curves, data were obtained by taking the accured elongations at each scribe line. To obtain the unit elongation data at any point, the total elongation at that point was diminished by the total elongation at the previous point.

It may be noted that the unit elongation of the first tenth of an inch of each specimen appears on the graph sheet as negative in value. This elo gation is actually positive; it is merely plotted below the horizontal axis due to the manner of measuring it. Rather than use the shoulder at one end of the specimen test length as a reference mark for all measurements, the first tenth of an inch scribe line from the shoulder was used as the reference mark. This afforded more consistent accuracy of measurement as the shoulder point was difficult to determine with accuracy, due to the fact that this point was badly out of focus in the microscope which was focused on the test section of the specimen. The elongation of the first tenth of an inch then appears negative only in direction from the reference line.

The elongation shown for the tenth of an inch increment at each end of a specimen is not considered to be as accurate as for the rest of the specimen owing to focus difficulties and to inexactness of machining.

The shapes of the strain distribution curves show considerable similarity. There are in general three different phases of strain distribution resulting on each specimen from repeated tension impacts. These can perhaps best be seen in Fig. 21-a wherein the distribution after each blow has been plotted. After blows 1, 2, and 3 the distribution remains quite uniform, with regular displacement upward, the amount of displacement decreasing only slightly with increasing number of blows. This phase of uniform distribution holds for 25% of the total number of blows to break in this particular case, but the average of all specimens tested shows this phase to hold for about 35% of the total number of blows to break.

After the fourth blow (Fig. 21-a) we find that the ends of the specimen did not elongate at all but that the central portion suffered elongation much more severe than previously, with the result that the increase in total elongation as shown in Fig. 21-b remains nearly the same as before. The next, or fifth, blow shows similar results except that the distribution is reversed, the central portion holding steady while the ends elongate excessively. The portions which previously elongated had increased yield strength due to the cold working and hence did not elongate. The sixth blow shows the same effect except that here the elongation occurs in four regions, one at each end and one about one-third of the length from each end. Subsequent blows show the same tendencies with the regions where elongation occurs moving back and forth along the length of the specimen but always quite symmetrical about the center of the specimen. The average unit and the total elongations show a fairly uniform increase in magnitude until necking begins.

The third or necking phase begins just before the specimen breaks and is characterized by excessively high unit elongation over a short length of the specimen. This necking and subsequent break usually occur near one end of the specimen but in a few cases occur in the central region. There seems to be no way of predicting at which end of the specimen the break will occur since there is almost invariably a similar necking of only slightly lesser magnitude occuring at the opposite end. Fig. 20-a perhaps shows this property best. In this instance there was an actual crack part way through the specimen at the end opposite to the break. For an average of all specimens tested the necking phase occurs during the last 20% of the blows.

To summarize, the strain distribution falls into the following three phases:

1. Uniform distribution for first 35% of the blows.
2. Symmetrical variably located local elongation for the next 45% of the blows.
3. Extremely localized necking for the last 20% of the blows.

Energy wave propagation theory (see ref. n) would indicate a marked increase in stress as evidenced by higher unit elongation near each end of the specimen due to the reflection and consequent reinforcement of the energy waves in the specimen at these points. In most of the specimens this tendency is not evidenced to any considerable extent in the first few blows, a fairly uniform distribution being obtained for the first 35% of the blows as mentioned above. However, in the second and third phases the higher end elongations usually become evident. For specimens D and E this phenomenon appears even in the first phase.

The strain distributions on the specimens subjected to static tests and to dynamic tests were observed. These distributions, shown in graphical form in Figs. 38 to 49 inclusive, are all seen to be of the same general order as for the final blow of the repeated impact specimens. The unit strain level is approximately constant along the length except in the region where necking occurs. This leads to the conclusion that the general strain distribution is not materially altered by the method of testing, except for the energy wave reflection effects in the repeated impact cases.

The maximum unit elongations in the necking region vary somewhat with the three methods of testing. In general, comparing particular groups of specimens, we find the static tests to give the lowest, and the repeated impact tests to give the highest maximum unit elongations, with the value for the dynamic tests falling roughly midway between the other two methods. The average maximum unit elongations are as follows:

By static tests 45.5%

By dynamic tests 54.0%

By repeated tension impact tests. 62.0%

Only slight variation in total elongation after failure with method of testing is evidenced. The average values (see Table III) show repeated impact tests to give an elongation of 15.9%, static tests 15.0%, and dynamic tests 16.8%. However, these results vary so widely between types of specimen that they are not at all conclusive.

Examination of the necking length shown in figures 3-a to 37-a inclusive indicated that in all cases the average length of specimen affected by necking was approximately 1.67 d. On this premise we are led directly to the conclusion that there is a relationship between the length-to-diameter (l/d) ratio and the total elongation. As the total length of the specimen is decreased and approaches 1.67 d, the necking length becomes a greater portion of the whole length, and consequently the average percent total elongation should increase. As the length of the specimen increases and approaches infinity, the necking length should have less and less effect, so that the average total elongation should reach some practically constant value for large l/d ratios. This effect is experimentally verified by comparison of the average total elongations of the various specimens which are plotted against l/d ratio in Fig. 63. These experiments, however, do not extend to high enough l/d ratios to indicate precisely the asymptotic value reached by the total elongation but it will probably be in the neighborhood of 11%. Neither do they extend low enough to indicate what variation may be expected at or below a length of 1.67 d.

It may be of interest to point out what effect the scribe marks had on determining the location of the final fracture. In all cases for the static and the dynamic tests except one the fracture occurred at a scribe mark; i.e., the edge of the fracture contained the scribe mark. In the repeated impact tests there were many instances where the break occurred between scribe marks. This would tend to indicate that the specimens are generally less sensitive to surface irregularities or notch effects under repeated tension impact tests than under either static or dynamic tests.

Variation of Number of Blows to Break with Dimensions of Specimen and with Energy Available per blow

Previous investigations, Ref. b, c, and d, have shown that the number of blows required to break a given specimen, N, varies inversely as the energy available per blow, E_A. Theoretical considerations indicate that the number of blows at a given energy per blow would vary directly with the volume of the specimen. To investigate the effect of volume change and of relative dimension changes a series of tests was conducted for which the specimens were chosen as follows:

(a) Specimens A, B, C, and D to have the same diameter and cross sectional area but to have lengths of 1, 4, 8 and 2.83 inches respectively. Hence, the volumes and the length-to-diameter ratios (l/d) vary directly as the lengths.

(b) Specimen E to have the same volume as Specimen A but to have the same length as Specimen D.

(c) Specimen F to have the same volume as Specimen D but to have the same length as Specimen B.

The following table gives the most important dimensional properties of the series of specimens.

Specimen Letter	Diameter, d, in.	Area, A, sq. in.	Length, l, in.	l/d	Volume in.^{3}
A	0.300	0.0707	1.00	3.33	0.0707
B	0.300	0.0707	4.00	13.33	0.2828
C	0.300	0.0707	8.00	26.67	0.5656
D	0.300	0.0707	2.83	9.42	0.2000
E	0.178	0.0249	2.83	15.90	0.0707
F	0.252	0.0499	4.00	15.87	0.2000

Table I gives comparisons showing the effect of the variations of the above dimensions on the number of blows required to break. The following effects are apparent:

(a) With the diameter and cross sectional area constant, the number of blows increases with the length of the specimen.

(b) With length constant, the number of blows varies directly with the cross-sectional area.

(c) With the volume constant, the number of blows remains constant. One group of specimens does not agree with this statement; however, the other group does, and this, together with the comparisons of (a) and (b) above, indicates this statement to be true. It should be noted that between the A and the E specimens there is a radical change in l/d ratio. This would seem to indicate that the l/d ratio might have some influence on the result.

From this comparison we may derive the general conclusion that the number of blows to break varies almost directly with the volume of the specimen, but that there is some indication that the number of blows may also vary inversely as the l/d ratio.

Following the lines of attack of previous investigators at the GALCIT the values of N, E, and N/E were calculated in Table II. Curves of E vs. N and of N/E vs. N were plotted as shown on Fig. 59. These curves showed the same general forms as indicated in reference (b).

The values of E vs. N, E vs. N/V and E vs. N/EV were then plotted on log-log coordinate paper as shown in figures 60 to 62 respectively. The first, E vs. N, showed roughly parallel curves. The E vs. N/V plot showed a wide scatter of points through which no definite curves could be faired. However, the plot of E vs. N/EV showed a linear form with not too great a variation from an average value. The equations for the median line and for the boundary lines indicated by the test points were worked out as shown on the figure. From these, equivalent equations for the relations between E and N/V were derived and plotted on Fig. 61. The lines thus determined include all the test data satisfactorily and it is believed that they might be used in predicting the number of blows to break for a given volume of material. However, it is not felt that such predictions would be sufficiently accurate to justify their use. As a typical example, at energy level of 8 ft.lbs. per blow, the mean line would predict 200 blows per cubic inch, whereas the limits indicate it might break in as few as 80 blows or it might hold through 430 blows.

Such a series of comparisons or predictions then seems to be too far outside the desired limits of accuracy to be worth while. However, to determine approximately the order of magnitude of the number of blows to be expected, the following equation might be used:

$$N = 2630 \frac{V}{E^{1.25}}$$

where N = number of blows to break

V = volume, in cubic inches

E = energy available per blow, in ft. lbs.

However, it should be used only to determine the order of magnitude and even this may not be a close value.

Correlation of Repeated Impact, Static and Dynamic Stress-Strain Data

Since the above calculations attempting to relate the Volume, Number of blows and the Energy Available per blow do not produce any correlation enabling an accurate prediction of blows to break, an attempt was made to determine such relations by correlation of Repeated Tension Impact data with data from static stress-strain curves of the material.

The area under a force-total elongation diagram represents energy in units of inch pounds for example. Similarly the area under the corresponding stress-strain diagram represents energy per unit volume, or simply energy when multiplied by the volume of the specimen. A typical stress-strain curve, Fig. 58, was obtained for a specimen of 17ST and this curve was used in making all the following calculations.

One assumption is made in the following analysis which the authors have not verified experimentally but which they believe leads to no significant error in the analysis. This assumption is that when the load is completely removed at any time after the yield point has been reached, the specimen will unload along a straight line exactly parallel to the slope in the elastic range; and that when the load is reapplied the specimen will load up again following the exact same line until it intersects the original stress-strain curve, and will then follow the original stress-strain curve. This assumption is more or less justified by references (b) and (p) wherein this effect is shown to be approximately as stated.

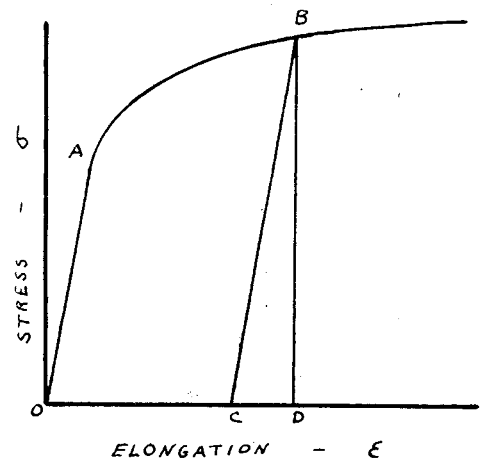
One other assumption is made; that the static stress-strain curve we are using is not changed appreciably by the rate of application of load, at least in the low speeds (about 13.3 ft. per. sec.) here encountered. This assumption is justified by reference (k) and is further verified by tests to be discussed later.

The first attempt at analysis was made by taking the total kinetic energy available per blow, $1/2\ MV^2$, and laying out its equivalent area under the stress-strain curve, determining from this a maximum stress and a maximum strain encountered during the blow. Using the above assumptions, the energy recovered during unloading of the specimen was calculated. The difference between these quantities was considered to be the plastic energy delivered to the specimen per blow. This process was repeated for subsequent blows until the last repetition took the values to the end point of the static stress-strain curve. The number of times this process was repeated was assumed to be the number of blows required to break the specimen. However, comparison with actual tests showed this number to be much less than the number actually required to break.

Any practical considerations must lead to the conclusion that not all of the kinetic energy of such a machine could be transferred to a specimen without losses of any kind. The above calculations verified this conclusion. The problem then became one of determining the amount or percentage of the energy of each blow which was transferred to the specimen. The key to finding this percentage of energy transferred to the specimen lies in the above discussion of strain distribution.

In the previous discussion we saw that the unit elongations are quite constant for about the first 35% of the blows. Hence we can pick an average percent elongation from the unit elongation charts or determine an average percent elongation by dividing the total elongation by the gage length. If the values for one blow are not given it will be sufficiently accurate to take the percent elongation for the least number of blows shown and divide this by the number of blows.

By the above method we locate the specimen on the stress-strain diagram at the zero stress level, point "C" on the accompanying figure. Then using the above unloading assumptions, draw CB parallel to OA, determining point "B" on the stress strain curve. Drop BD vertically to the strain axis. Then the area OABDO represents the energy per unit volume transferred to the specimen in the first blow. The ratio of this energy, which we shall call E_1, to the total kinetic energy per blow per unit volume, E_A = 1/2 $MV^2 \div$ vol., represents the energy transfer ratio for this particular specimen. Let us call this ratio K_1.



It is to be expected that K_1 should have a value less than unity. It seems possible that this K_1 might actually be a constant for all weights and all specimens although it might vary with either.

Calculations of K_1 for each specimen tested, Column 11, Table III showed that it varied from 0.614 to 1.555. Only one set of specimens, the L specimens, showed the remarkable property of an energy transfer greater than unity. Eliminating this entire set of specimens we find the average K_1 to be 0.800 with individual values ranging from 0.614 to 0.971. Only 5 of these are below 0.700 and only 6 above 0.900, the remaining 20 being within 12.5% of the mean value. It is believed that this value may be within the limits of accuracy of the experiments and that this energy transfer constant may be taken as 0.800.

As for the extreme variation of K_1 shown by the E specimens there is no completely satisfactory explanation apparent. Since it occurs generally for all the E specimens, the magnitude reaching a peak at one mass and decreasing with both greater and lesser masses, it seems to indicate a resonant vibrating condition. It is probable that the falling carriage itself tends to vibrate vertically after striking the anvil. We know that the weight on the end of the specimen vibrates vertically after the carriage strikes the anvil. It therefore seems highly possible that with the right combination of masses and with the right "effective spring constant" in the form of a particular specimen, the carriage may be vibrating upward with a very high acceleration while the mass on the end of the specimen is still moving downward, thereby applying momentary high stresses to a properly shaped specimen so as to result in excessive elongations. This suggestion is offered as a possible explanation for the extreme variation of K_1 shown by the E specimens. This resonant property may depend on volume and the l/d ratio, but it does not depend on the l/d ratio alone since the F specimens which have almost the same l/d ratio as the E specimens exhibit none of these peculiarities.

The area CBDC of the above sketch, the elastic energy recovered in unloading, was next calculated for all specimens. This elastic energy per unit volume per blow was subtracted from the total energy per unit volume transferred to the specimen per blow, giving the plastic energy per unit volume transferred to the specimen per blow. For a first approximation it was assumed that this same amount of plastic energy is absorbed by the specimen on each subsequent blow. This amount of energy was then multiplied by the number of blows to break and the total energy per unit volume required to break the specimen was obtained as shown in Column 14, Table III.

The above assumption of constant plastic energy per blow does not appear to be quite exact because of the fact that as greater elongations are reached, a greater percentage of the total energy transferred is recovered as elastic energy in unloading due to the constantly increasing yeild point. This variation should be particularly noticeable on specimens having very short elongations on the first blow, say less than 1%. A more exact method of procedure would be to repeat the above calculations and determine the exact amount of plastic energy transferred in each blow. This might give slightly lower total energies, but it is not felt that such refinement in technique is required at the present stage of the investigations.

For most of the specimens this value of total energy per unit volume to break remained fairly constant for each type of specimen. However, between types of specimens there seemed to be considerable variation. Thus a variation of total energy per unit volume with specimen dimensions was indicated. It was felt that possibly the actual static stress-strain curves of each particular type of specimen might exhibit variations which could explain these irregularities. Also it seemed desirable to make static tension tests of each specimen to see if it had been sufficiently accurate to use this particular curve as an average curve on which all calculations were based.

The results of these static tests are plotted in Figs. 50 to 55 inc. A comparative plot of all the static curves from these figures is shown in Fig. 56. It is evident that for all practical purposes and within the limits of accuracy of these tests these curves can be considered to coincide in the region up to the ultimate stress. After the ultimate stress is reached and the specimens start to neck there is a marked variation in the curves depending primarily on the 1/d ratio, the higher 1/d ratios generally showing smaller final average elongations as is to be expected. One of the F curves and the B curve do not follow this prediction exactly, possibly due to experimental errors. This particular F specimen, however, was made from a different bar than the other specimens which may account for its irregularity.

To determine exactly the effect of velocity on these specimens a dynamic tensile test of each type of specimen was made at an initial velocity of loading of 13.3 ft. per. sec. Since this is an extremely low velocity for this type of testing the velocity could not be considered as constant during the test. However, any variation would only make the conditions approach more closely those of the repeated impact tests. The dynamic stress-strain curves for these tests are plotted with the corresponding static curves on figures 50 to 55 inclusive. A comparative plot of all these dynamic curves is shown in fig. 57. For individual specimens there is no marked or consistent difference between the static and the dynamic curves. A comparison of the comparative plots of the static and the dynamic curves shows that within the limits of accuracy of these tests the static and the dynamic stress strain curves are identical up to the ultimate stress.

Comparing our typical stress-strain curve, fig. 58, with figures 56 and 57, we see that although it is perhaps not the best average curve of the group it is everywhere within the region covered by the curves of our tests. It is therefore considered that the above calculations based on this typical curve are reasonable and sufficiently accurate.

As a further means of comparison, the energies per unit volume to break were calculated for each type of specimen from the static and the dynamic stress-strain curves. The unit energies thus obtained are compared with the averages of the unit energies calculated by repeated impact tests for each specimen in Table IV. This Table brings out the fact that the unit energy at which failure occurs is roughly constant no matter what type of loading is applied. However, this unit energy to break varies considerably between specimens, indicating a possible variation with the dimensions of the specimen. The variations within each type of loading are of approximately the same magnitude, indicating that the repeated impact calculations approach the same accuracy as the static or dynamic stress-strain measurements. However, the average of these values for the type of testing showed the repeated impact values to be about 15% higher than the average of the other two types of testing.

It was decided to investigate the results of calculations based on the above mentioned assumptions using blows other than the first blow. Accordingly Table III was completed from columns 16 to 34 inclusive. This method is the same as for the calculations based on the first blow.

Mention should here be made of the fact that a maximum tensile stress of 59500 lbs. per square inch was chosen for uniformity, which value was said to occur for all elongations greater than 12.3%. Consequently when the elongation after the blow was shown to be greater than 11.7% the E_n' (column 26 of Table III) was obtained directly as the product of this ultimate stress and the change in percent elongation.

The K_1' values obtained (Column 30, Table III) are seen to be much more uniform than the K_1 values obtained from the previous calculations (column 11). Furthermore, the average is higher than before. Averaging all values gives K_1' of 0.861, the average for particular groups ranging from 0.811 to 0.917. The maximum variation for individual tests is from 0.703 to 0.996 with only one exception. This exception is the K_1' of 0.195 shown for specimen E-2, and this can be explained easily by the fact that practically none of the energy of the second or last blow was used in deforming the specimen. Fig. 29-b shows this fact clearly.

It should be noted that the E specimens which previously gave values of K_1 in excess of unity show normal values for K_1'. The resonant vibrating effect apparently disappears after the first blow in which the length is changed so that the critical l/d-volume combination no longer exists.

The plastic energy per cubic inch absorbed per blow was calculated in column 31. From this the total energy per unit volume to break was calculated in column 32. Since all of the energy of the last blow was probably not used in deforming the specimen, the total energy for one blow less than failure was also calculated as shown in column 33. In

In the cases marked "*" only two blows were required to break and the total energy to break is obtained directly by adding the plastic energies for each blow. In all other cases the strain distribution curves were examined to estimate how much of the energy of the last blow was used in deforming the specimen. These considerations led to the "Considered Average" of total energies per cubic inch to break as shown in column 34.

Examination of this quantity reveals that there is an even more marked constancy within groups of specimens than was observed by the previous calculations, column 14. The variation between groups was here more clearly evident and seemed to vary with the l/d ratio. The average of this unit energy for each type of specimen was plotted against l/d, as shown in Fig. 64. This plot approximates the hyperbolic form expected, but the variations are rather high.

The curves of E vs. l/d and of $\mathcal{E}$ vs. l/d, Figs. 63 and 64 respectively, were compared. The similarity between the two curves was quite striking and immediately suggested the possibility that the quotient of the two quantities, E and $\mathcal{E}$, might be a constant. The resultant quantity, inch pounds per cubic inch for one percent elongation, is calculated for each specimen as shown in column 37. The constancy of this quantity is here quite evident, both within groups and between groups of specimens. The weighted average value of this quantity is 553 in. lbs./cu.in. for 1% elongation for this type of test.

It was felt desirable to investigate this same quantity for the static and dynamic tests. This was done by dividing the total energy per cubic inch to break by the final percent total elongation for each specimen so tested. The results are shown in comparative form in Table VI from which it is apparent that this quantity is approximately constant regardless of the size or the shape of the specimen or the type of tension testing to which the specimen is subjected. This quantity appears to be a characteristic property of the material. We give this quantity the name of "Modulus of Destructiveness", with a value of 550 in.lbs./in.^{3} for one percent elongation for 17ST Duralumin.

Probably the more basic units for this Modulus would be in.lbs./in.^{3} for 100% elongation, or $\frac{\text{in.lbs./in.}^3}{\text{in./in.}}$ or lbs./in.^{2}. This would give the Modulus a numerical value of 55,000 lbs./in.^{2}. This brings out the fact that this Modulus is really an average stress on the stress-strain curve, which average holds for all types of tensile tests and for all sizes and shapes of specimens having circular cross sections.

By use of this Modulus of Destructiveness the total energy required to cause failure in tension of a given part of 17ST can be determined as follows:

1. Multiply the Modulus of Destructiveness by the volume of the part, obtaining the inch pounds of energy required to elongate the specimen one percent of its original length.
2. Multiply this energy by the percent total elongation at break determined from Fig. 63, obtaining the total inch pounds of energy required to break the part.

The number of Repeated Tension Impact blows which will cause failure of a given part can be predicted as follows:

1. Determine the inch pounds of energy required to break the part by the method shown above.

2. Subject the part to a few repeated tension impacts, measuring the total elongation suffered after each blow.

3. Determine the plastic energy delivered to the part per blow by use of a typical static stress-strain diagram for 17ST by the method previously described.

4. Divide this plastic energy per blow into the total energy at break, obtaining the number of blows required to cause failure.

It must be emphasized that this method of analysis is known to be valid only for 17ST duralumin, for a number of blows below about 130, and at an impact velocity of about thirteen feet per second. It is believed that variations in impact velocity will not affect the method or the results for 17ST. For a number of blows greater than about 130 the conditions begin to approximate those for no plastic energy per blow, and the failure seems to become of a different nature, resembling a fatigue failure. In specimens C-4 and C-5, Figs. 17 and 18, the only two specimens tested to over 130 blows, the break occurred as a fatigue break at the fillet rather than as a normal tension break in the body of the specimen. For a number of blows greater than 130 this method of analysis may then not be valid. Furthermore it appears doubtful whether this method could be applied to other materials which have marked changes in properties with rate of loading.

CONCLUSIONS

The following conclusions are determined for 17ST Duralumin with velocity of impact of 13.3 feet per second or less:

1) The strain distribution due to repeated tension impacts assumes the following forms as the number of blows is increased until the specimen breaks:

a) Nearly uniform unit elongations for about the first 35% of the blows.

b) Symmetrical variably located local elongations for the next 45% of the blows.

c) Highly localized necking for the last 20% of the blows.

2) The maximum unit elongation at the break by repeated tension impact is 36% greater than that caused by static tension break, and 15% greater than that caused by dynamic tension break.

3) The total elongation for both static and dynamic tension failure varies less than 6% from that for repeated tension impact failure.

4) An approximately hyperbolic relationship exists between the length-to-diameter ratio and the total elongation suffered by a round specimen at failure in tension for length-to-diameter ratios varying from 3 to 27.

5) No exact relationship was found between the dimensions of a specimen, the energy available per blow, and the number of blows to cause failure by repeated tension impacts.

6) An approximately hyperbolic relationship exists between the length-to-diameter ratio and the total energy per unit volume required to break a round specimen in tension, for length-to-diameter ratios varying from 3 to 27.

7) A "Modulus of Destructiveness", defined as the energy per unit volume per percent elongation at tension failure, is proposed. Its value as determined in this investigation is 550 inch pounds per cubic inch for one percent elongation. This value is nearly the same for tension failures of static, dynamic, or repeated impact types.

8) The number of repeated tension impacts which will cause failure of a given part can be predicted quite closely from the following data:

a) The percent total elongation at failure in tension as herein determined from specimen dimensions.

b) A typical static stress-strain curve of the material.

c) The percent increase in total elongation caused by one impact blow of the type to which the part will be subjected.

The validity of results is not certain if the number of impacts predicted exceeds 130.

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TABLE I

Blows Required to Break

Area = constant = .0707 in^2

Specimen	Length in.	Energy Available per blow - ft. lbs. 49.7	33.05	21.92	10.87	6.74	1.74
C	8	12	13	32	180	--	--
B	4	6	10	15	53	127	--
D	2.83	3	6	8	22	--	--
A	1	2	3	5	10	22	--

Volume = constant = .0707 in^3

Specimen	Length in.	Energy Available per blow - ft. lbs. 49.7	33.05	21.92	10.87	6.74	1.74
A	1	2	3	5	10	22	--
E	2.83	1	2	2	4	7	71

Volume = constant = .200 in^3

Specimen	Length in.	Energy Available per blow - ft. lbs. 49.7	33.05	21.92	10.87	6.74	1.74
D	2.83	3	6	8	22	--	--
F	4	4	6	7	24	--	--

Length = constant = 2.83 in

Specimen	Area sq. in.	Energy Available per blow - ft. lbs. 49.7	33.05	21.92	10.87	6.74	1.74
D	.0707	3	6	8	22	--	--
E	.0249	1	2	2	4	7	71

Length = constant = 4"

Specimen	Area sq. in.	Energy Available per blow - ft. lbs. 49.7	33.05	21.92	10.87	6.74	1.74
B	.0707	6	10	15	53	127	--
F	.0499	4	6	7	24	--	--

TABLE II

1	2	3	4	5	6	7	8	9
Specimen Number	Weight	N Blows to Break	E Energy Available Per Blow ft. lbs.	E_T Total Energy to Break E × N ft. lbs	N/E	V Volume in^3	N/V	$\frac{N}{EV}$
A-1	17.922	2	49.70	99.4	.0403	.0707	28.3	.560
A-2	11.923	3	33.05	99.1	.0907	.0707	42.4	1.283
A-3	7.923	5	21.92	109.7	.228	.0707	70.7	3.225
A-4	3.930	10	10.87	108.7	.920	.0707	141.3	13.02
A-5	2.430	22	6.74	148.2	3.265	.0707	311.0	46.20
A-6	0.629	-	1.74	-	-	.0707	-	-
B-1	17.922	6	49.70	298.0	.121	.2828	21.2	.428
B-2	11.923	6	33.05	198.2	.182	.2828	21.2	.642
B-5	11.923	11	33.05	353.5	.333	.2828	38.8	1.178
B-8	11.923	11	33.05	353.5	.333	.2828	38.8	1.178
B-9	11.923	9	33.05	297.5	.273	.2828	31.8	.962
B-3	7.923	15	21.92	329.0	.684	.2828	53.0	2.415
B-4	3.930	20	10.87	217.2	1.84	.2828	70.7	6.50
B-6	3.930	86	10.87	935.0	7.91	.2828	303.5	27.95
B-7	2.430	127	6.74	856.0	18.87	.2828	449.0	66.70
C-1	17.922	12	49.70	596.0	.242	.5656	21.2	.427
13	17.922	12	49.70	596.0	.242	.5656	21.2	.427
C-2	11.923	18	33.05	595.0	.545	.5656	31.8	.960
11	11.923	22	33.05	707.0	.666	.5656	38.9	1.178
C-3	7.923	32	21.92	702.0	1.46	.5656	56.5	2.575
12	7.923	44	21.92	964.5	2.01	.5656	77.8	3.55
C-4	3.930	182	10.87	1978.0	16.75	.5656	321.0	29.55
C-5	3.930	178	10.87	1934.0	16.38	.5656	314.0	28.90
D-1	17.922	3	49.70	149.0	.0605	.2000	15.0	.303
D-5	17.922	3	49.70	149.0	.0605	.2000	15.0	.303
D-2	11.923	6	33.05	198.2	.1814	.2000	30.0	.907
D-3	7.923	8	21.92	175.6	.365	.2000	40.0	1.825
D-4	3.930	24	10.87	261.0	2.21	.2000	120.0	11.05
D-6	3.930	20	10.87	217.0	1.84	.2000	100.0	9.20
E-1	17.922	1	49.70	49.7	.0202	.0707	14.1	.286
E-2	11.923	2	33.05	66.1	.0605	.0707	28.3	.856
E-3	7.923	2	21.92	43.8	.0912	.0707	28.3	1.29
E-4	3.930	4	10.87	43.5	.368	.0707	56.6	5.20
E-5	2.430	7	6.74	47.1	1.039	.0707	99.0	14.70
E-6	0.629	71	1.74	123.5	40.8	.0707	1003.0	578.0
F-1	17.922	4	49.70	198.8	.0807	.2000	20.0	.403
F-2	11.923	6	33.05	198.2	.1814	.2000	30.0	.907
F-3	7.923	7	21.92	153.6	.319	.2000	35.0	1.595
F-4	3.930	24	10.87	261.0	2.21	.2000	120.0	11.05

TABLE III

1 Specimen Number	2 Weight (Lbs.)	3 N Blows to Break	4 E_R Energy Available per Blow (In. Lbs.)	5 E_R/V Energy Available per Blow per Unit Volume (In.Lbs./Cu.In.)	6 l/d	7 Total Elongation First Blow (Inches)	8 Total Elongation First Blow (Percent)	9 Maximum Stress First Blow (Lbs/Sq.In.)	10 Energy Absorbed First Blow (In.Lbs./In³)	11 K_1	12 Elastic Energy Recovered First Blow (In.Lbs./In³)	13 Plastic Energy First Blow (In.Lbs./In³)	14 E_T (In.Lbs./In³)	15 E_{T-1} (In.Lbs./In³)	16 n Blow Number	17 Total Elongation nth Blow (Inches)	18 Total Elongation nth Blow (Percent)	19 $n-1$ Blow Number	20 Total Elong. $(n-1)$ Blow (Inches)
A-1	17.922	2	595.9	8430	3.33	.115	11.5	59500	6450	.759	177	6273	12540	6273	2	.225	22.5	1	.115
A-2	11.923	3	396.4	5610	3.33	.089	8.9	57700	4865	.868	166	4699	14080	9380	2	.163	16.3	1	.089
A-3	7.923	5	263.4	3720	3.33	.051	5.1	54000	2680	.719	146	2534	12640	10150	3	.54	15.4	2	.103
A-4	3.930	10	130.7	1849	3.33	.026	2.6	50900	1418	.767	130	1288	12880	11590	7	.170	17.9	6	.15
A-5	2.430	22	80.8	1143	3.33	.013	1.3	48300	720	.630	117	603	13270	12060	12	.144	14.4	1	.13
A-6	0.629	-	20.9	296	3.33	.0025	0.25	44000	221	.747	97	124	-	-	-	-	-	-	
Average					3.33														
B-1	17.922	6	595.9	2105	13.33	.144	3.60	52200	883	.895	136	1747	10480	8740	4	.510	12.75	3	.38
B-2	11.923	6	396.4	1400	13.33	.1015	2.54	50700	1361	.973	128	1233	7410	6190	4	.374	9.48	3	.29
B-5	11.923	11	396.4	1400	13.33	.0935	2.34	50400	1240	.885	127	1113	12260	11130	8	.675	16.89	7	.60
B-8	11.923	11	396.4	1400	13.33	.0705	1.76	49500	965	.690	122	843	9270	8430	8	.556	13.90	7	.48
B-9	11.923	9	396.4	1400	13.33	.087	2.18	50200	1190	.850	126	1064	9580	8590	8	.605	15.13	7	.54
B-3	7.923	15	263.4	930	13.33	.0583	1.46	48700	818	.880	118	700	10500	9800	9	.479	11.97	8	.42
B-4	3.930	20	130.7	461	13.33	.028	0.70	46400	440	.953	108	332	6640	6410	11	.271	6.78	10	.24
B-6	3.930	86	130.7	461	13.33	.0177	0.44	45300	324	.702	103	221	19000	18780	30	.359	8.98	29	.347
B-7	2.430	127	80.8	285	13.33	.0075	0.019	43400	185	.649	44	91	11570	11470	65	.290	7.25	64	.287
Average					13.33														
C-1	17.922	12	595.9	1053	26.67	.156	1.95	49500	965	.916	122	843	10110	9270	9	1.100	13.76	8	.99
C-2	11.923	18	396.4	701	26.67	.097	1.21	48000	672	.959	115	557	10020	9460	13	1.008	12.60	12	.93
C-3	7.923	32	263.4	465	26.67	.049	0.613	46000	389	.835	106	283	9050	8770	24	1.008	12.60	23	.970
C-4	3.930	182	130.7	231	26.67	.0153	0.191	43500	195	.8221	95	100	18200	18100	100	.4705	5.89	99	.46
C-5	3.930	178	130.7	231	26.67	.006	0.075	41500	142	.614	86	56	4970	4910	60	.285	3.56	59	.282
Average					26.67														
D-1	17.922	3	595.9	2980	9.42	.136	4.81	53700	2519	.845	144	2375	7130	4750	2	.2555	9.03	1	.136
D-5	17.922	3	595.9	2980	9.42	.1245	4.40	53200	2331	.783	141	2190	6570	4380	2	.244	8.62	1	.124
D-2	11.923	6	396.4	1980	9.42	.0755	2.67	50900	1418	.715	130	1288	7730	6440	4	.2785	9.83	3	.214
D-3	7.923	8	263.4	1317	9.42	.053	1.87	49600	985	.752	123	862	6890	6130	5	.260	9.18	4	.211
D-4	3.930	24	130.7	653	9.42	.0197	0.70	46300	435	.666	107	328	7880	7550	20	.344	12.15	19	.328
D-6	3.930	20	130.7	653	9.42	.023	0.81	46900	497	.751	110	387	7740	7460	12	.254	8.97	11	.23
Average					9.42														
E-1	17.922	1	595.9	8430	15.90	.3435	12.13	59800	6869	.813	179	6690	6690	0	0	-	-	-	
E-2	11.923	2	396.4	5610	15.90	.2905	10.27	58800	5681	1.010	163	5518	11036	5518	2	.3355	11.85	1	.290
E-3	7.923	2	263.4	3720	15.90	.196	6.92	56000	3783	1.013	157	3626	7252	3626	2	.330	11.67	1	.196
E-4	3.930	4	130.7	1849	15.90	.0925	3.27	54300	2443	1.533	147	2296	9184	6788	3	.2625	9.26	2	.185
E-5	2.430	7	80.8	1143	15.90	.0815	2.88	51250	1520	1.335	131	1389	9720	8330	5	.2835	10.00	4	.24
E-6	0.629	71	20.9	296	15.90	.0128	0.452	45250	320	1.079	102	218	15490	15270	35	.2355	8.31	34	.232
Average					15.90														
F-1	17.922	4	595.9	2980	15.87	.1945	4.87	53750	2519	.853	144	2375	9500	7125	3	.530	13.24	2	.368
F-2	11.923	6	396.4	1480	15.87	.1348	3.37	52000	1831	.922	135	1696	6790	5090	5	.54[illegible]	14.93	4	.474
F-3	7.923	7	263.4	1317	15.87	.0893	2.23	50250	1210	.905	126	1084	7590	6510	6	.4805	12.21	5	.412
F-4	3.430	24	130.7	653	15.87	.0354	0.885	47050	510	.776	111	399	9570	9170	20	.543	13.60	19	.518
Average					15.87														
Total Average																			

38 Specimen Number	21 Total Elongation $(n-1)$ Blow (Percent)	22 Maximum Stress nth Blow (Lbs/In²)	23 Maximum Stress $(n-1)$th Blow (Lbs/In²)	24 ΣE_n (In.Lbs./In³)	25 ΣE_{n-1} (In.Lbs./In³)	26 E_n' (In.Lbs./In³)	27 E_{e_n} (In.Lbs./In³)	28 $E_{e_{n-1}}$ (In.Lbs./In³)	29 E_n (In.Lbs./In³)	30 K_1'	31 E_{P_n} Plastic Energy nth Blow (In.Lbs./In³)	32 E_T' (In.Lbs./In³)	33 E_{T-1}' (In.Lbs./In³)	34 E'_{Total} Considered Average (In.Lbs./In³)	35 Total Elongation at Break (Inches)	36 Total Elongation at Break ε_T (Percent)	37 $\frac{E'_{Total}}{\varepsilon_T}$ In.Lbs./In³ for 1% Elongation
A-1	11.5	59500	59500	-	-	6550	177	177	6727	.799	6550	12823	*	12800	.2237	22.9	560
A-2	8.9	59500	57800	9245	4922	4323	177	167	4440	.800	4333	13000	8670	11600	.2334	23.3	498
A-3	10.3	59500	56800	8710	5681	3029	177	173	3202	.861	3033	15150	12120	14100	.2521	25.2	560
A-4	15.5	59500	59500	-	-	1429	177	177	1606	.864	1429	14290	12850	14300	.2647	26.5	540
A-5	13.3	59500	59500	-	-	655	177	177	832	.727	655	14400	13750	14400	.2670	26.7	540
A-6	-		-	-	-	-	-	-	-	-		-	-		-	-	-
Average										.811				13440		24.9	540
B-1	9.97	54500	55500	7135	5446	1689	177	171	1860	.384	1695	10170	8480	10200	.730	18.2	560
B-2	7.35	58200	56400	5213	4008	1205	169	159	1364	.974	1215	7290	6070	6900	.533	13.4	515
B-5	15.03	59500	59500	-	-	1107	177	177	1284	.917	1107	12180	11070	11300	.859	21.5	525
B-8	12.18	59500	59500	-	-	1023	177	177	1220	.857	1023	11260	10230	11200	.729	18.2	615
B-9	13.60	59500	59500	-	-	910	177	177	1087	.776	910	8190	7280	8190	.683	17.1	479
B-3	10.92	59500	59200	6670	6095	575	177	175	750	.807	577	8650	8070	8350	.742	18.5	451
B-4	6.15	55800	55250	3615	3309	306	155	152	458	.993	309	6180	5880	6180	.507	12.7	487
B-6	8.68	57800	57500	4922	4700	222	167	165	387	.839	224	19280	19040	19200	.688	17.2	1116
B-7	7.18	56300	56200	3951	3895	56	158	158	214	.751	56	7110	7060	7100	.457	11.4	622
Average										.866				8678		17.6	532
C-1	12.40	59500	59500	-	-	809	177	177	986	.936	809	9700	8900	8900	1.341	16.8	530
C-2	11.73	59500	59500	-	-	518	177	177	695	.992	518	9330	8810	8900	1.297	16.2	549
C-3	12.12	59500	59500	-	-	286	177	177	463	.996	286	9160	8870	8800	1.258	15.7	560
C-4	5.86	54950	54900	3144	3116	28	151	151	179	.776	28	5100	5070	5100	.526	6.6	772
C-5	3.52	52200	52100	1883	1856	27	136	135.5	162.5	.703	27	4810	4780	4800	.448	5.6	857
Average										.881				7300		12.2	654
D-1	4.81	57900	53700	4980	2519	2461	167	144	2605	.874	2484	7460	4970	7460	.453	16.0	462
D-5	4.40	57500	53200	4700	2331	2369	165	144	2510	.342	2393	7180	4790	7200	.347	12.3	585
D-2	7.56	58500	56600	5446	[illegible]	1325	171	160	1485	.749	1336	8010	6680	7300	.379	13.4	545
D-3	7.47	58000	56500	5038	4064	974	168	159	1133	.862	983	7870	6880	7800	.398	14.1	553
D-4	11.59	59500	59500	-	-	393	177	177	570	.873	393	9430	9040	9400	.415	14.7	640
D-6	8.30	57800	57300	4922	4577	345	167	164	509	.780	348	6970	6610	7000	.426	15.0	467
Average										.830				7683		14.3	542
E-1	-	-	-	-	-	-	-	-	-	-	-	-	-	6690	.344	12.1	553
E-2	10.27	59500	58800	6599	5681	918	177	173	1091	.195	422	6440	*	6440	.336	11.9	541
E-3	6.42	59500	56000	6492	3750	2742	177	157	2899	.779	2762	6388	*	6388	.330	11.7	546
E-4	6.53	58000	55600	5038	3503	1535	168	154	1689	.913	1549	6200	4650	6100	.321	11.3	540
E-5	8.48	58600	57450	5505	4680	825	172	165	990	.866	832	5820	4990	5800	.387	13.7	423
E-6	8.19	57300	57150	4577	4490	87	164	163	250	.845	88	6250	6160	6250	.398	14.1	444
Average										.875				6278		12.5	508
F-1	4.20	59500	58000	7426	5038	2388	177	168	2556	.857	2397	9600	7200	9600	.683	17.1	561
F-2	11.97	59500	59500	-	-	1750	177	177	1927	.973	1750	10500	8750	9900	.685	17.1	579
F-3	10.30	59500	58800	6313	5681	1132	177	172	1304	.992	1137	7960	6820	8000	.562	14.0	572
F-4	12.96	59500	59500	-	-	381	177	177	558	.855	381	9140	8760	9100	.642	16.0	569
Average										.917				9150		16.1	570
Total Average										.861				8632		15.9	553

TABLE IV

Energy Per Unit Volume to Break
inch pounds per cubic inch

Specimen	l/d	Static Test	Dynamic Test	Repeated First Calculation	Impact Test Considered Average	Weighted Average
A	3.33	11204	13970	13076	13440	12372
D	9.42	--	10098	7535	7683	8390
B	13.33	6716	8780	10598	8678	8058
F	15.87	7345	5088	9212	9150	7194
E	15.90	8640	9628	10158	6278	8132
C	26.67	9070	6062	10882	7300	7144
Average	--	8596	8938	10210	8632	8665

TABLE V

Total Elongation After Failure - Percent

Specimen	ℓ/d	Static Test	Dynamic Test	Repeated Impact Test	Weighted Average
A	3.33	20.0	21.5	24.9	23.7
D	9.42	-	17.7	14.3	14.7
B	13.33	15.5	17.0	17.6	16.4
F	15.87	14.0	11.1	16.1	14.8
E	15.90	16.2	17.0	12.5	13.5
C	26.67	14.6	11.9	12.2	12.5

TABLE VI

Modulus of Destructiveness
inch pounds per cubic inch for one percent elongation

Specimen	Static Test	Dynamic Test	Repeated Impact Test	Weighted Average
A	560	649	540	558
B	434	516	532	521
C	621	510	654	629
D	--	620	542	553
E	533	568	508	519
F	437	458	570	534
Weighted Average	526	554	553	549

Fig. 1-a

GALCIT Falling Carriage Type

Repeated Tension Impact

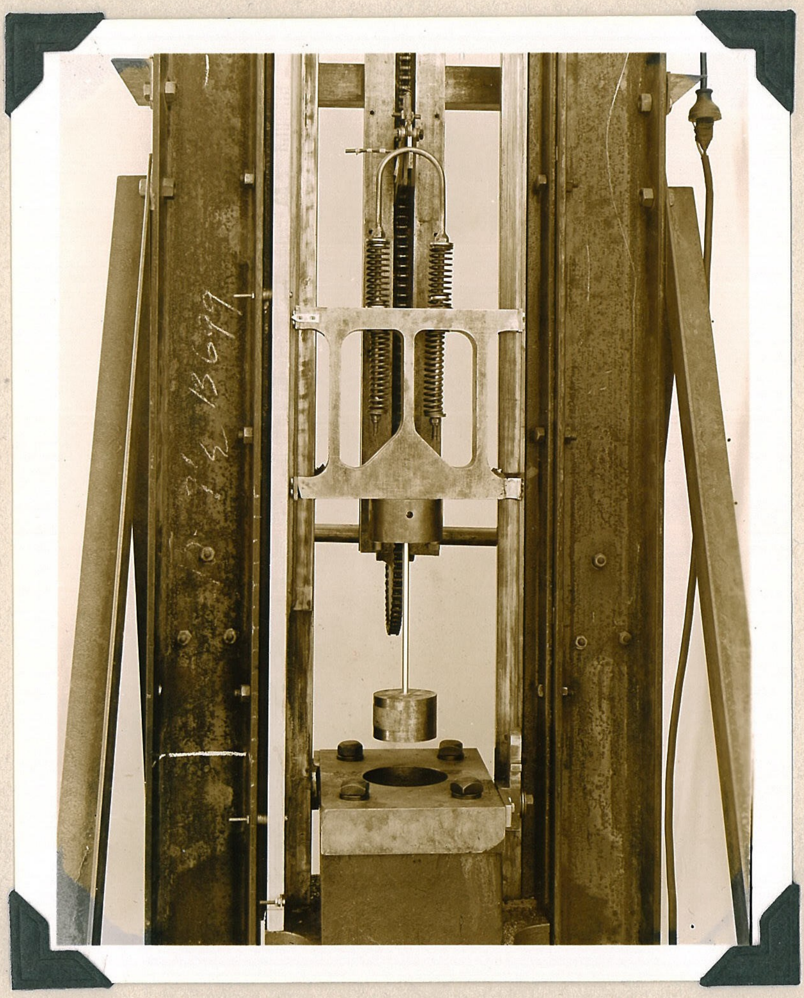
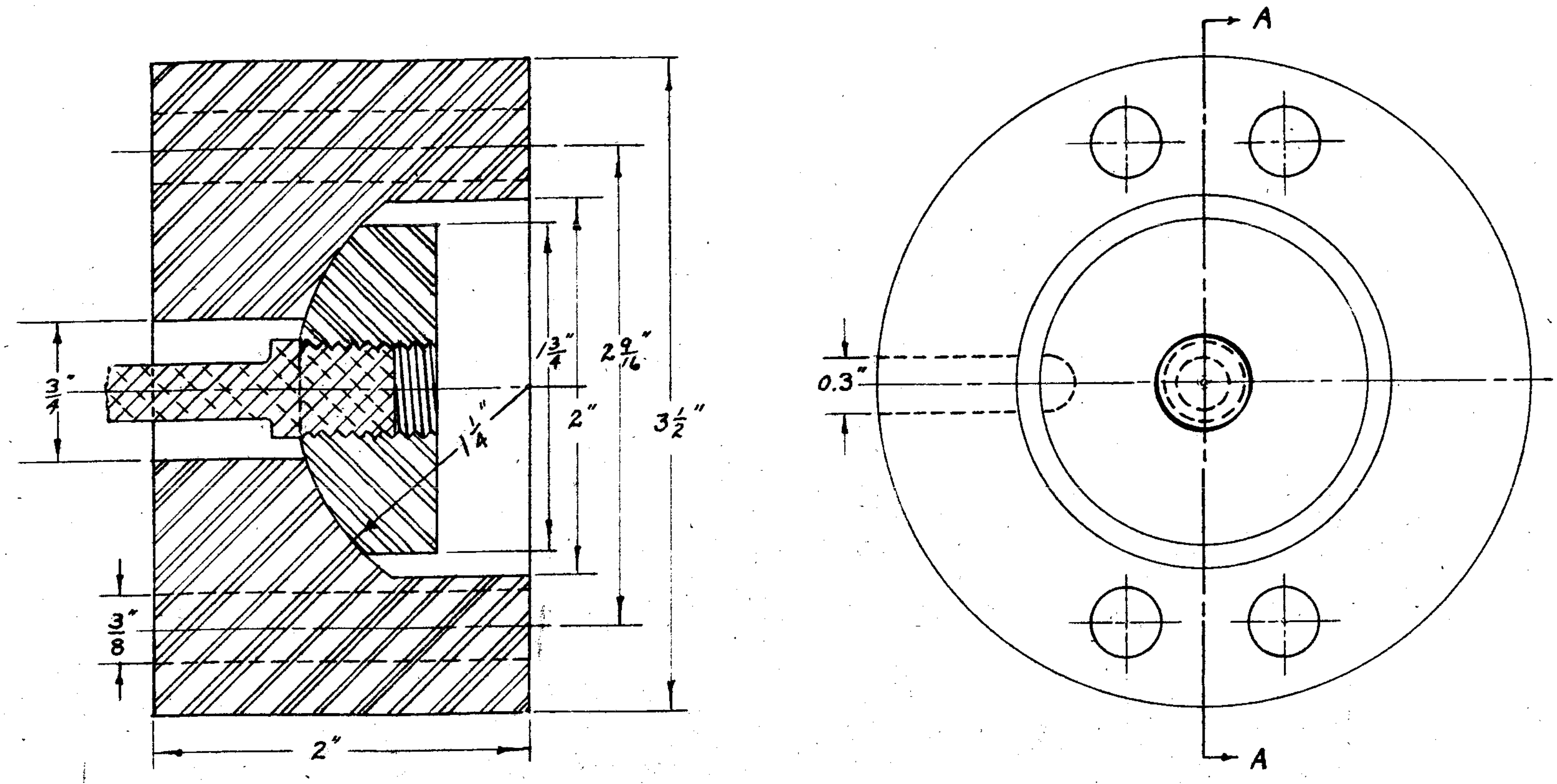


Fig. 1-b

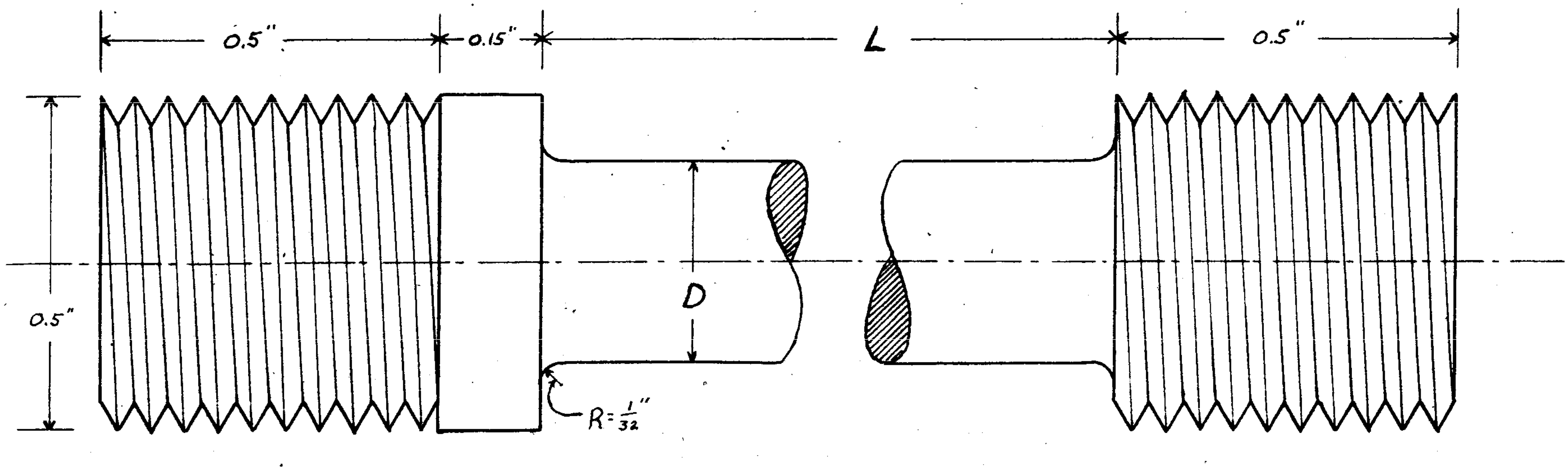
Close up view of testing machine.



SECTION VIEW AT A-A

			C.W. STIRLING	E.S. LEE, Jr.			TOLERANCES ± .010 OR 1/64 UNLESS OTHERWISE NOTED.
MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	
GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY			BALL AND SOCKET UNIT				
			NAME				DRAWING NO.

FIG. 1-C



SPECIMEN LETTER	L inches	D inches
A	1	0.300
B	4	0.300
C	8	0.300
D	2.83	0.300
E	2.83	0.178
F	4	0.252

MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER
17 ST			E.S. LEE, Jr.	C.W. STIRLING		

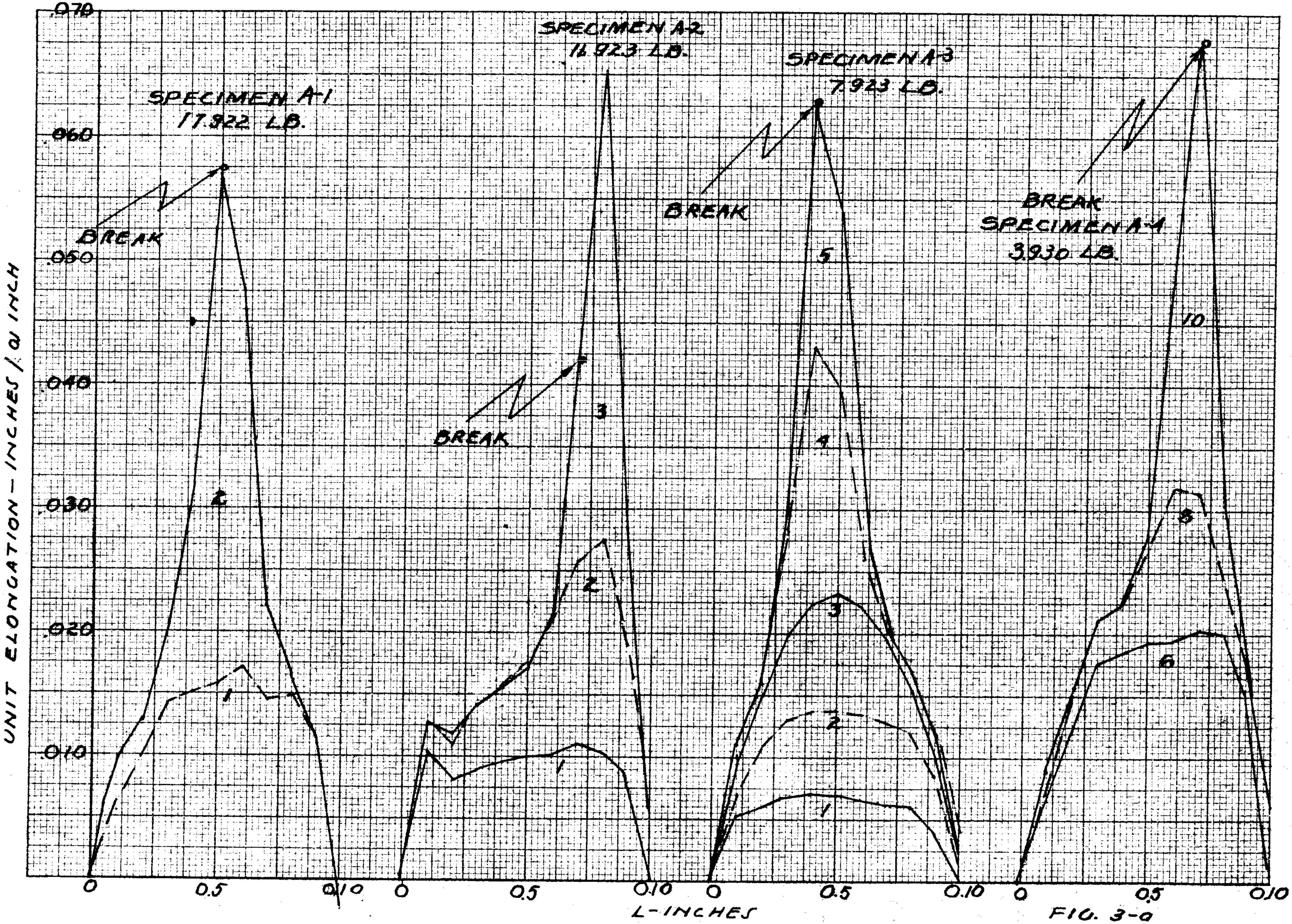
TOLERANCES $\pm$ .010 OR $\frac{1}{64}$ UNLESS OTHERWISE NOTED

GUGGENHEIM AERONAUTICAL LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

NAME: TEST SPECIMEN

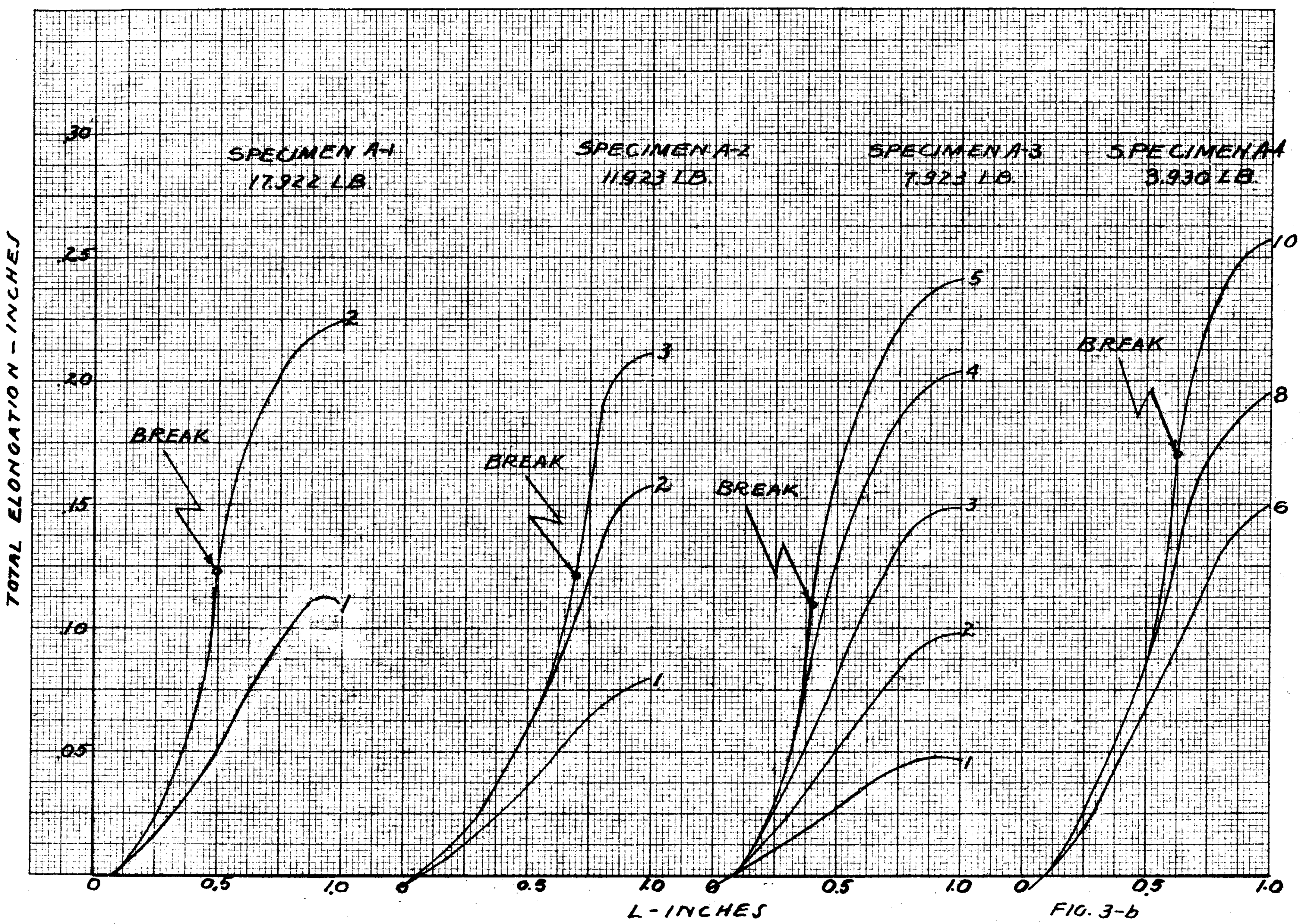
DRAWING NO.

FIG. 2



SPECIMEN A-1
17.922 LB.
BREAK
SPECIMEN A-2
16.923 LB.
BREAK
SPECIMEN A-3
7.923 LB.
BREAK
BREAK
SPECIMEN A-4
3.930 LB.
UNIT ELONGATION - INCHES / .01 INCH
L-INCHES
.070
.060
.050
.040
.030
.020
.010
0
0.5
0.10
1
2
3
4
5
6
8
10

FIG. 3-a



SPECIMEN A-1
17.922 LB.
SPECIMEN A-2
11.923 LB.
SPECIMEN A-3
7.923 LB.
SPECIMEN A-4
3.930 LB.
BREAK
BREAK
BREAK
BREAK
TOTAL ELONGATION - INCHES
.30
.25
.20
.15
.10
.05
0
0.5
1.0
L-INCHES

FIG. 3-b

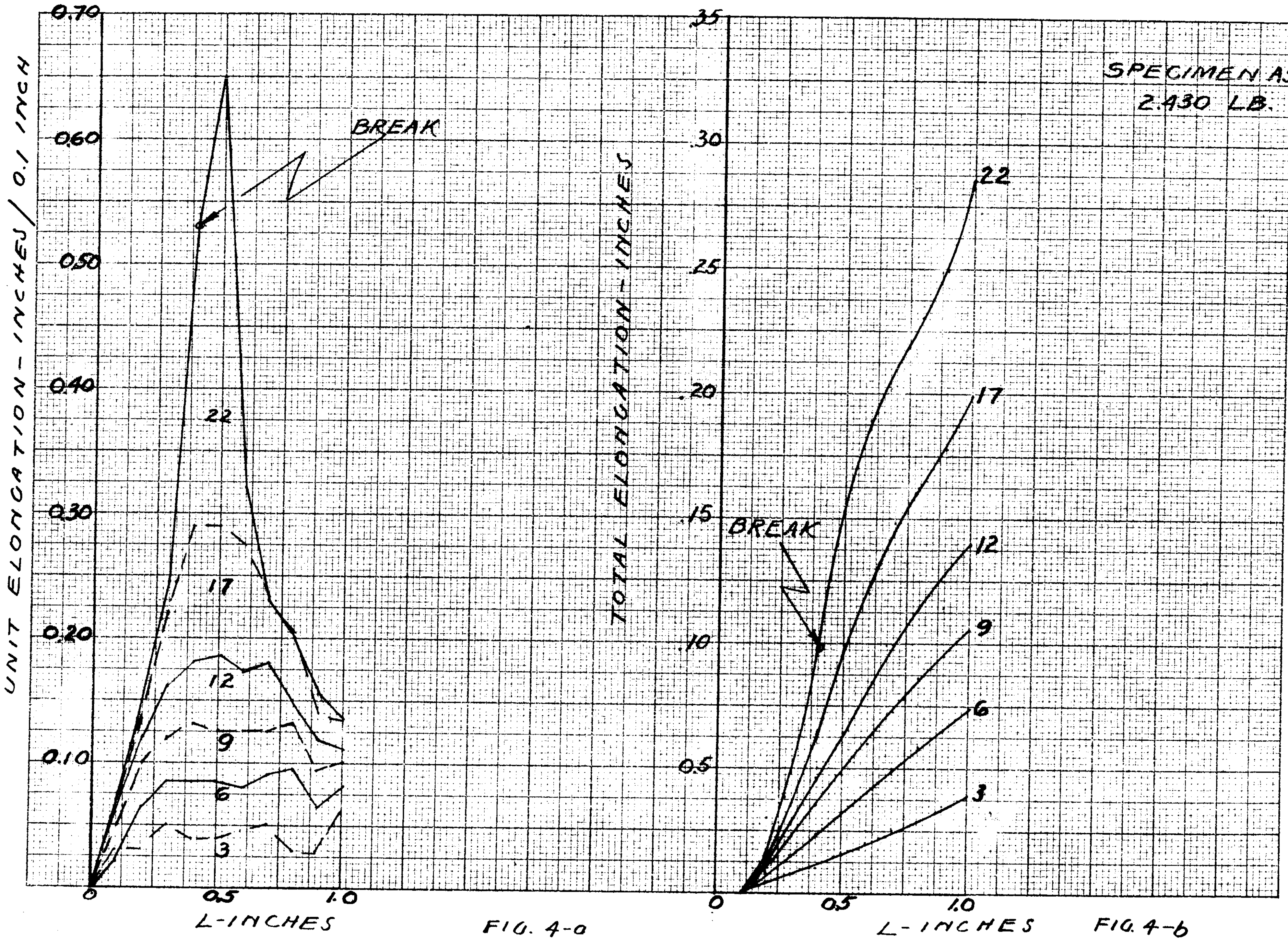

SPECIMEN A5
2.430 LB.
UNIT ELONGATION - INCHES / 0.1 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
0.5
1.0
L-INCHES
BREAK
22
17
12
9
6
3
TOTAL ELONGATION - INCHES
.35
.30
.25
.20
.15
.10
0.5
0
0.5
1.0
L-INCHES
BREAK
22
17
12
9
6
3

FIG. 4-a

FIG. 4-b

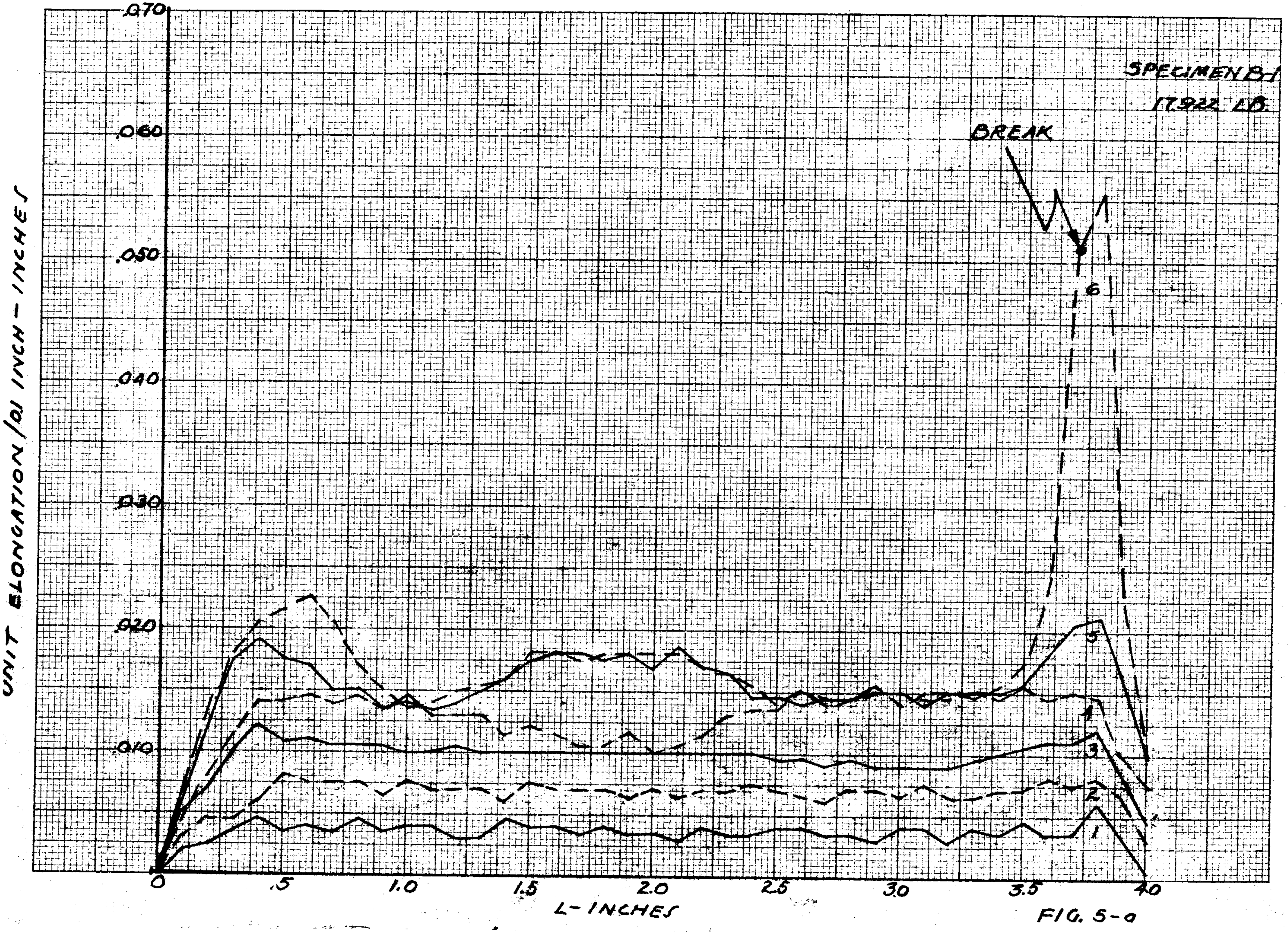

SPECIMEN B-1
17,922 LB.
BREAK
1
2
3
4
5
6
.070
.060
.050
.040
.030
.020
.010
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
UNIT ELONGATION /.01 INCH - INCHES
L - INCHES

FIG. 5-a

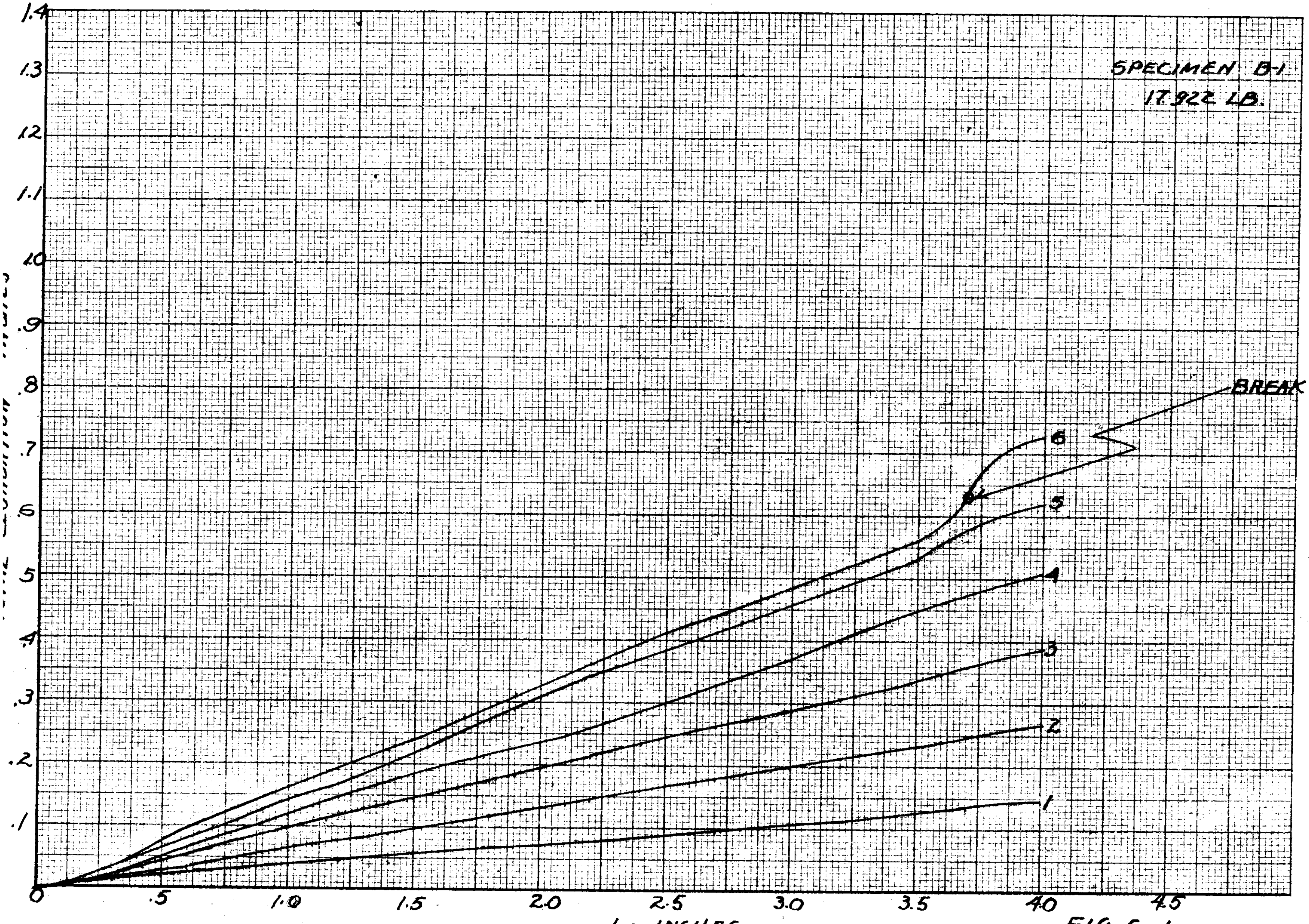
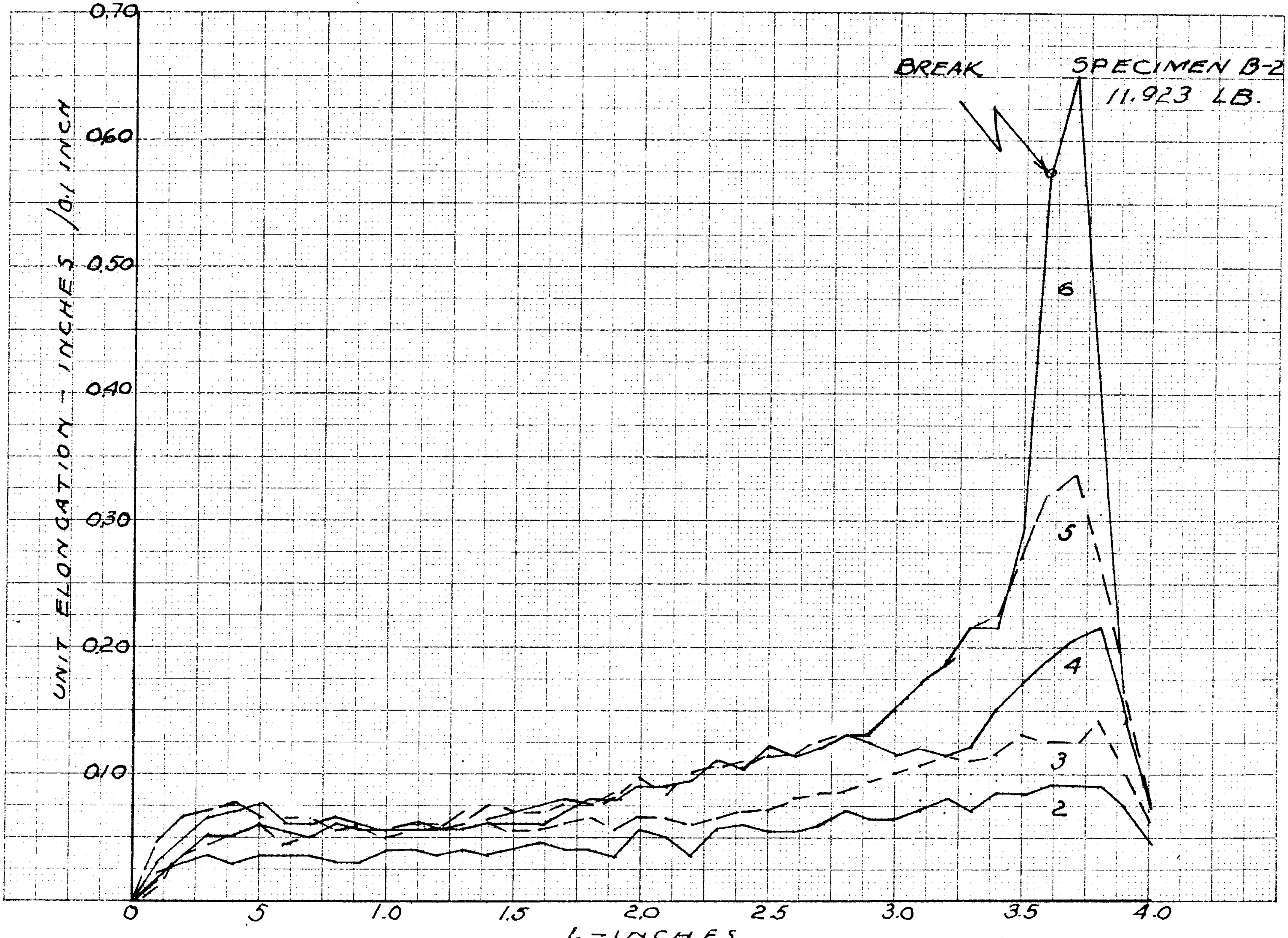

SPECIMEN B-1
17.922 LB.
BREAK
1
2
3
4
5
6
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
L — INCHES

FIG. 5-b



SPECIMEN B-2
11.923 LB.
BREAK
6
5
4
3
2
UNIT ELONGATION - INCHES /0.1 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L-INCHES

FIG. 6-a

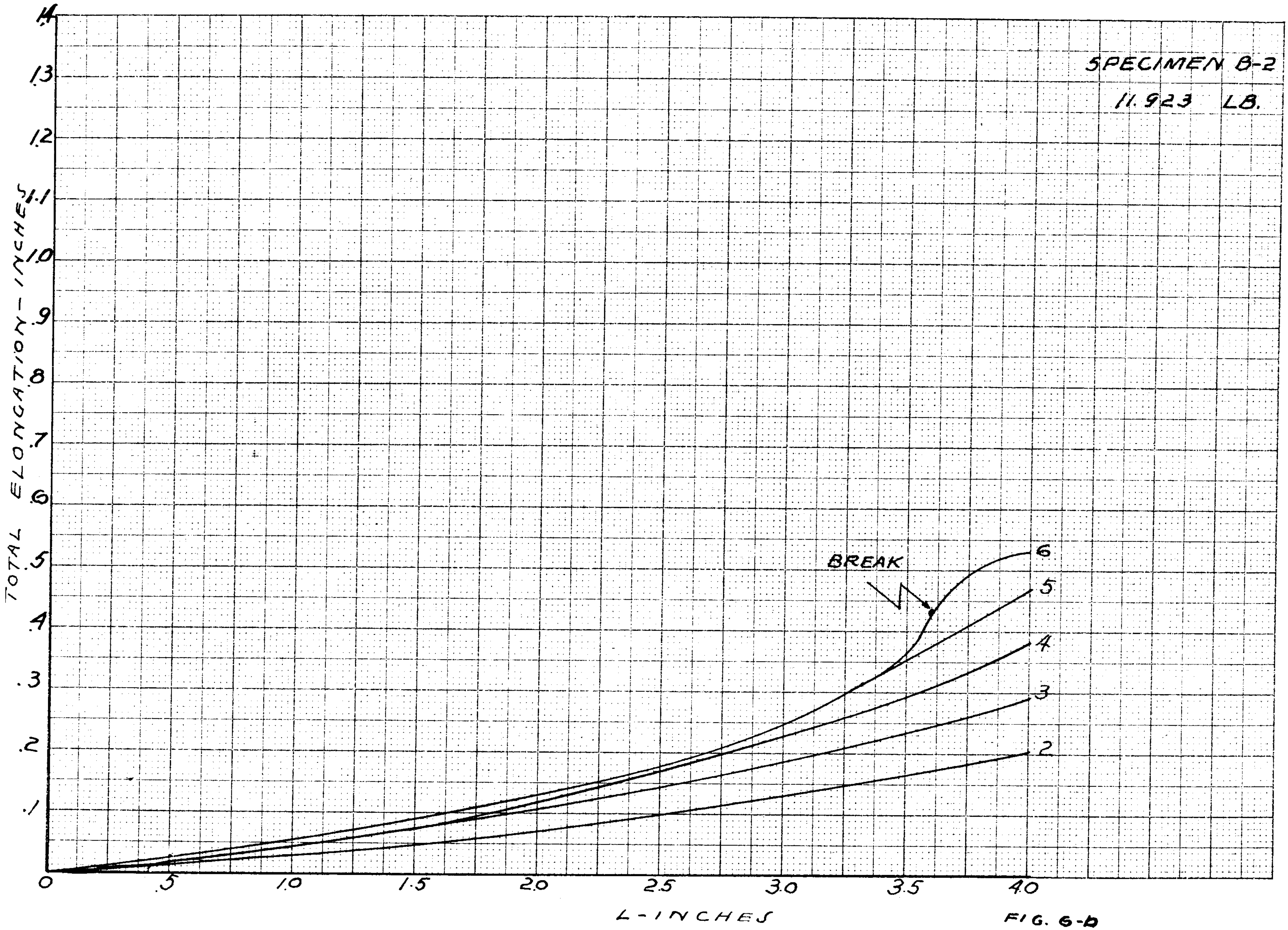
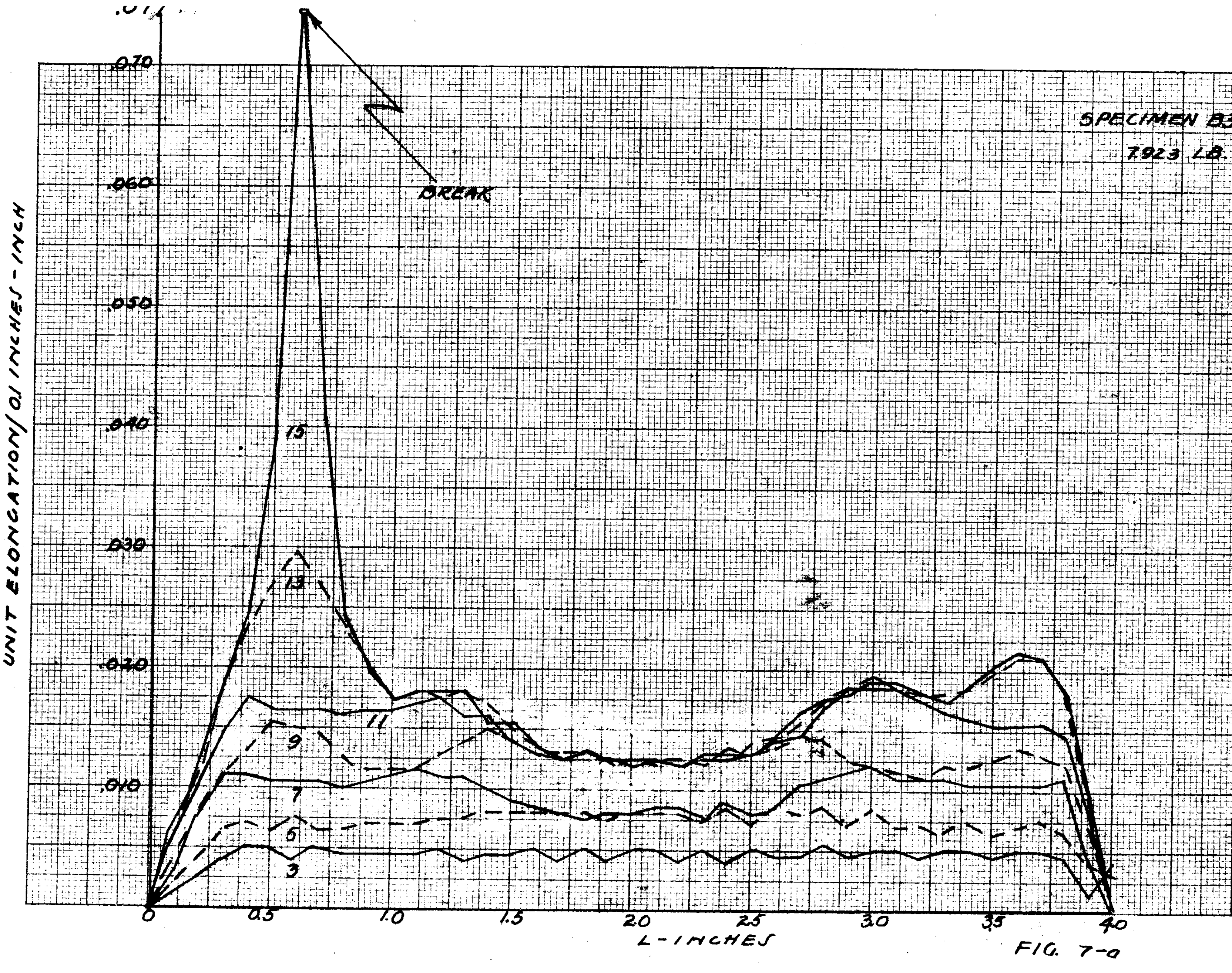
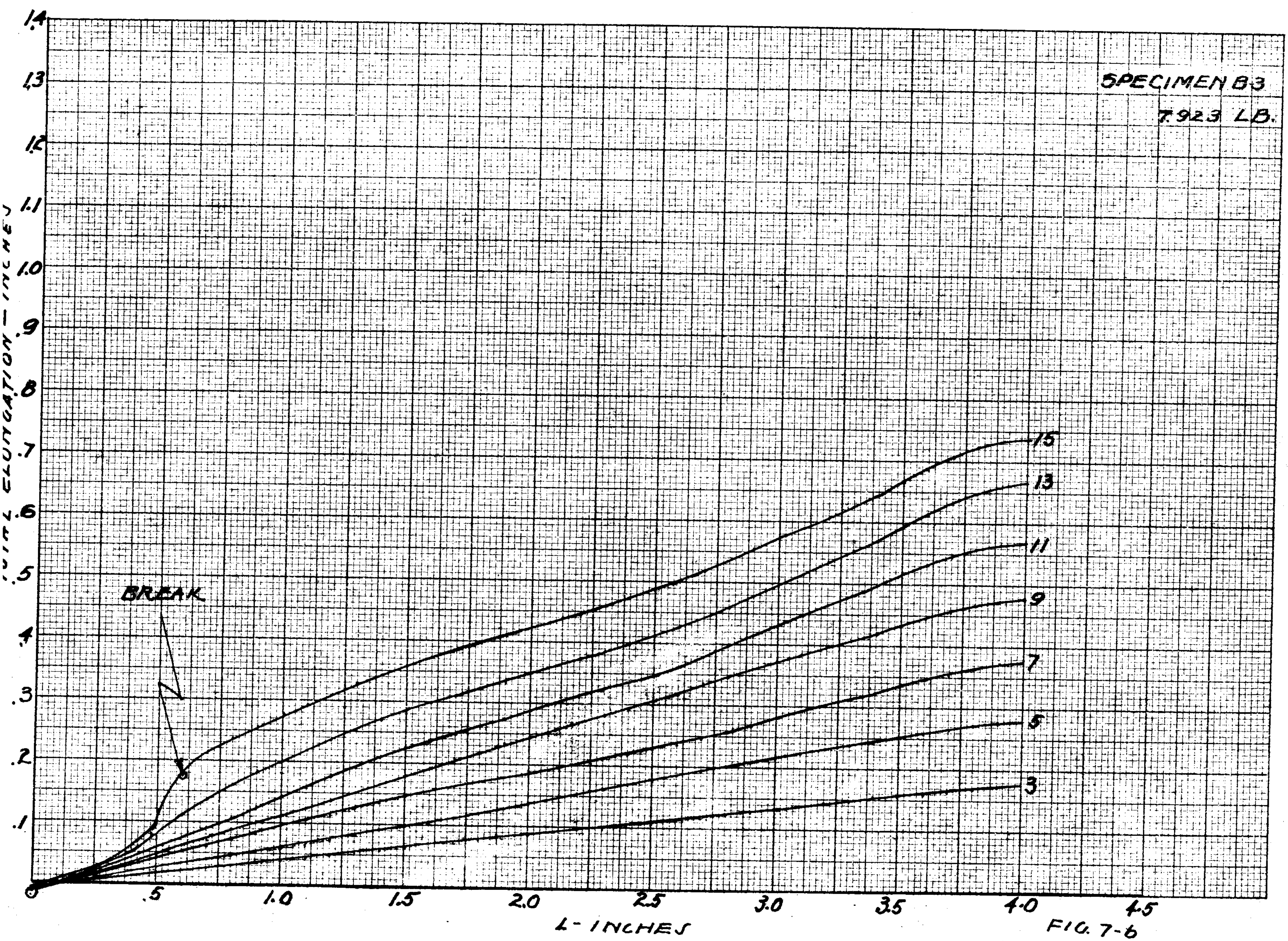

SPECIMEN B-2
11.923 LB.
BREAK
6
5
4
3
2
TOTAL ELONGATION - INCHES
L - INCHES
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4

FIG. 6-b



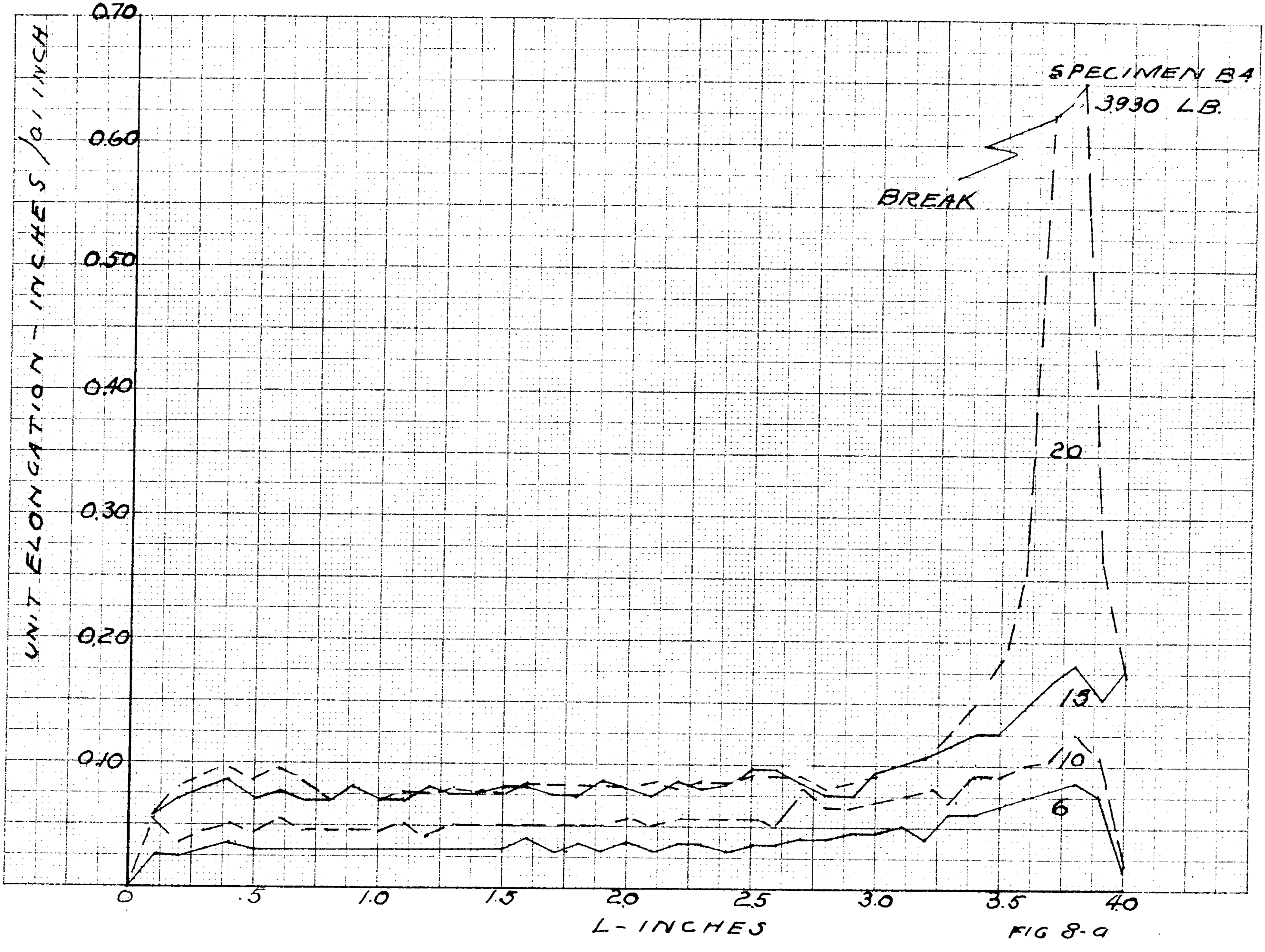
SPECIMEN B3
7923 LB.
BREAK
UNIT ELONGATION/0.1 INCHES - INCH
.070
.060
.050
.040
.030
.020
.010
15
13
11
9
7
5
3
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L - INCHES

FIG. 7-a



SPECIMEN B3
7.923 LB.
BREAK
15
13
11
9
7
5
3
TOTAL ELONGATION - INCHES
L - INCHES
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4

FIG. 7-6



SPECIMEN B4
3930 LB.
BREAK
20
15
10
6
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
UNIT ELONGATION - INCHES / 0.1 INCH
L - INCHES

FIG 8-a

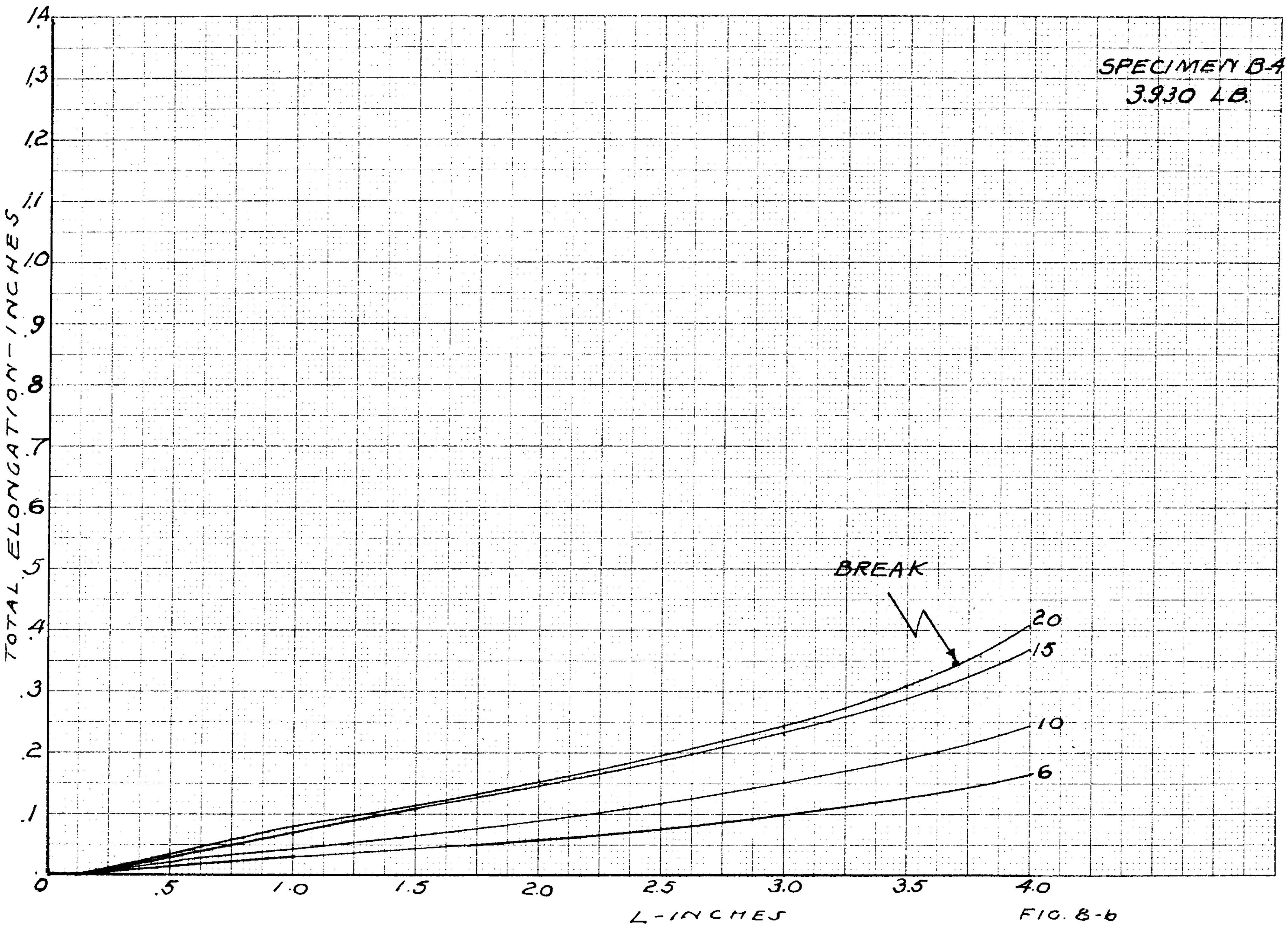

SPECIMEN B-4
3930 LB.
BREAK
20
15
10
6
TOTAL ELONGATION - INCHES
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L - INCHES

FIG. 8-6

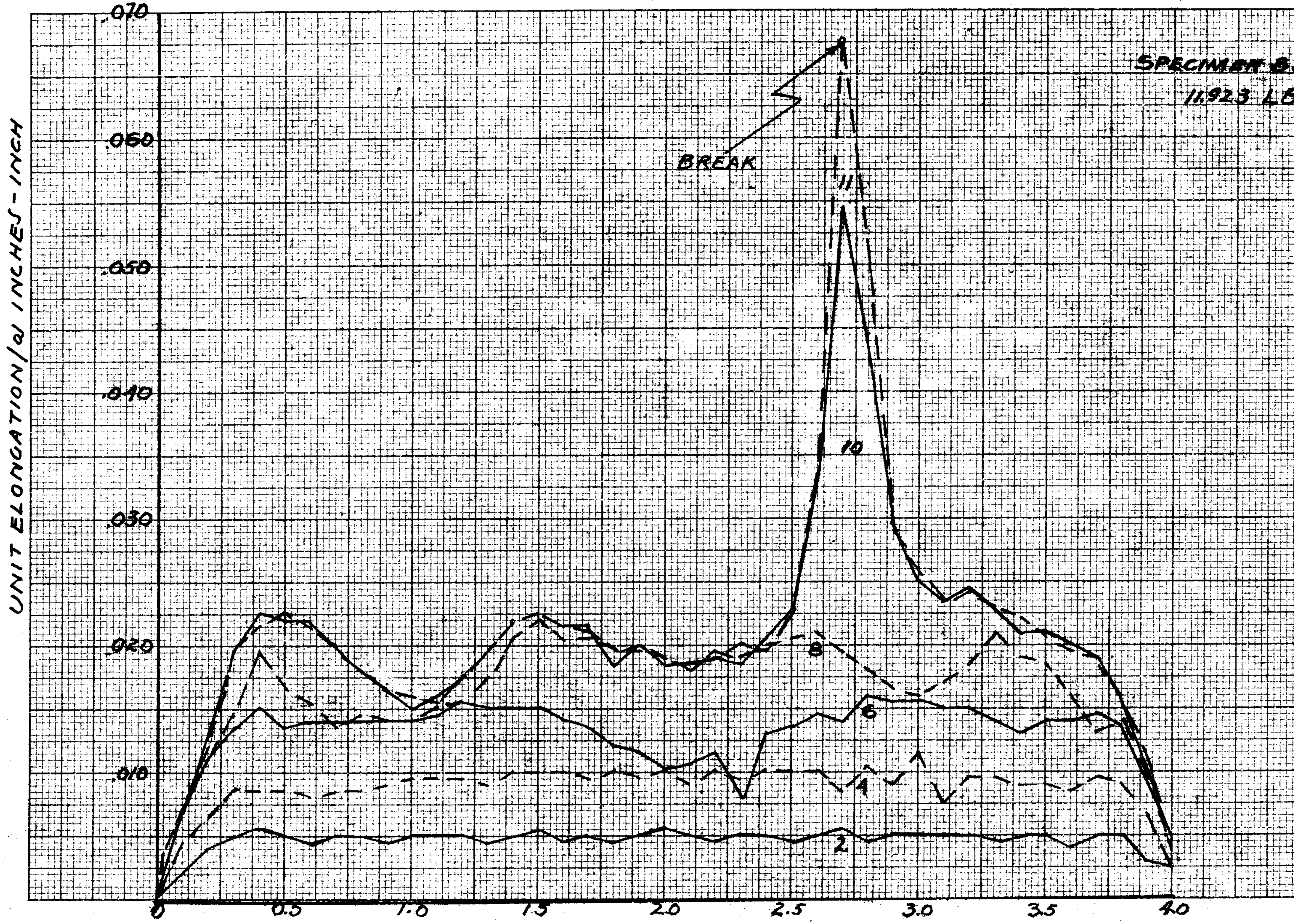
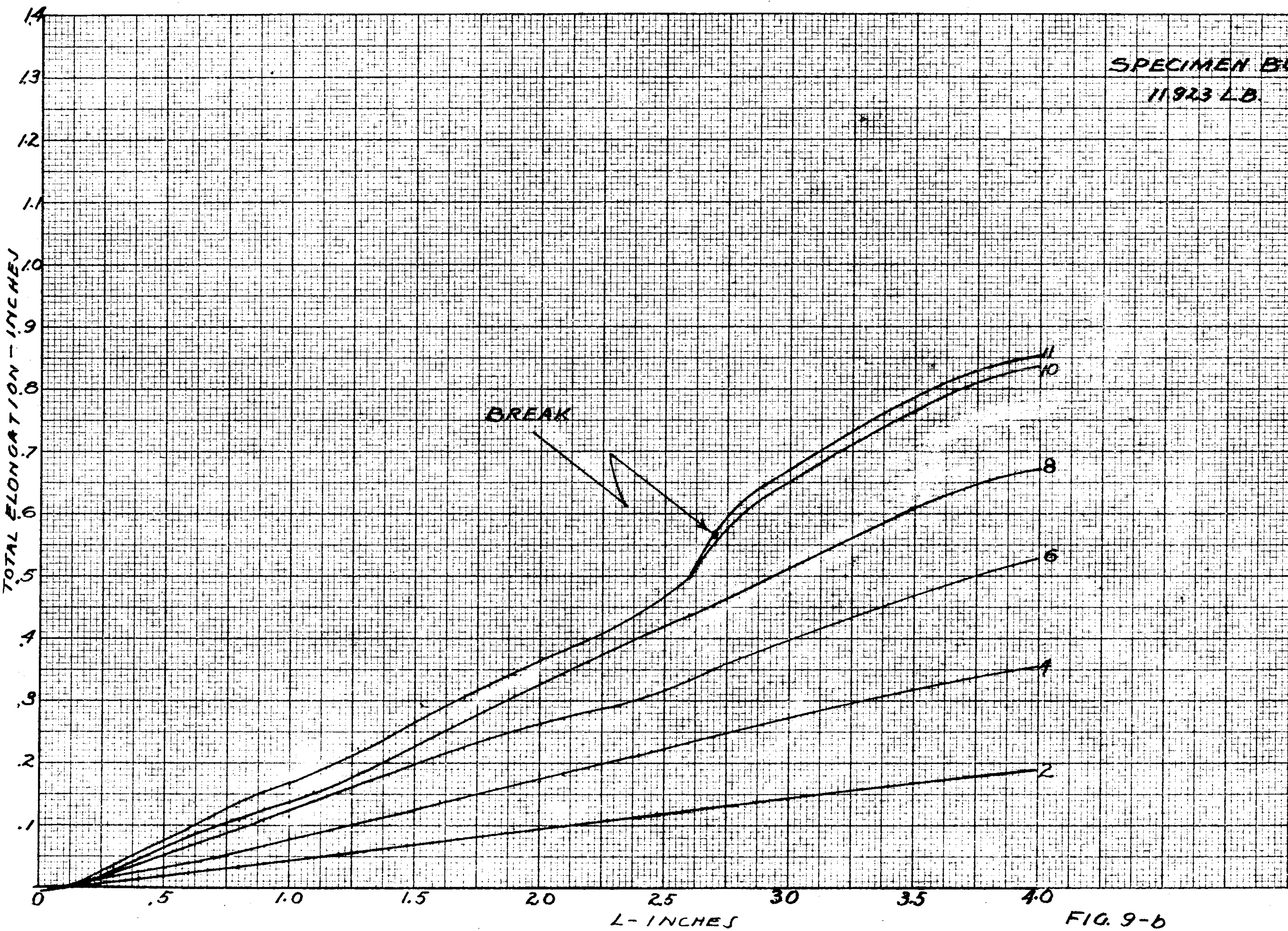

SPECIMEN B5
11,923 LB
BREAK
11
10
8
6
4
2
UNIT ELONGATION/.01 INCHES-INCH
.070
.060
.050
.040
.030
.020
.010
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L-INCHES

FIG. 9-a



SPECIMEN B6
11923 LB.
BREAK
TOTAL ELONGATION - INCHES
L - INCHES
2
4
6
8
10
11

FIG. 9-b

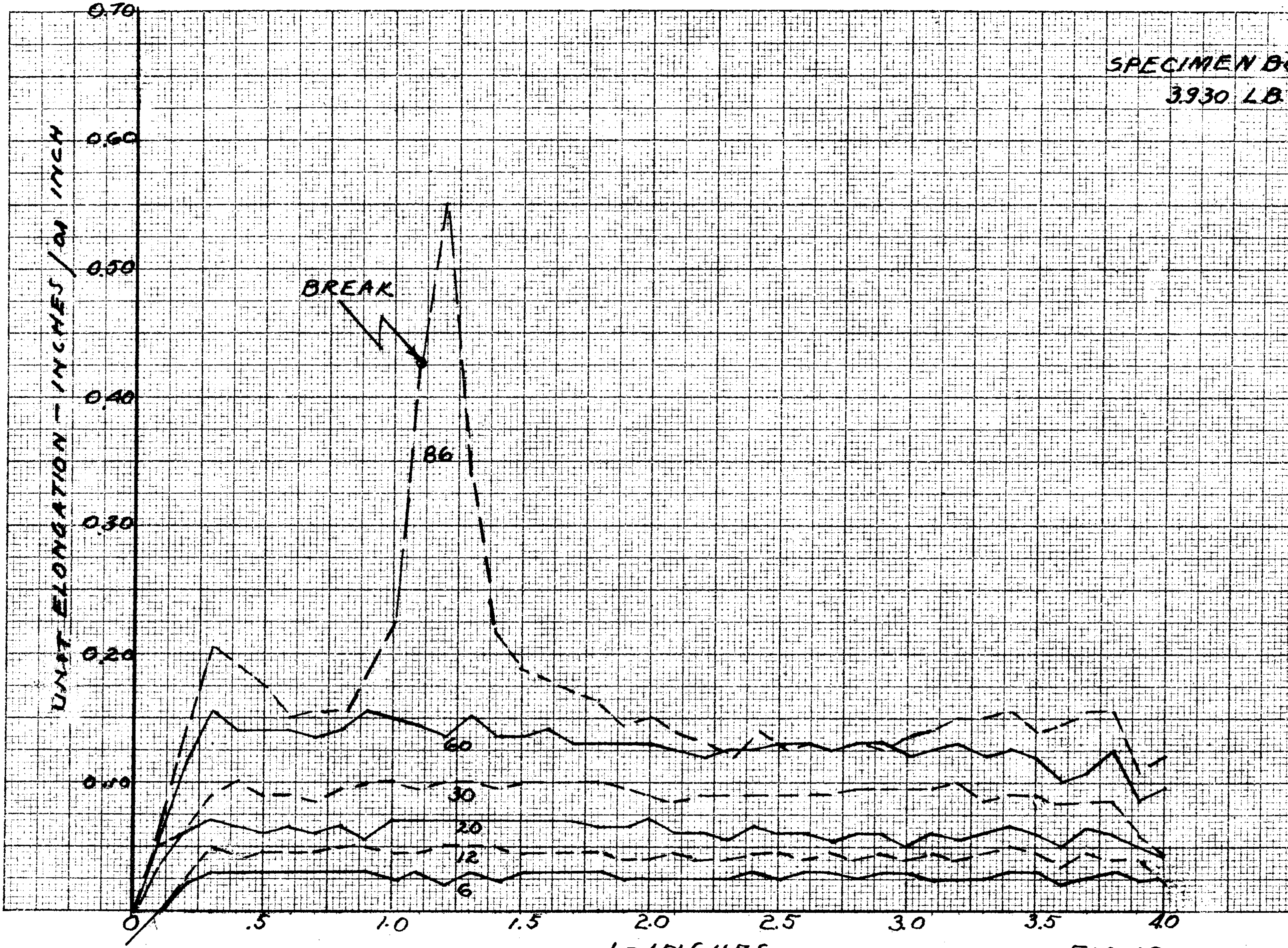

SPECIMEN BG
3930 LB
BREAK
86
60
30
20
12
6
UNIT ELONGATION - INCHES / IN INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L-INCHES

FIG. 10-a

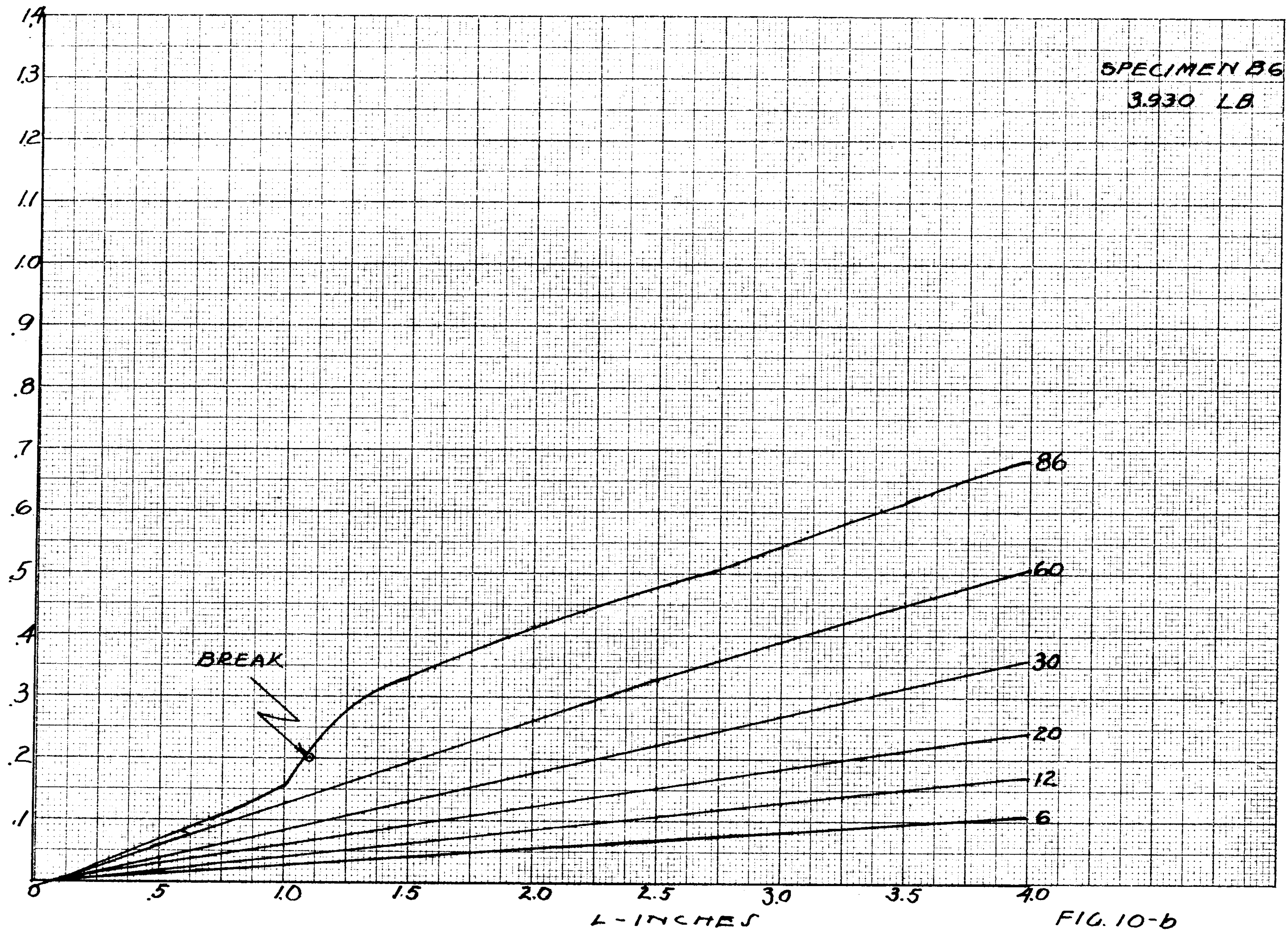
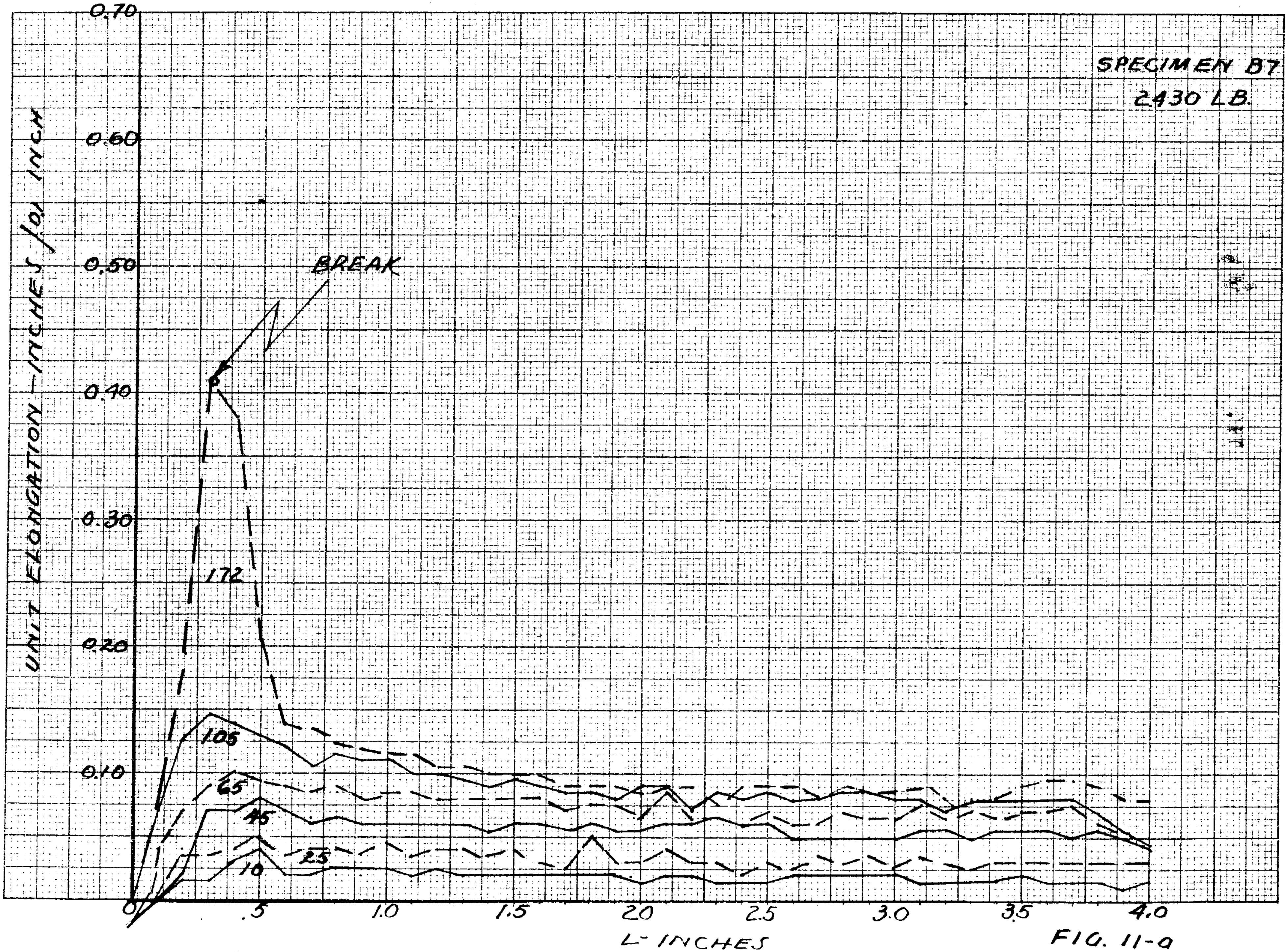

SPECIMEN B6
3.930 LB
BREAK
86
60
30
20
12
6
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L - INCHES

FIG. 10-b



SPECIMEN B7
2430 LB.
UNIT ELONGATION - INCHES / 0.1 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L - INCHES
BREAK
172
105
65
45
25
10

FIG. 11-a

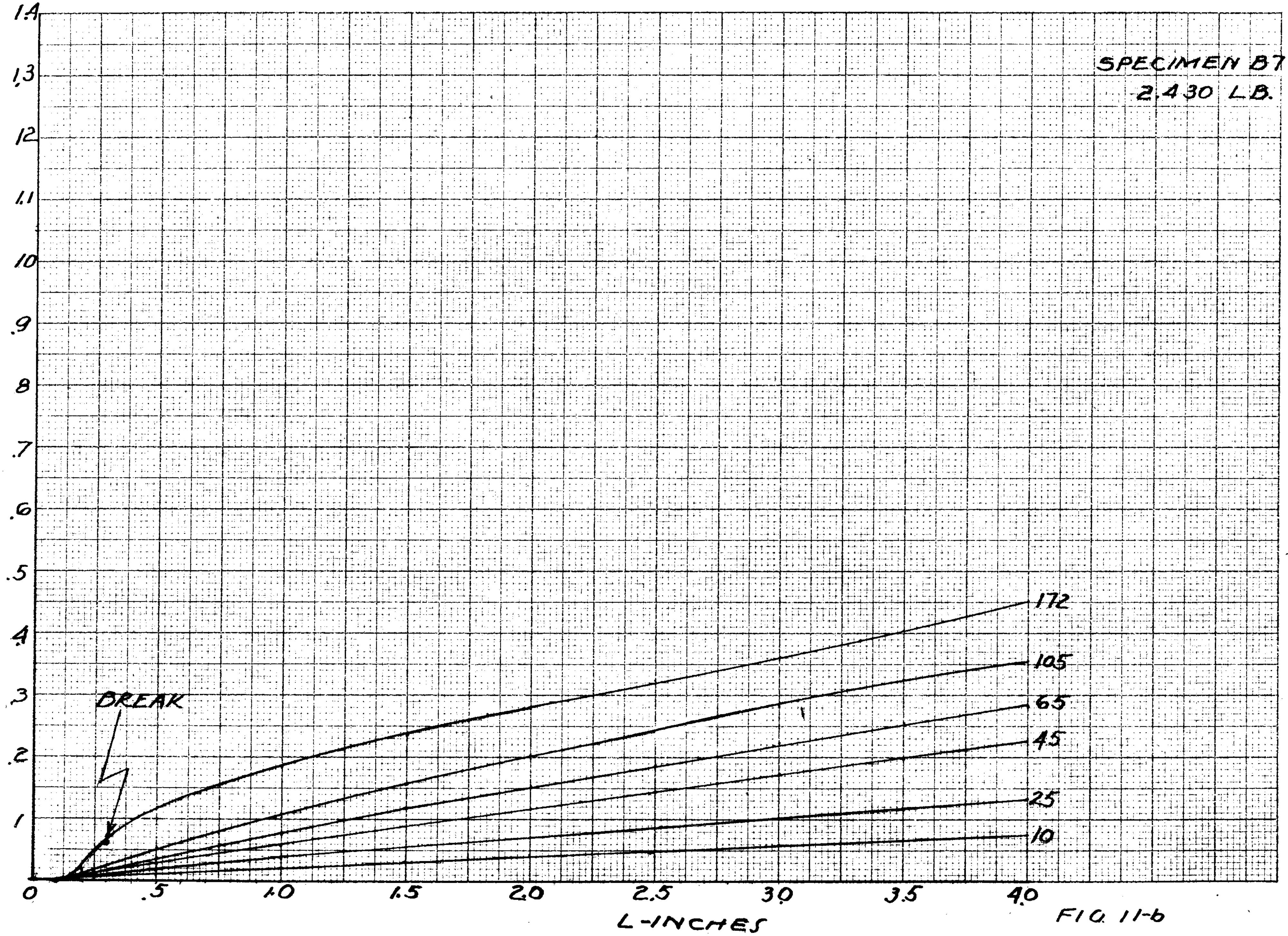

SPECIMEN B7
2,430 LB.
BREAK
172
105
65
45
25
10
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L-INCHES
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4

FIG. 11-6

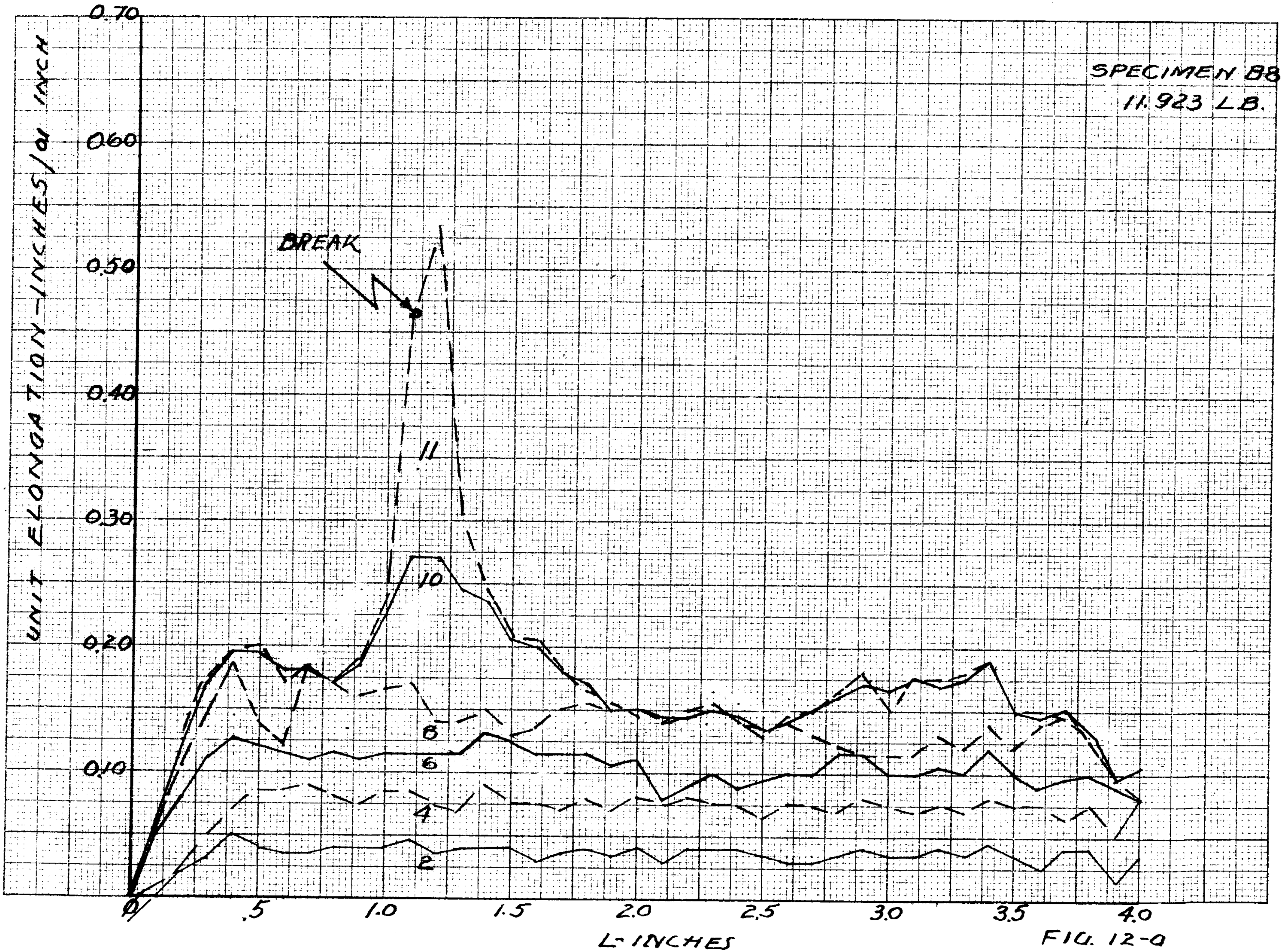
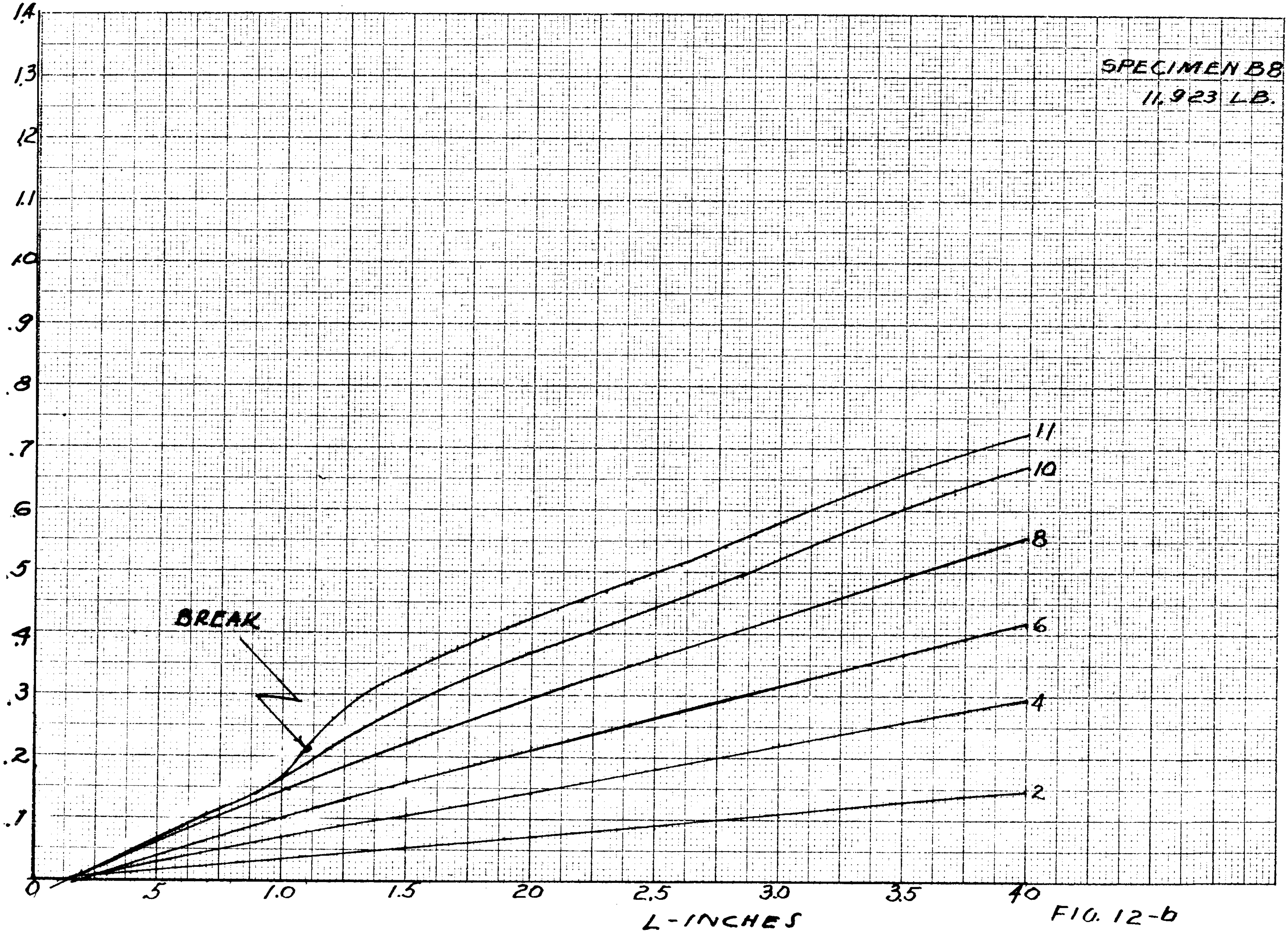

SPECIMEN B8
11.923 LB.
UNIT ELONGATION-INCHES/.01 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
BREAK
11
10
8
6
4
2
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L-INCHES

FIG. 12-a



SPECIMEN B8
11,923 LB.
BREAK
11
10
8
6
4
2
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L-INCHES

FIG. 12-b

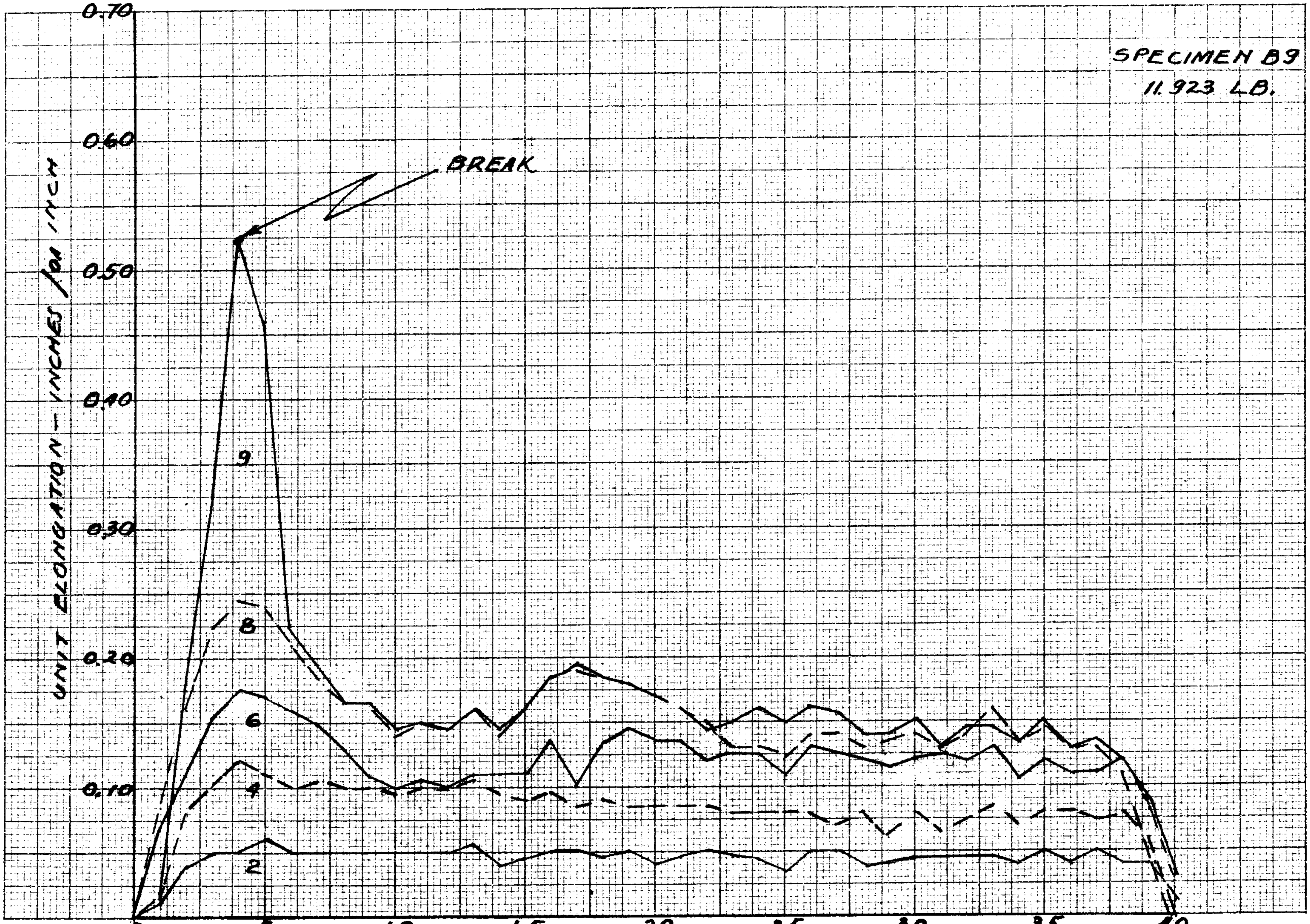

SPECIMEN B9
11.923 LB.
BREAK
UNIT ELONGATION – INCHES /01 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
9
8
6
4
2
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L-INCHES

FIG. 13-a

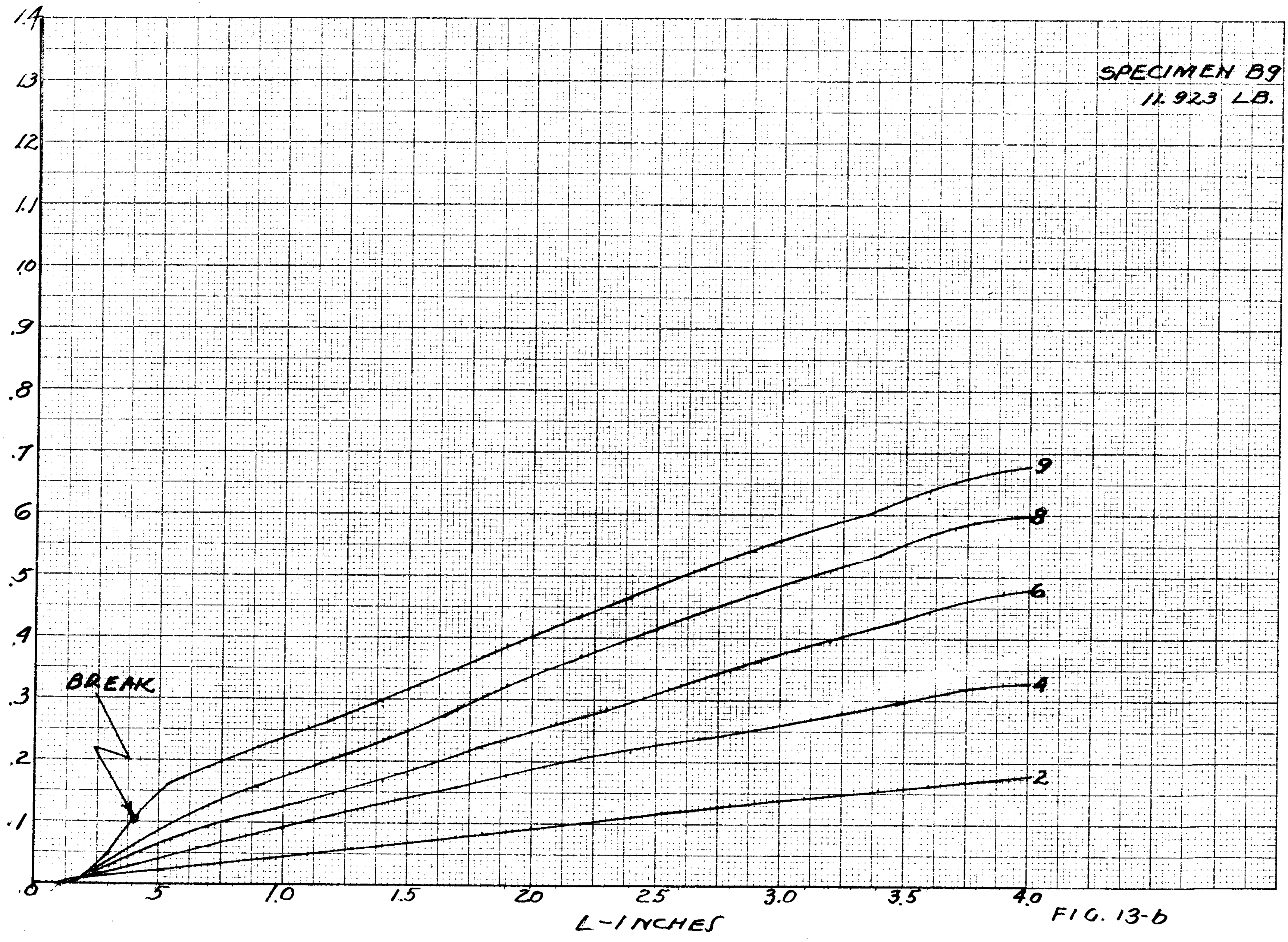

SPECIMEN B9
11.923 LB.
BREAK
.0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L-INCHES
9
8
6
4
2

FIG. 13-b

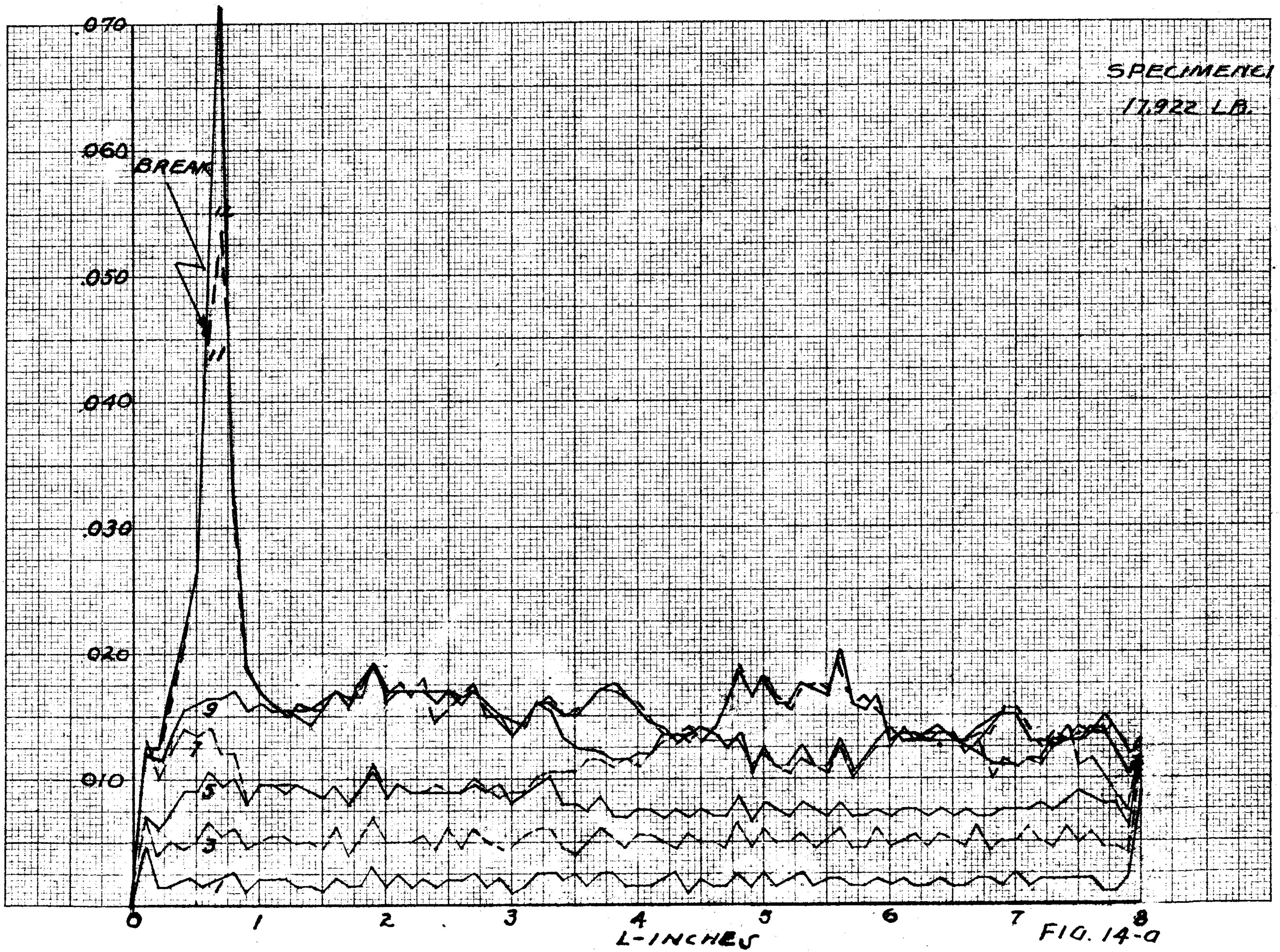

SPECIMEN C1
17,922 LB.
BREAK
.070
.060
.050
.040
.030
.020
.010
0
1
2
3
4
5
6
7
8
1
3
5
7
9
11
12
L-INCHES

FIG. 14-a

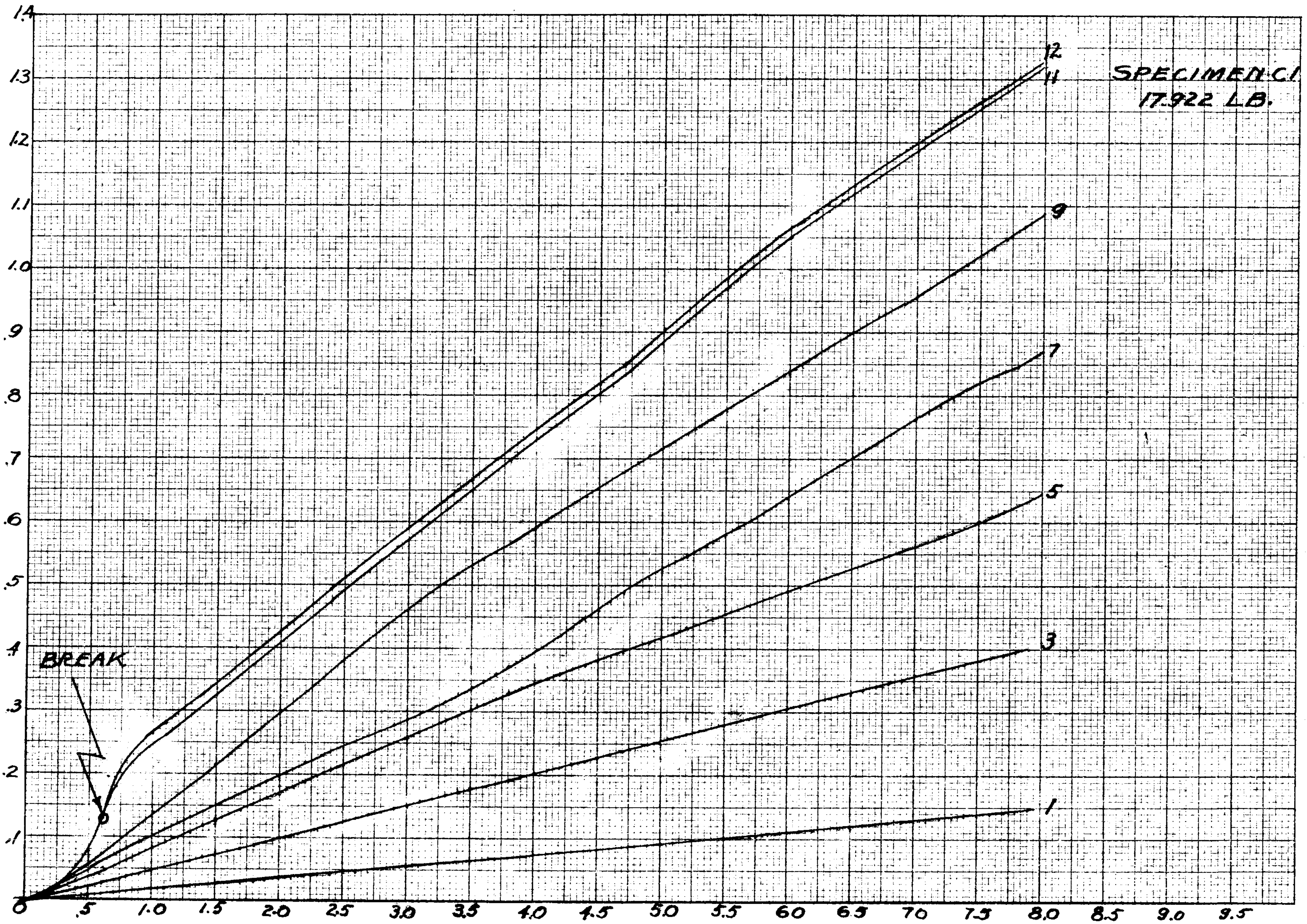
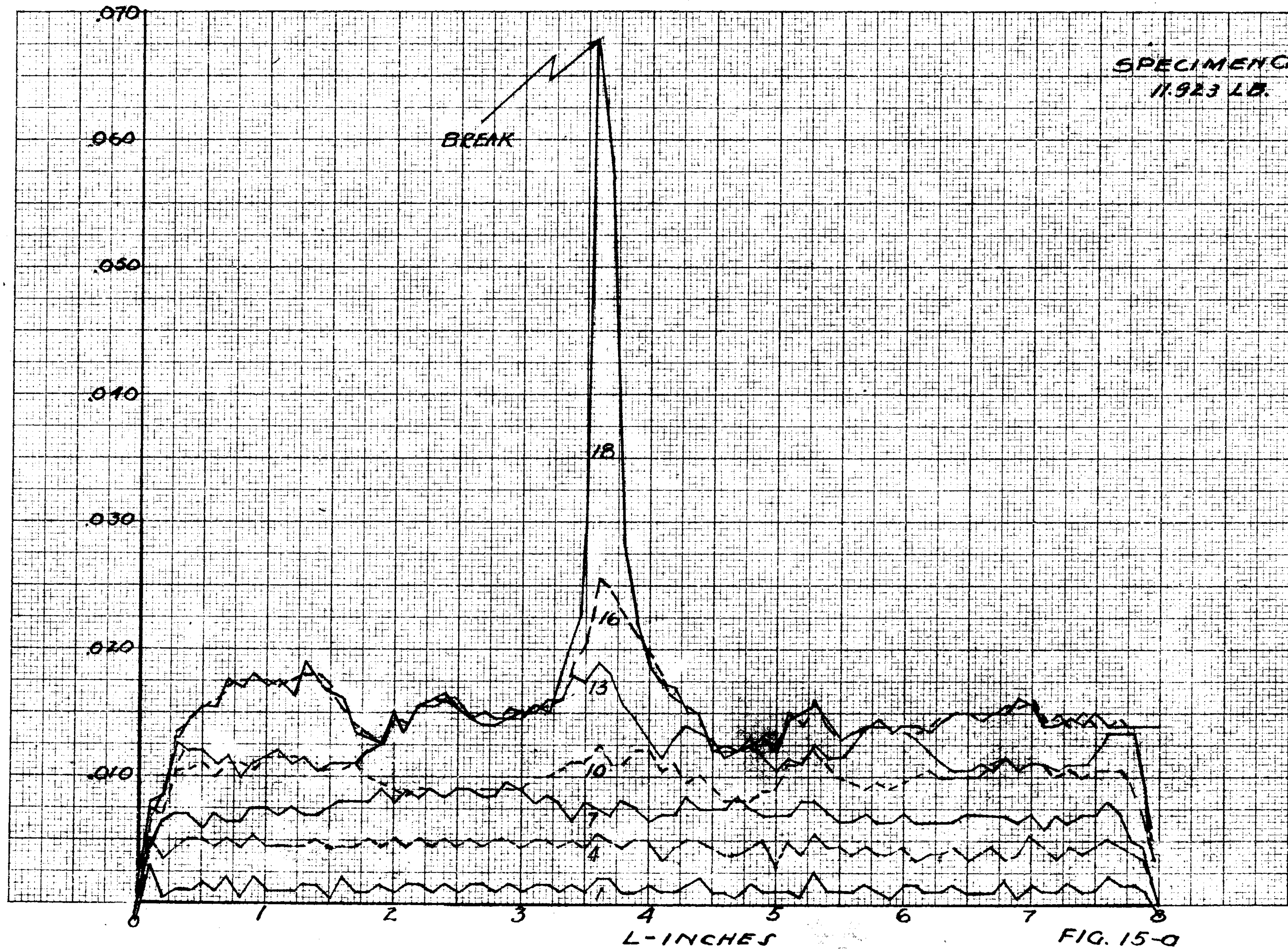
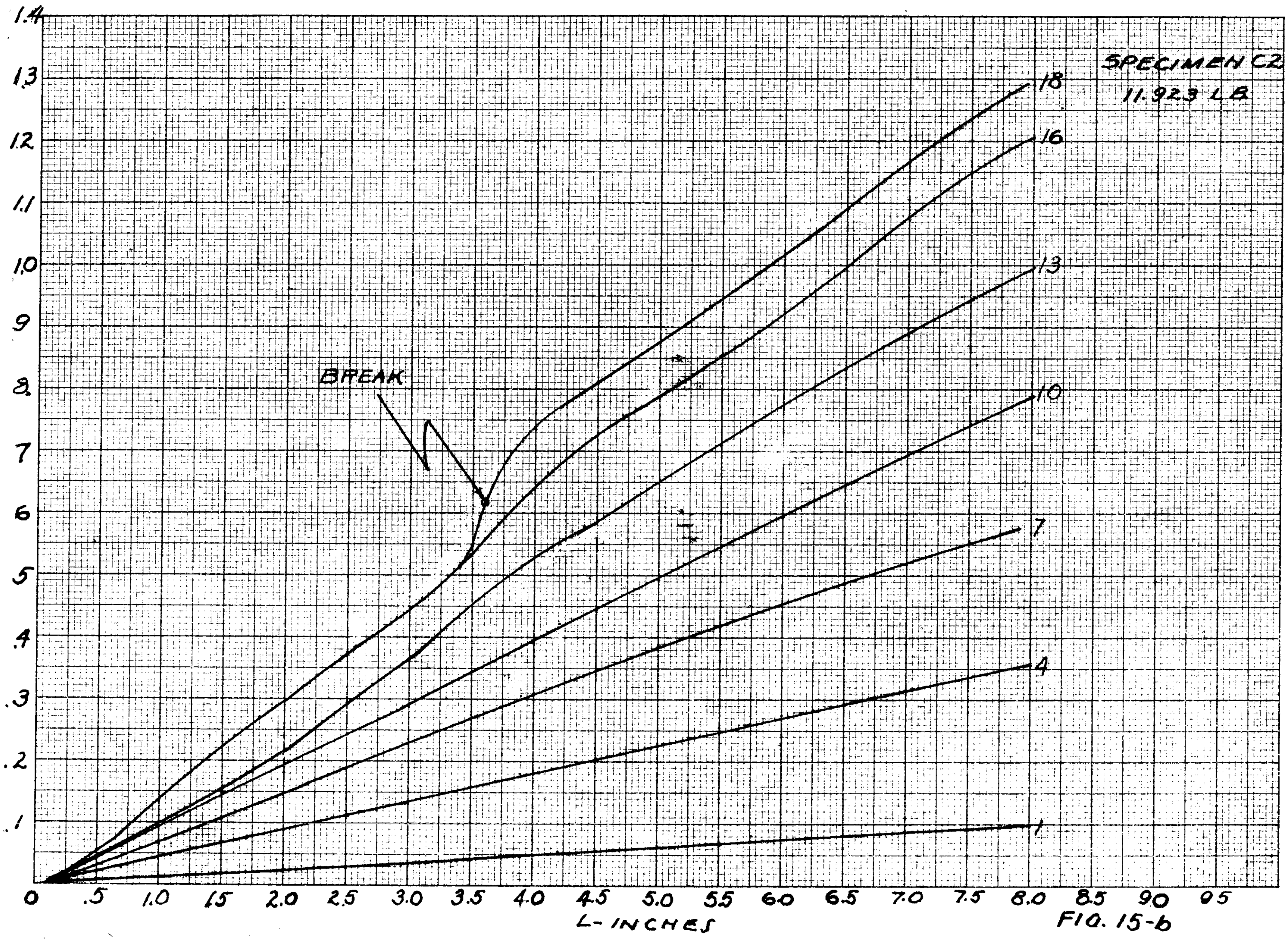


FIG. 14-b



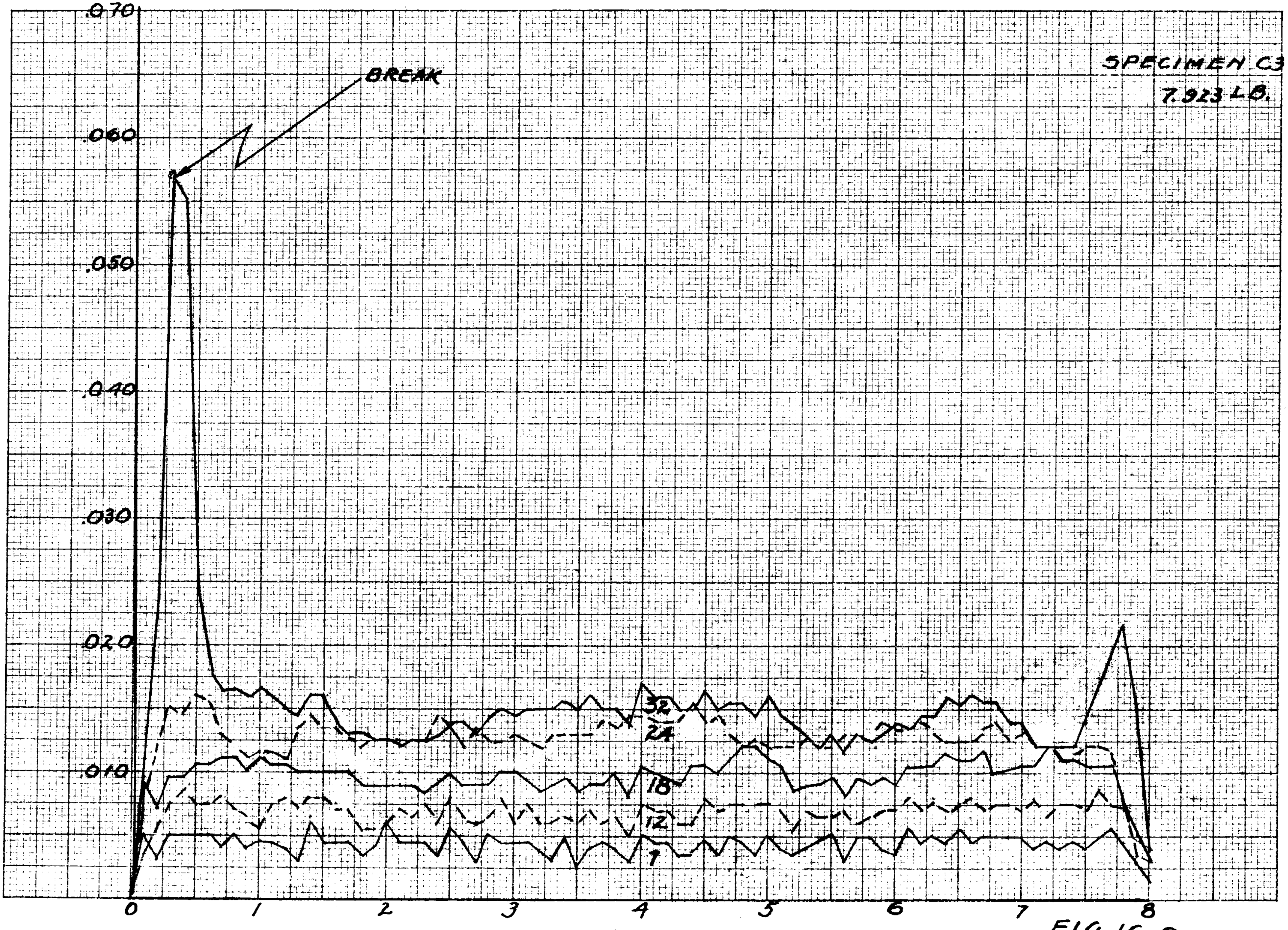
SPECIMEN C2
11.923 LB.
BREAK
.070
.060
.050
.040
.030
.020
.010
0
1
2
3
4
5
6
7
8
18
16
13
10
7
4
1
L-INCHES

FIG. 15-a



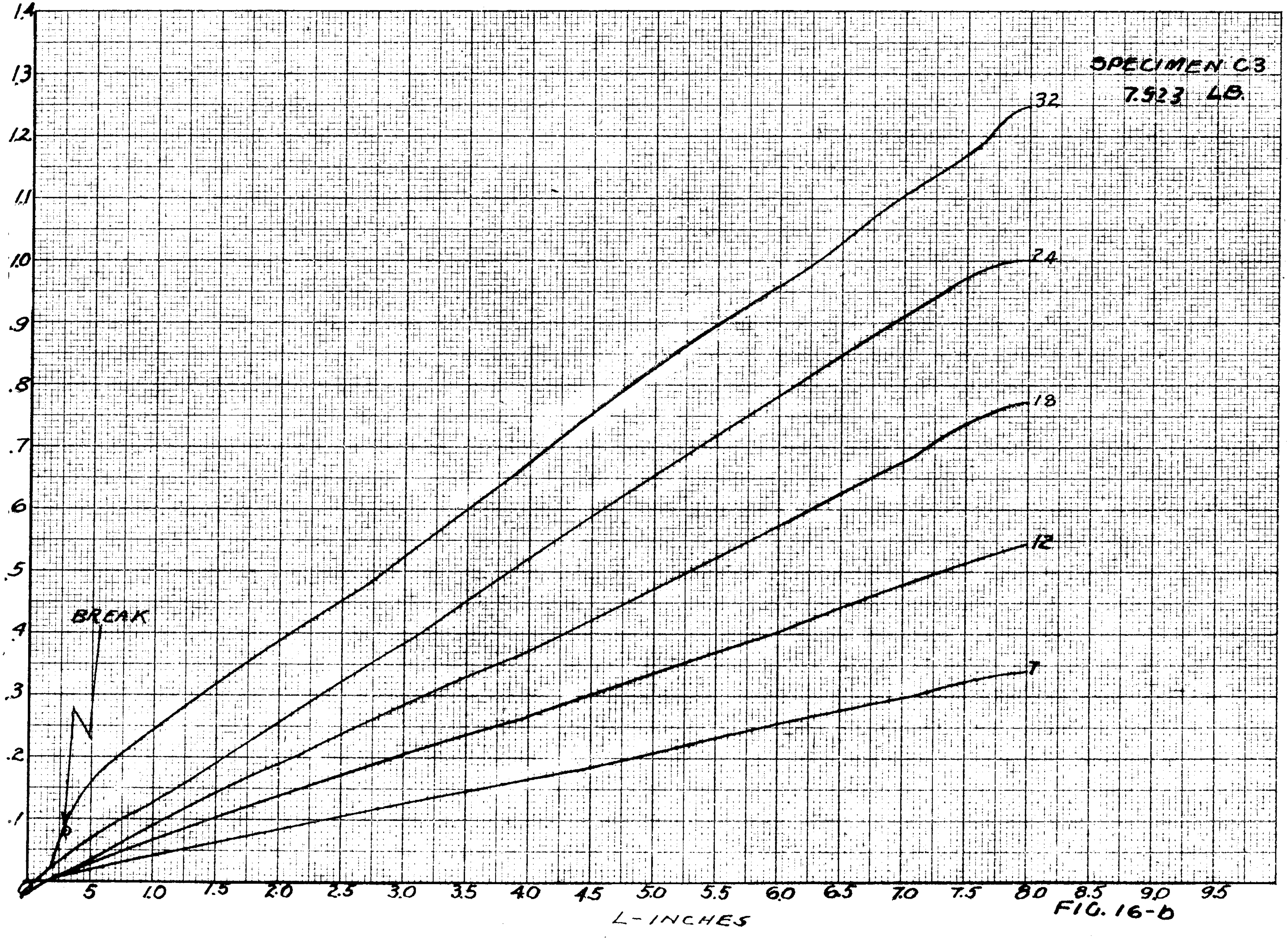
SPECIMEN C2
11.923 LB
BREAK
18
16
13
10
7
4
1
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
L - INCHES

FIG. 15-b



SPECIMEN C3
7.923 LB.
BREAK
.070
.060
.050
.040
.030
.020
.010
32
24
18
12
1
0
1
2
3
4
5
6
7
8
L-INCHES

FIG. 16-a



SPECIMEN C3
7.523 LB.
BREAK
32
24
18
12
7
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
L-INCHES

FIG. 16-b

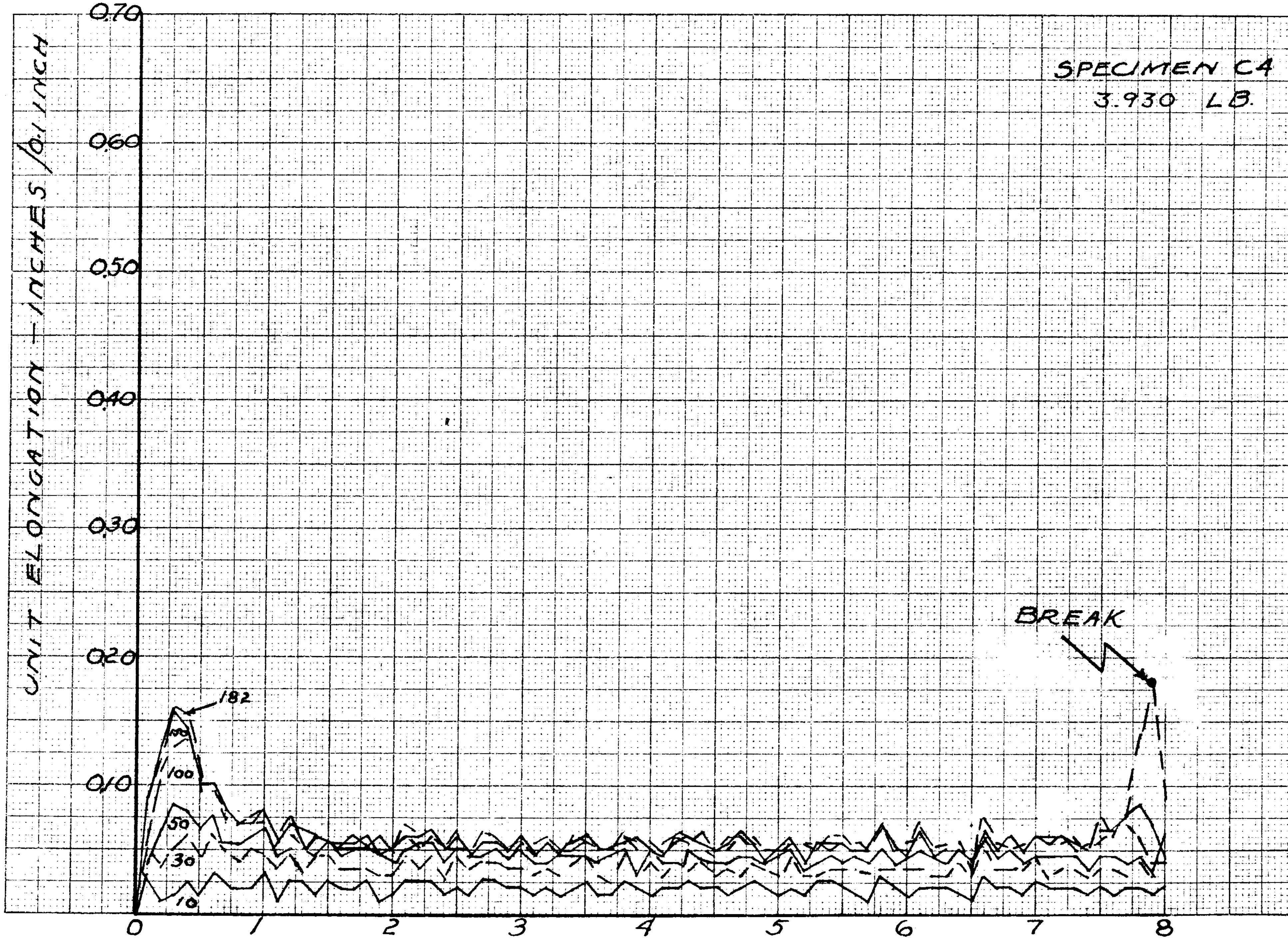

UNIT ELONGATION - INCHES /0.1 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
1
2
3
4
5
6
7
8
L-INCHES
SPECIMEN C4
3.930 LB.
BREAK
182
100
50
30
10

FIG. 17-a

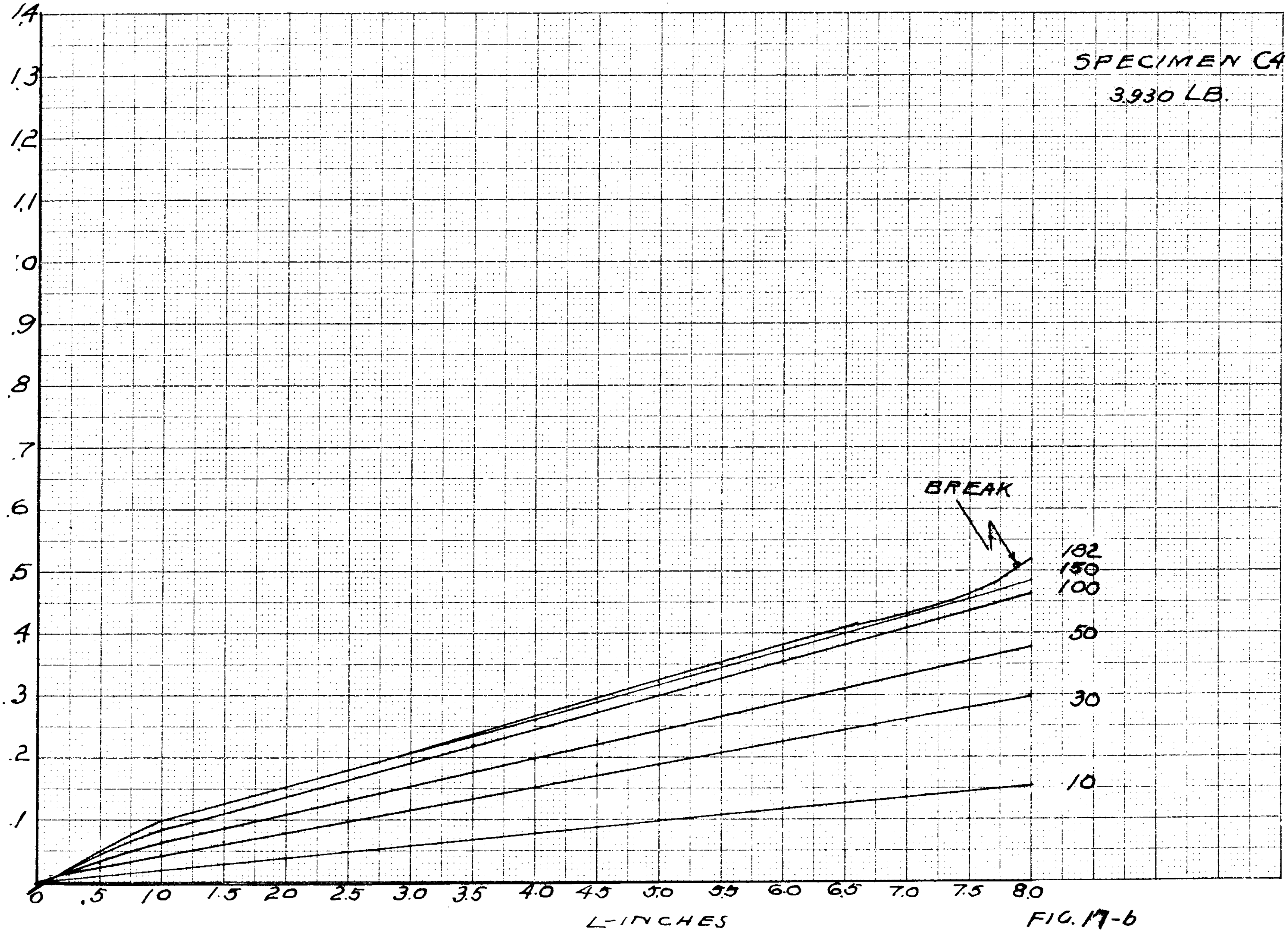
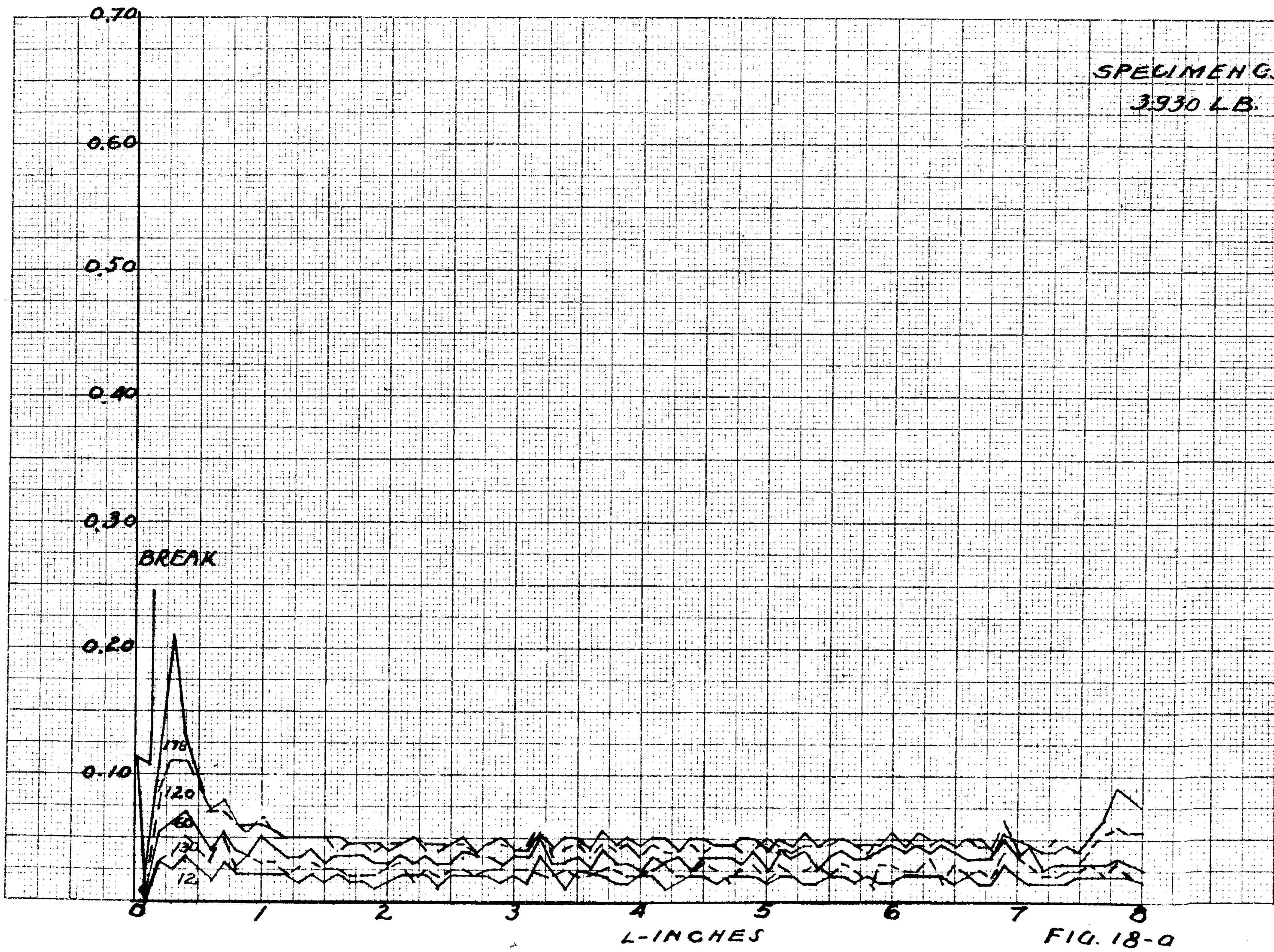
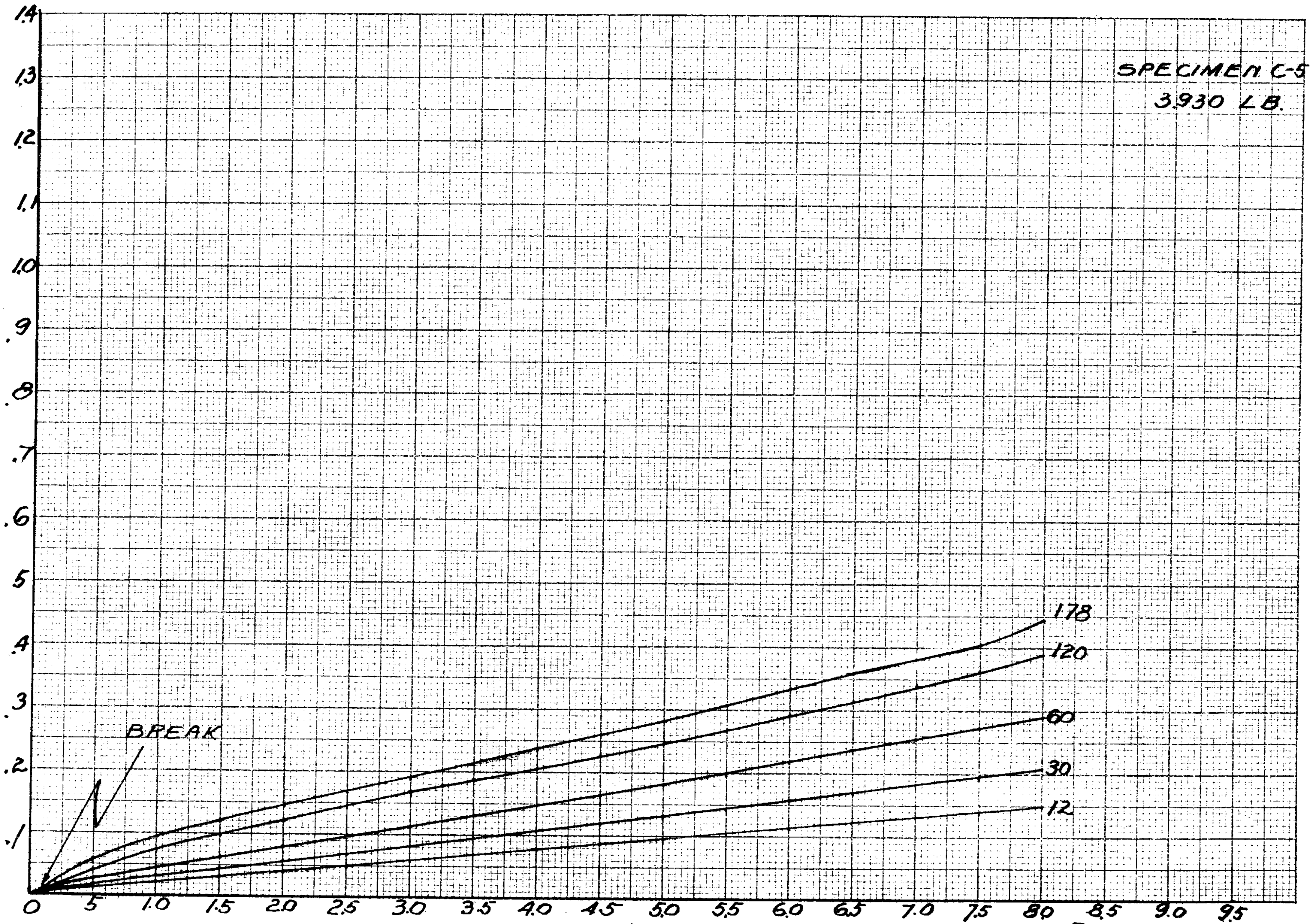

SPECIMEN C4
3,930 LB.
BREAK
182
150
100
50
30
10
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
L-INCHES

FIG. 17-6



SPECIMEN G5
3930 LB.
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
BREAK
178
120
60
130
12
1
2
3
4
5
6
7
8
L-INCHES

FIG. 18-a


SPECIMEN C-5
3.930 LB.
BREAK
178
120
60
30
12
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
L - INCHES
FIG. 18-b

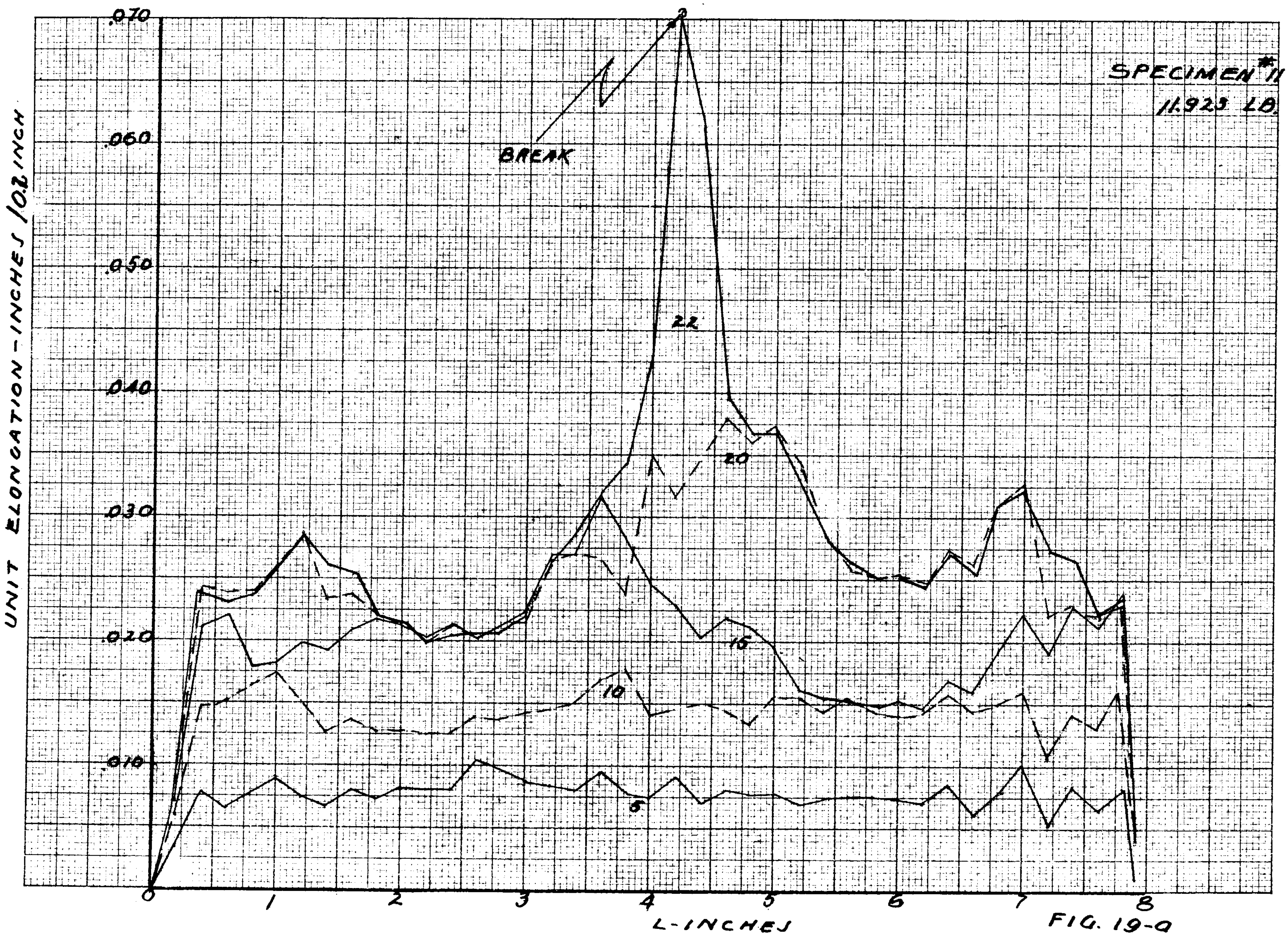

SPECIMEN #11
11.923 LB.
BREAK
UNIT ELONGATION-INCHES/0.2 INCH
.070
.060
.050
.040
.030
.020
.010
0
1
2
3
4
5
6
7
8
L-INCHES
22
20
15
10
5

FIG. 19-a

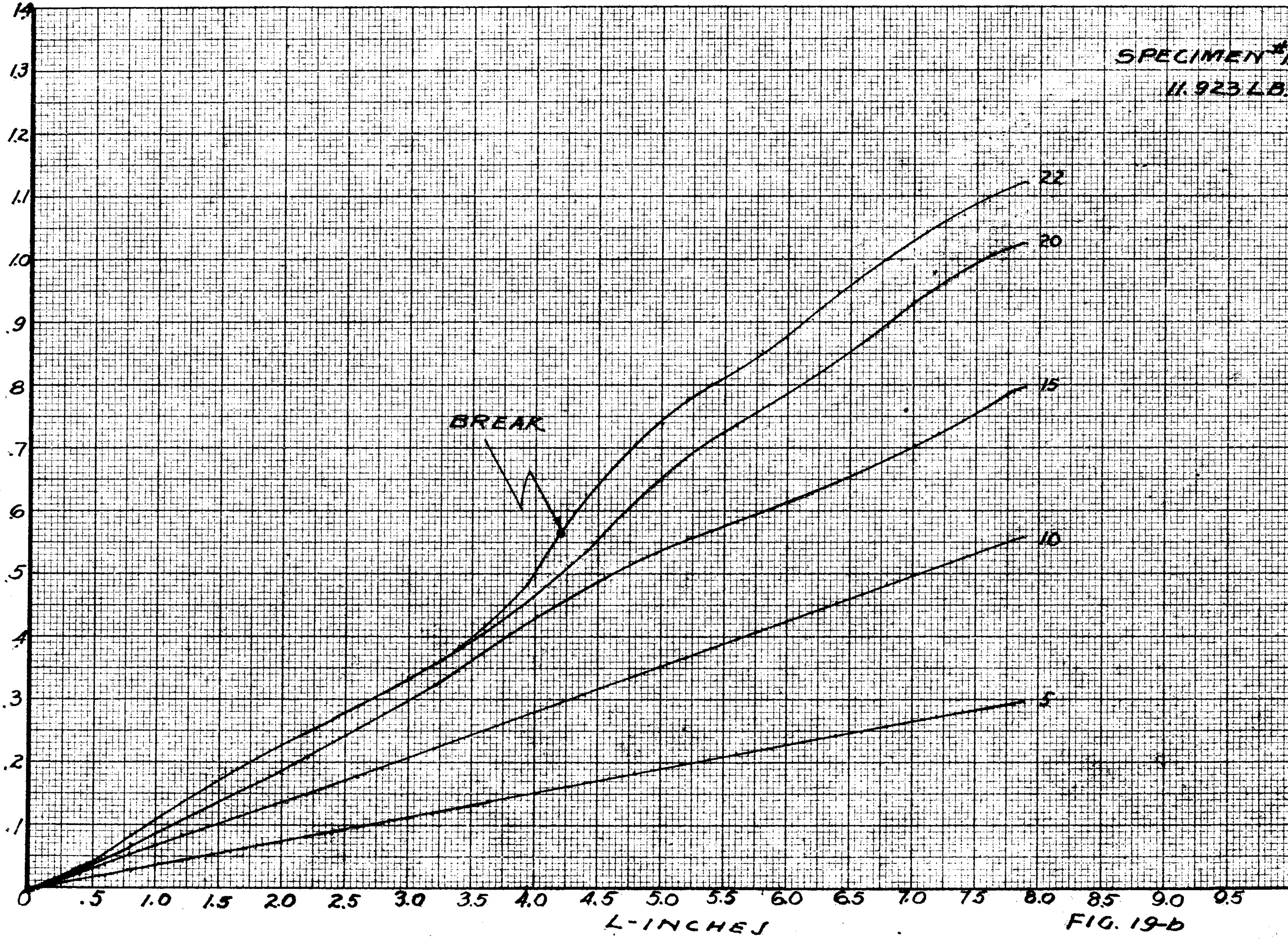


FIG. 19-b

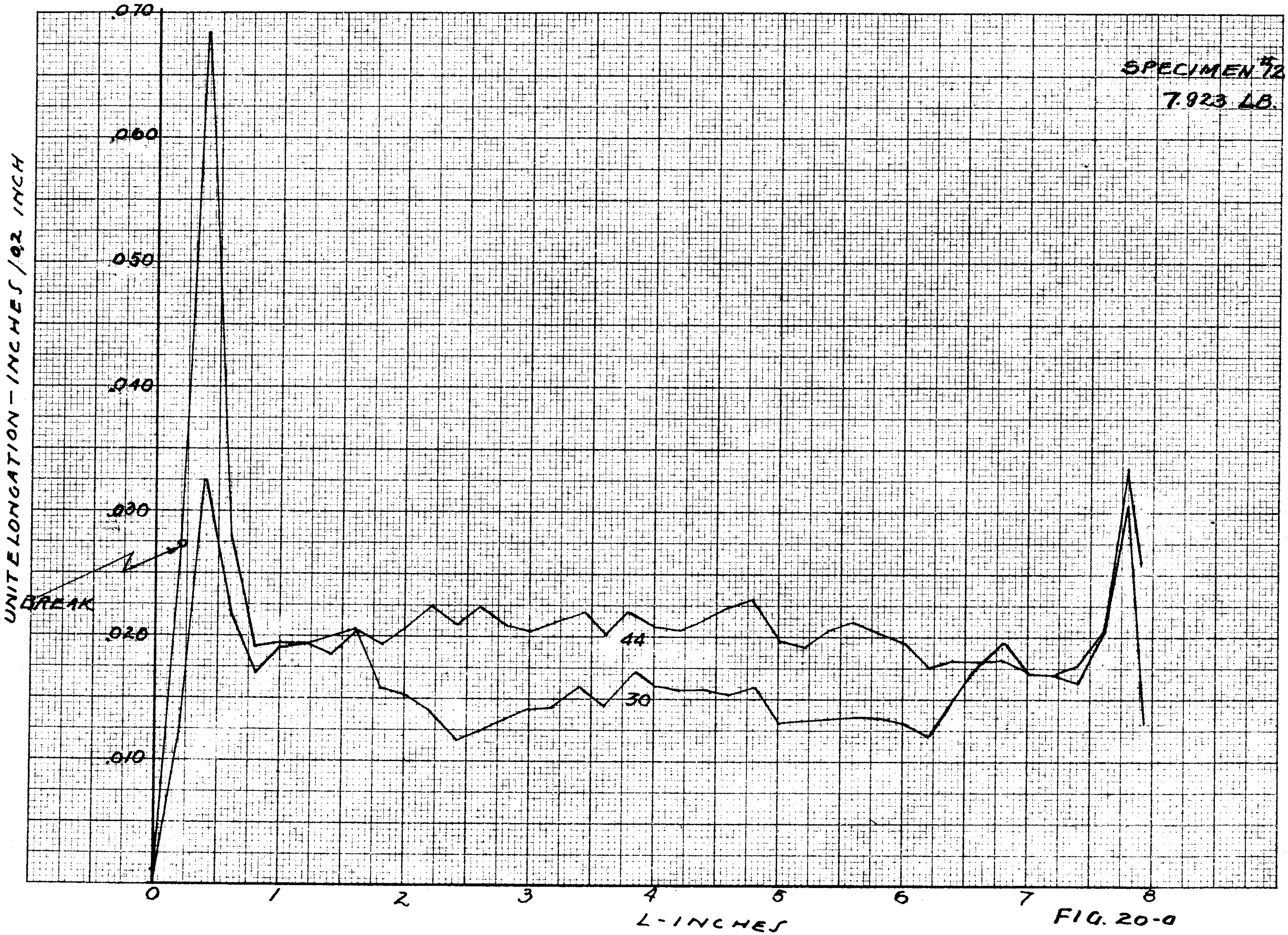

SPECIMEN #72
7.923 LB.
UNIT ELONGATION - INCHES / 0.2 INCH
.070
.060
.050
.040
.030
.020
.010
BREAK
44
30
0
1
2
3
4
5
6
7
8
L-INCHES

FIG. 20-a

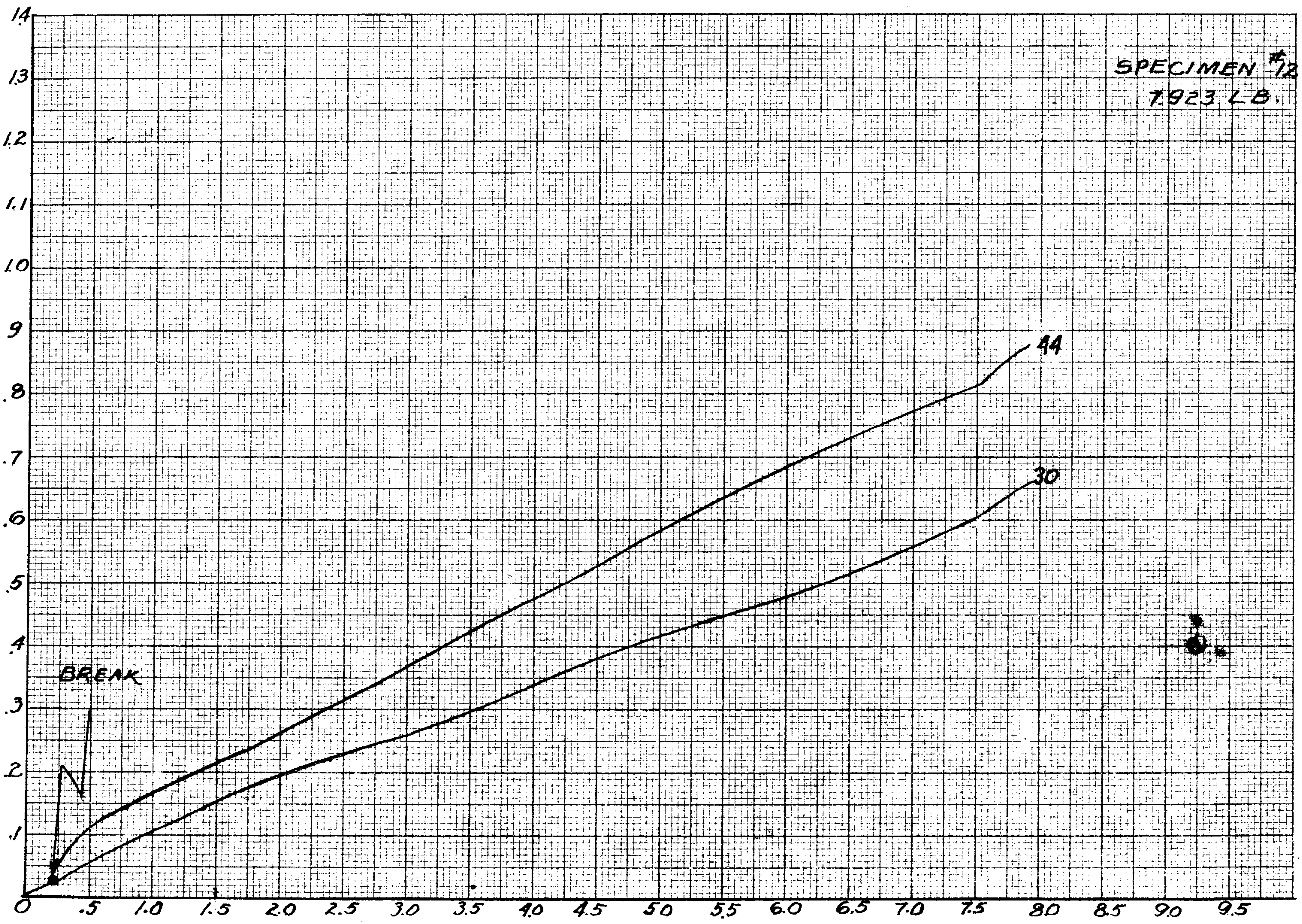

SPECIMEN #12
7.923 LB.
BREAK
44
30
14
13
1.2
1.1
1.0
9
.8
.7
.6
.5
.4
.3
.2
.1
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
L-INCHES

FIG. 20-b

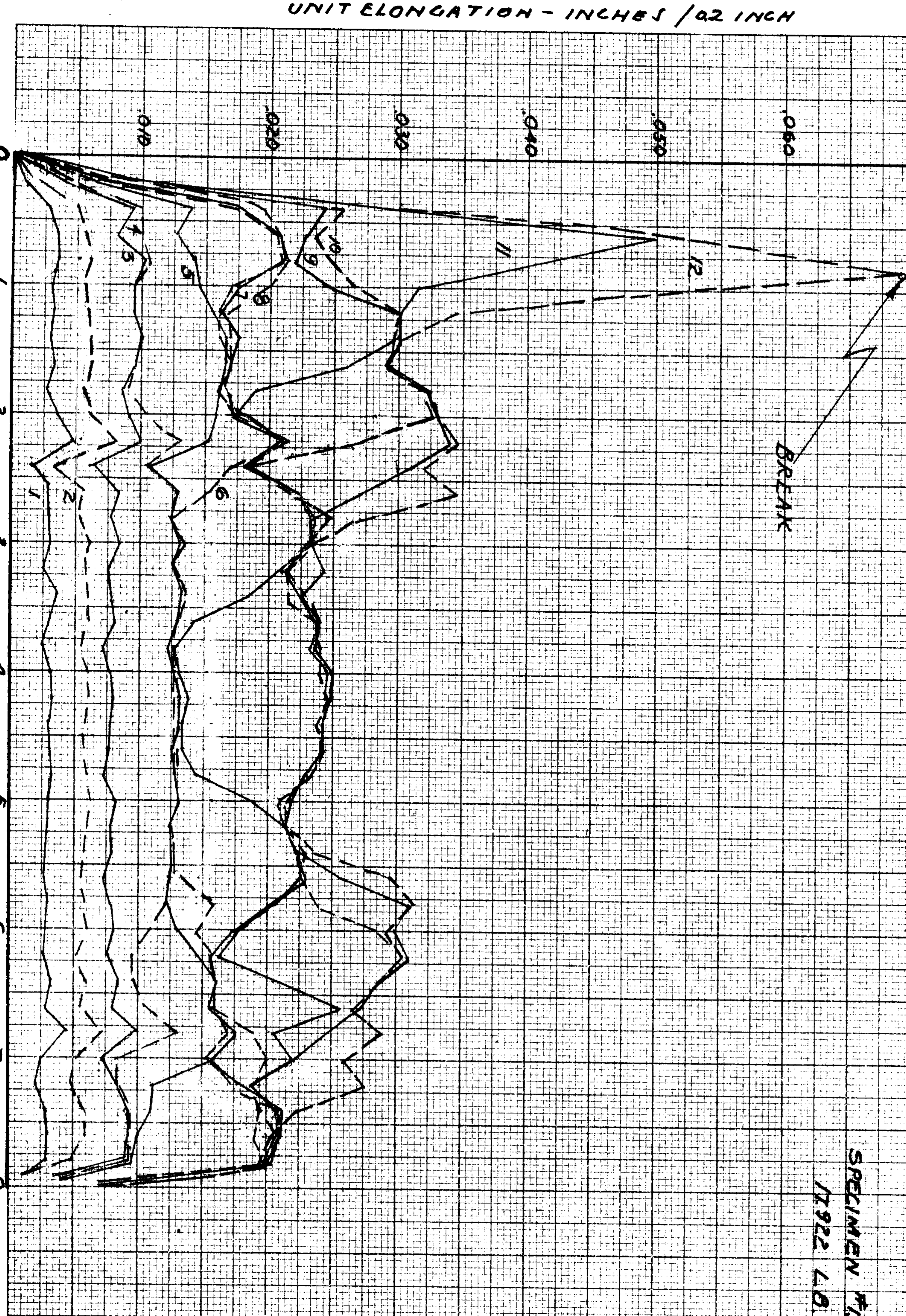
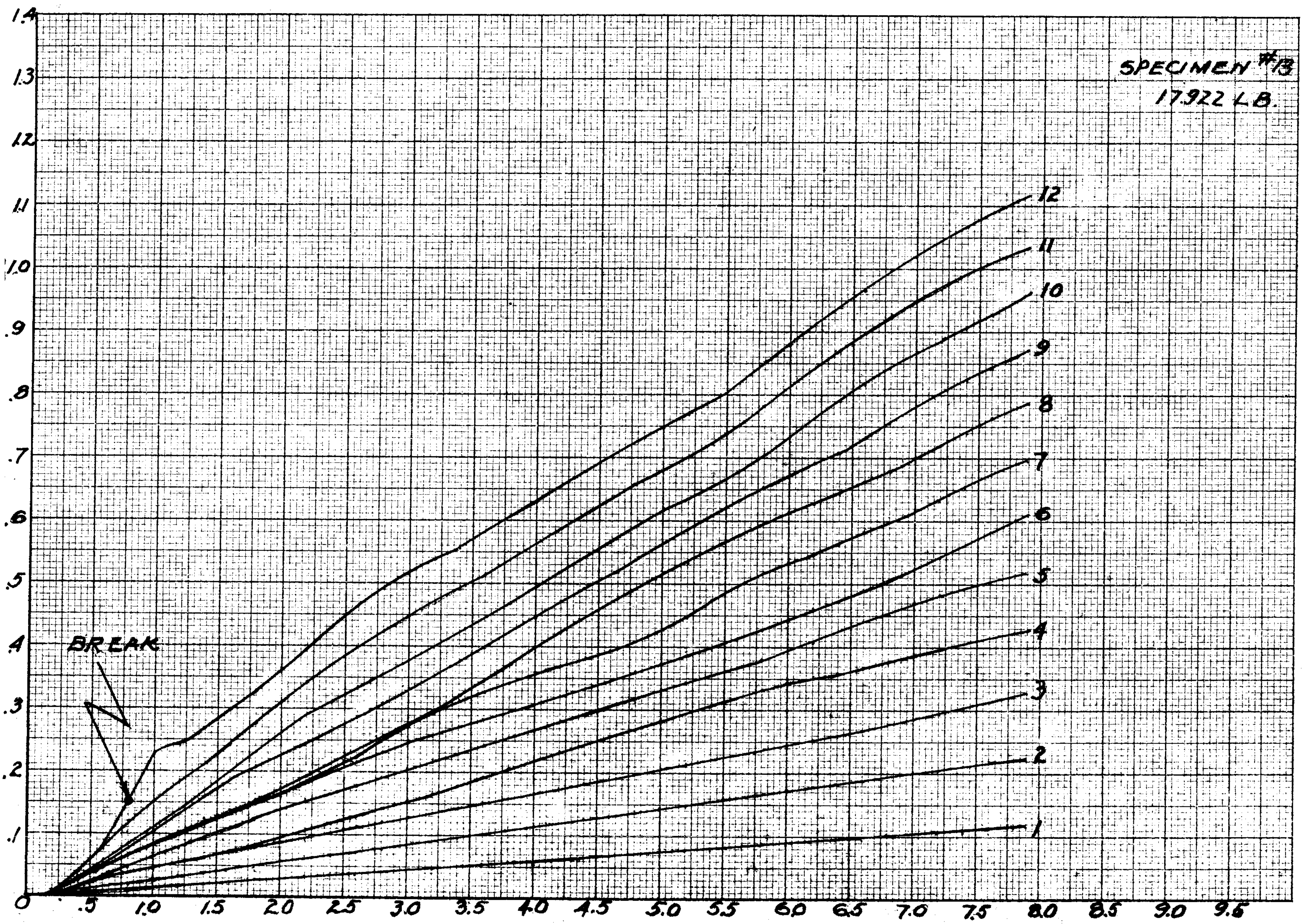
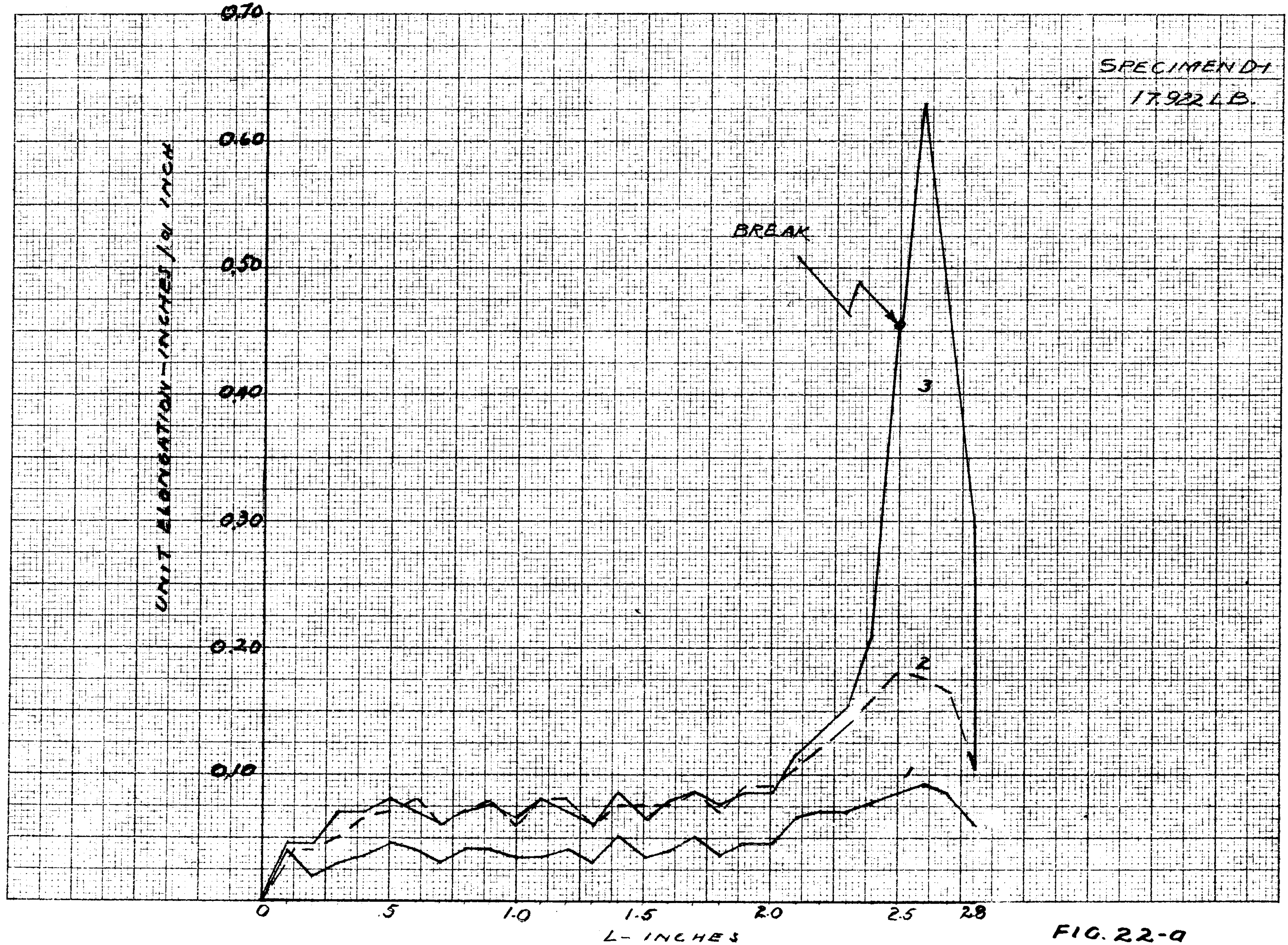

UNIT ELONGATION - INCHES / 0.2 INCH
.010
.020
.030
.040
.050
.060
.070
0
1
2
3
4
5
6
7
8
L-INCHES
BREAK
1
2
4
5
6
9
10
11
12
SPECIMEN #13
17922 L.B.

FIG. 21-0



SPECIMEN #13
17.922 LB.
BREAK
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
1
2
3
4
5
6
7
8
9
10
11
12
L-INCHES

FIG. 21-b



SPECIMEN D-1
17.922 LB.
UNIT ELONGATION - INCHES / .01 INCH
0.10
0.20
0.30
0.40
0.50
0.60
0.70
BREAK
3
2
1
0
.5
1.0
1.5
2.0
2.5
2.8
L - INCHES

FIG. 22-a

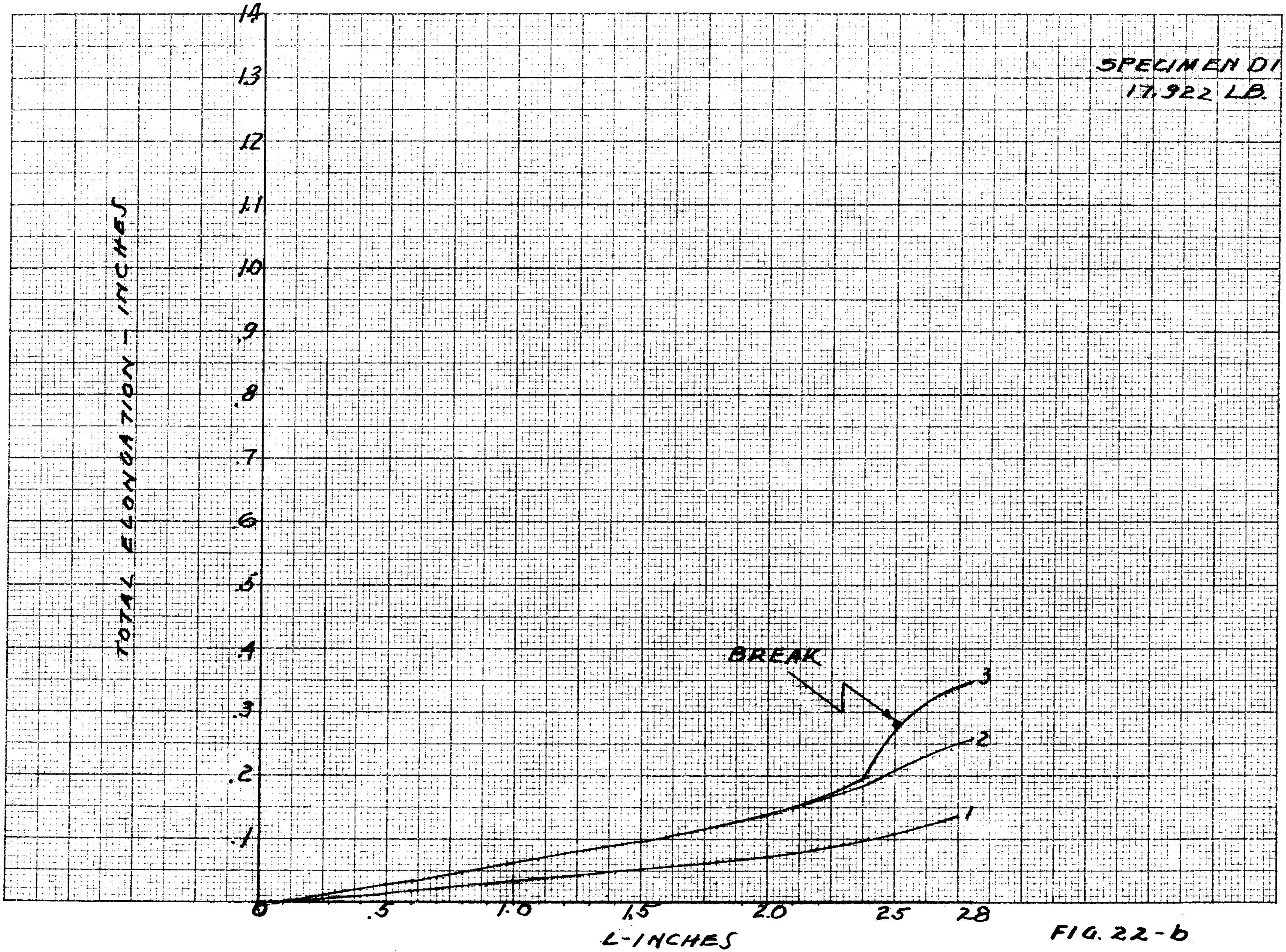
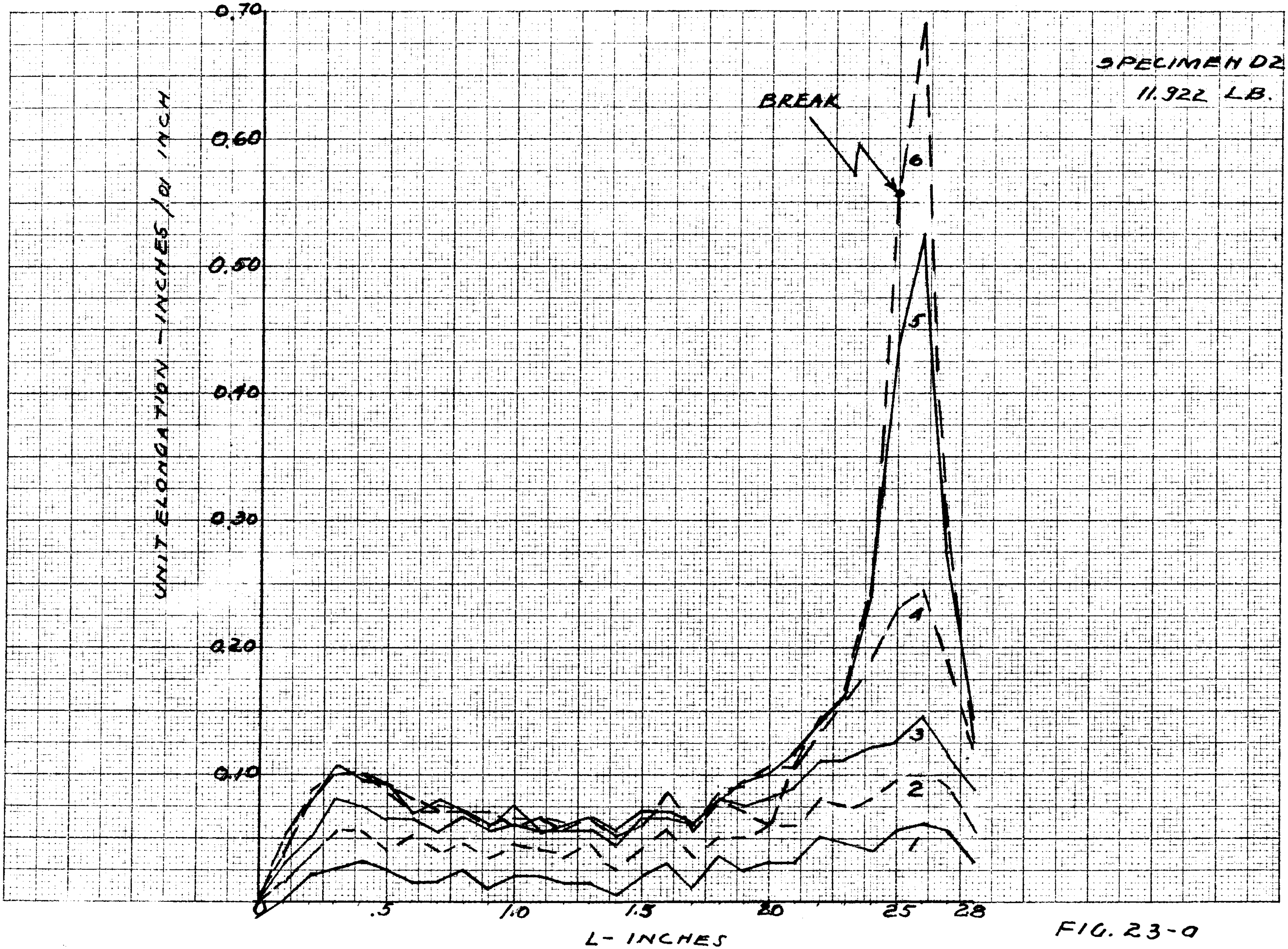
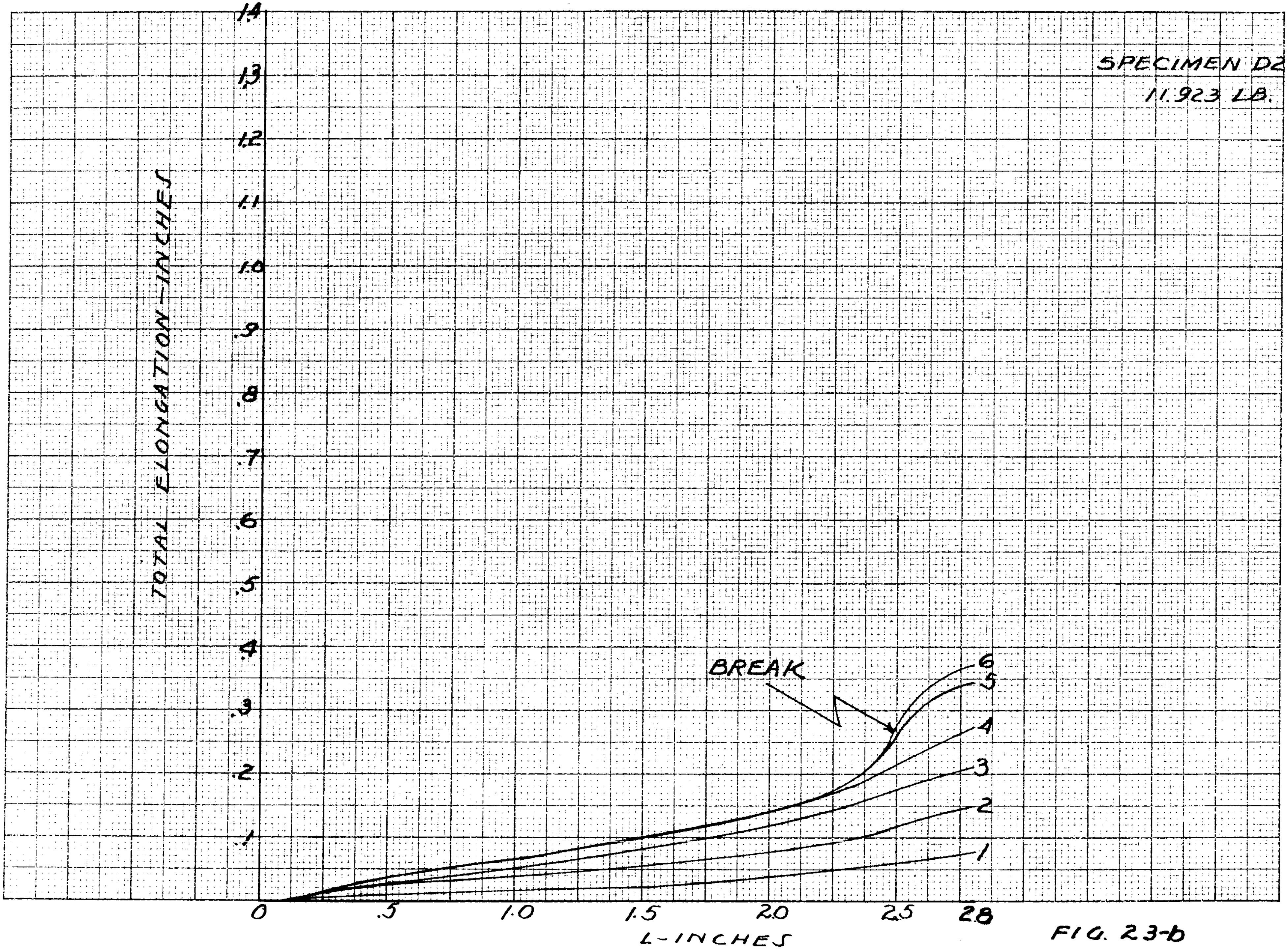

SPECIMEN D1
17,922 LB.
TOTAL ELONGATION - INCHES
14
13
12
11
10
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.5
1.0
1.5
2.0
2.5
2.8
L-INCHES
BREAK
1
2
3

FIG. 22-b



SPECIMEN D2
11.922 LB.
BREAK
UNIT ELONGATION - INCHES/.01 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
.5
1.0
1.5
2.0
2.5
2.8
L- INCHES
1
2
3
4
5
6

FIG. 23-0



SPECIMEN D2
11.923 LB.
TOTAL ELONGATION-INCHES
L-INCHES
BREAK
0
.5
1.0
1.5
2.0
2.5
2.8
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1
2
3
4
5
6

FIG. 23-b

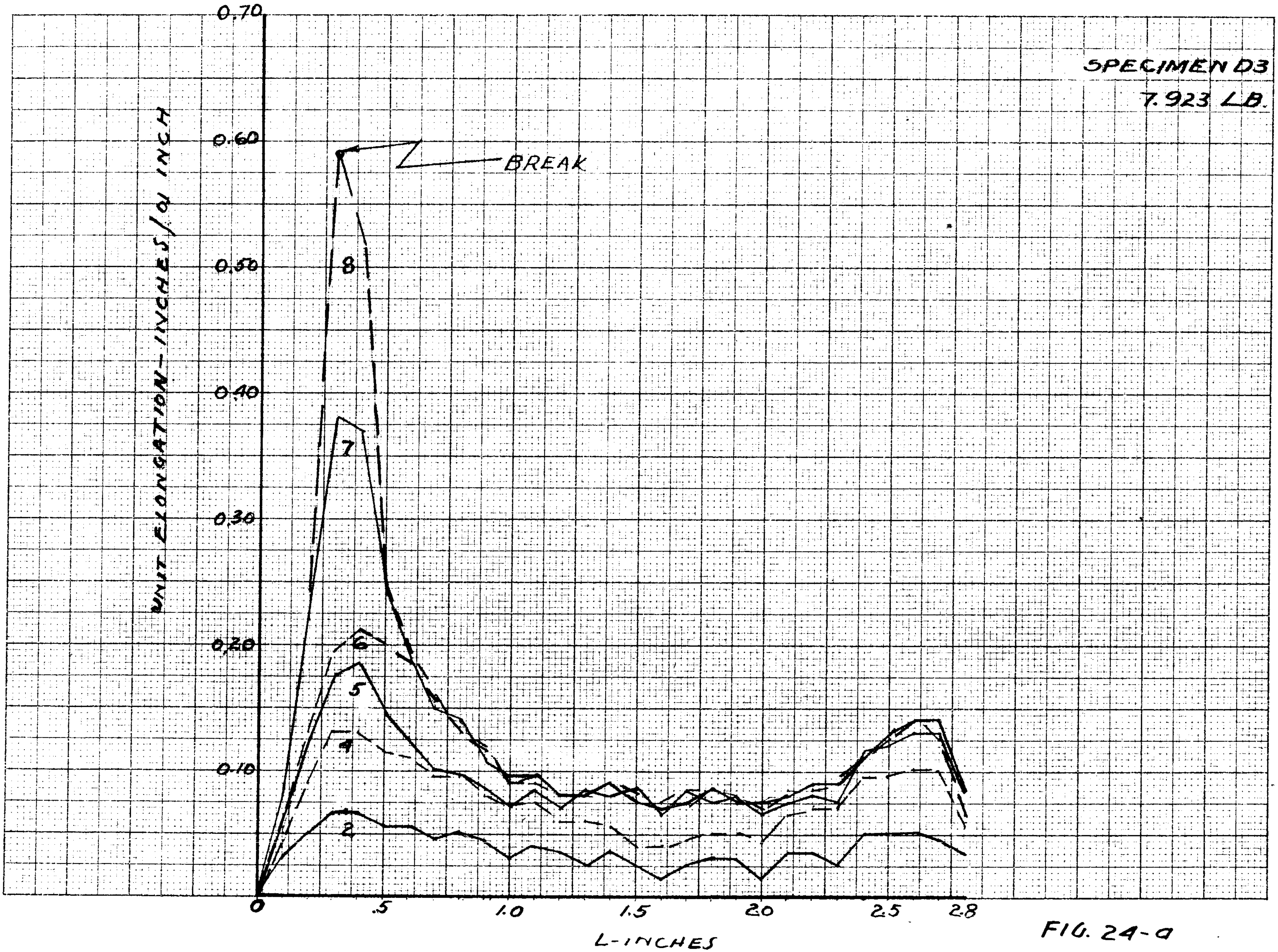
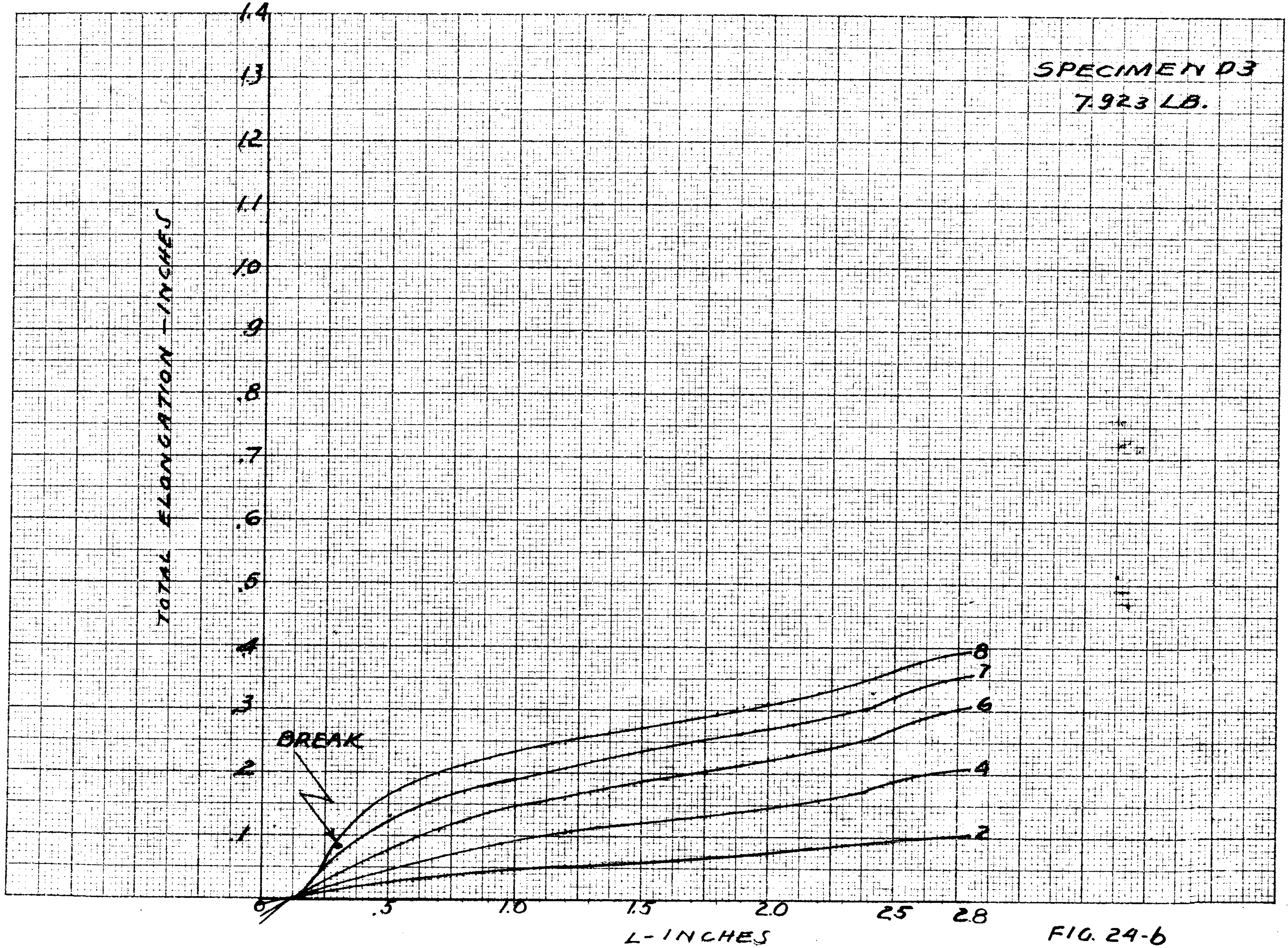

SPECIMEN D3
7.923 LB.
UNIT ELONGATION - INCHES/.01 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
.5
1.0
1.5
2.0
2.5
2.8
L-INCHES
BREAK
8
7
6
5
4
2

FIG. 24-a



SPECIMEN D3
7.923 LB.
TOTAL ELONGATION - INCHES
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
BREAK
8
7
6
4
2
.5
1.0
1.5
2.0
2.5
2.8
L - INCHES

FIG. 24-6

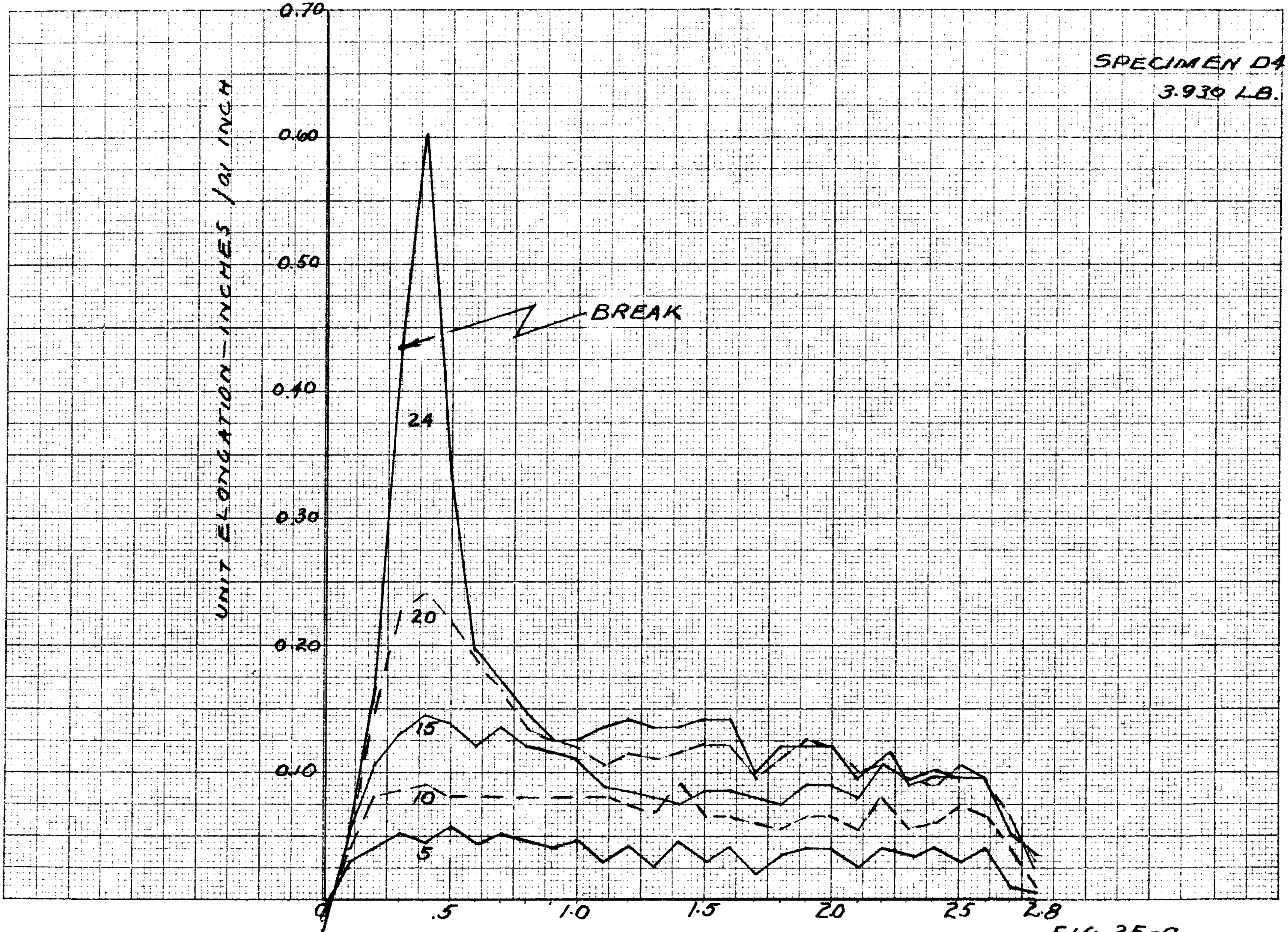

SPECIMEN D4
3.930 LB.
UNIT ELONGATION-INCHES /0.1 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
BREAK
24
20
15
10
5
0
.5
1.0
1.5
2.0
2.5
2.8
L-INCHES

FIG. 25-a

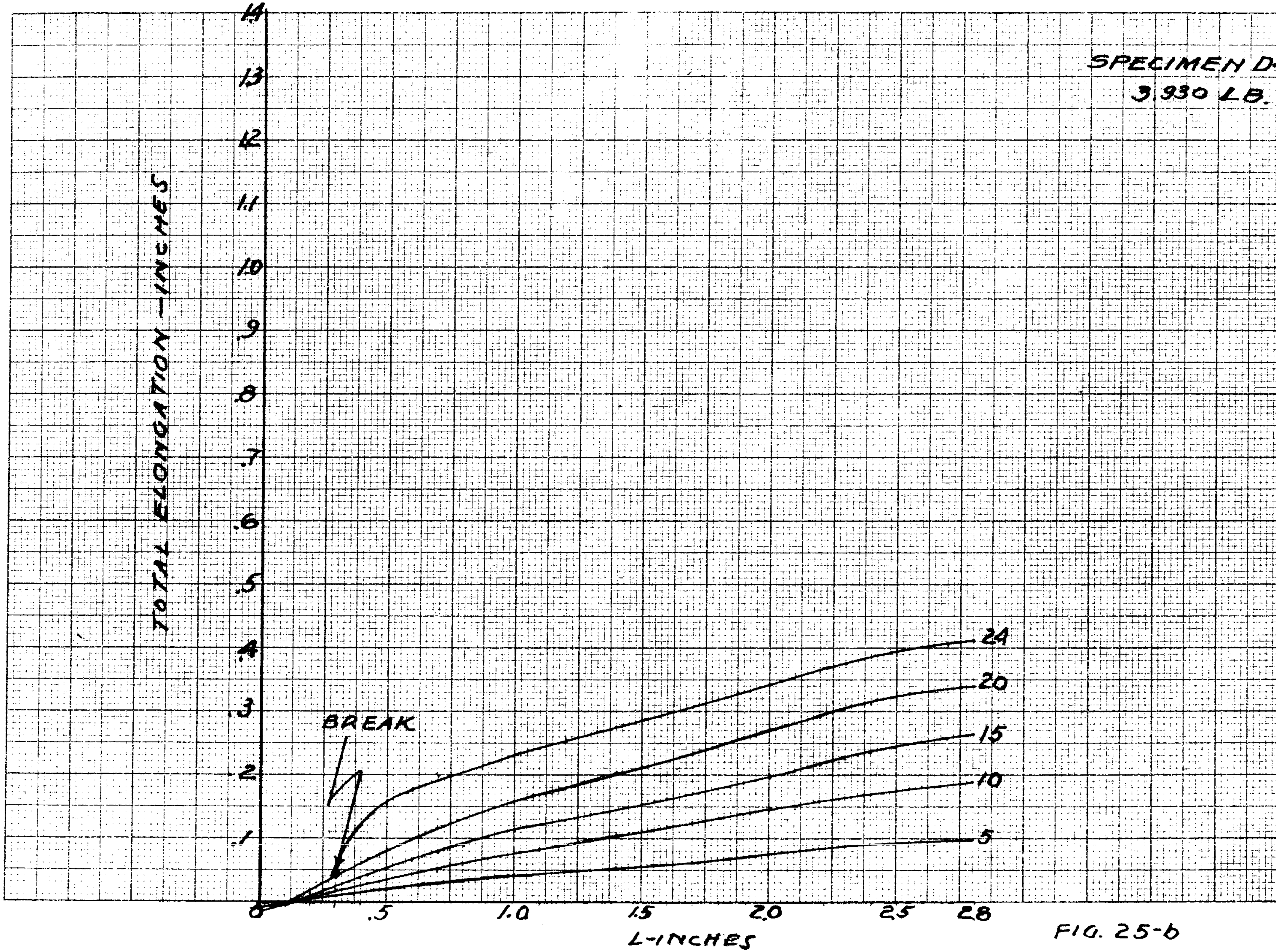

SPECIMEN D4
3.930 LB.
TOTAL ELONGATION - INCHES
L-INCHES
BREAK
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
.5
1.0
1.5
2.0
2.5
2.8
24
20
15
10
5

FIG. 25-b

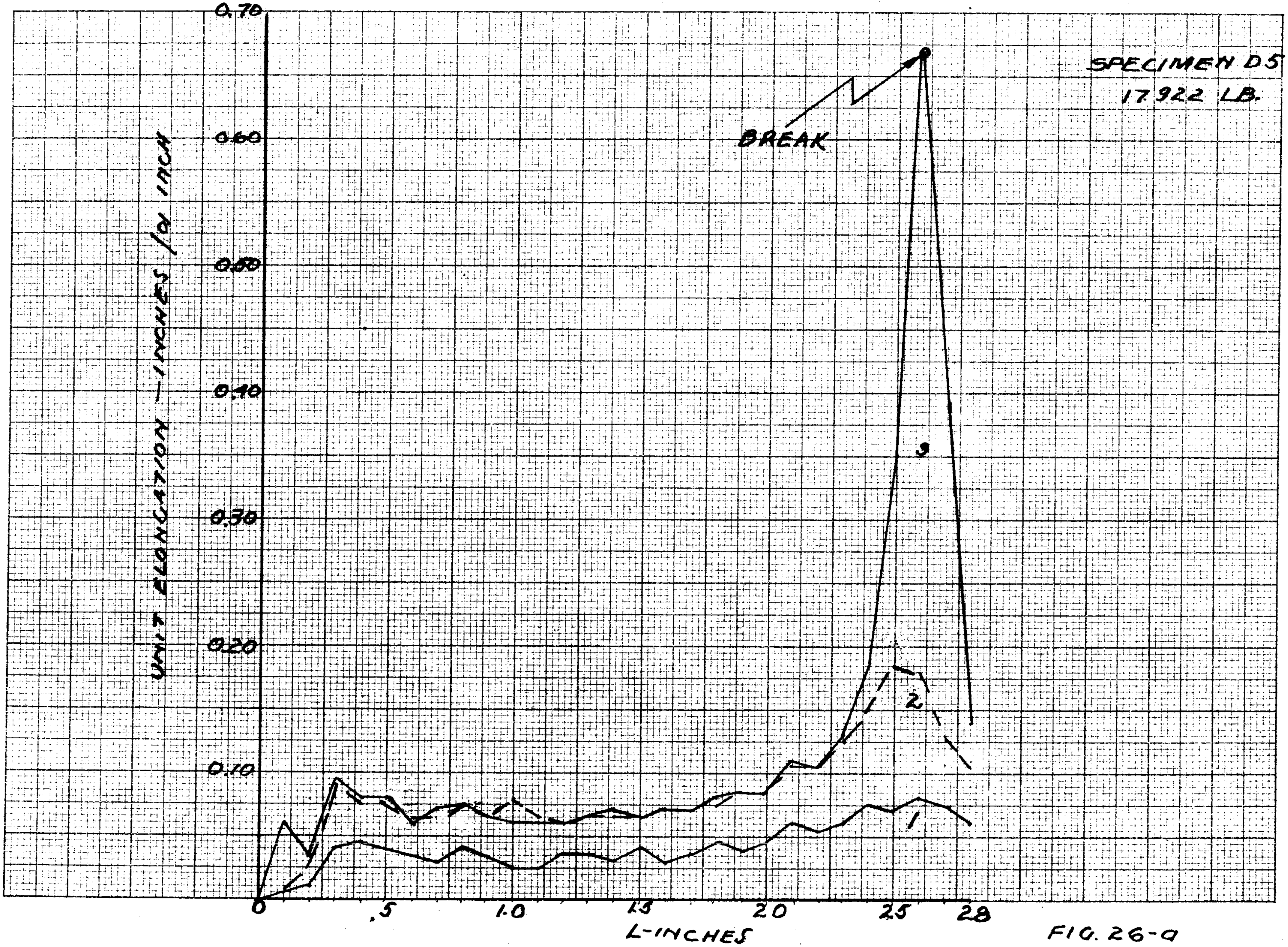
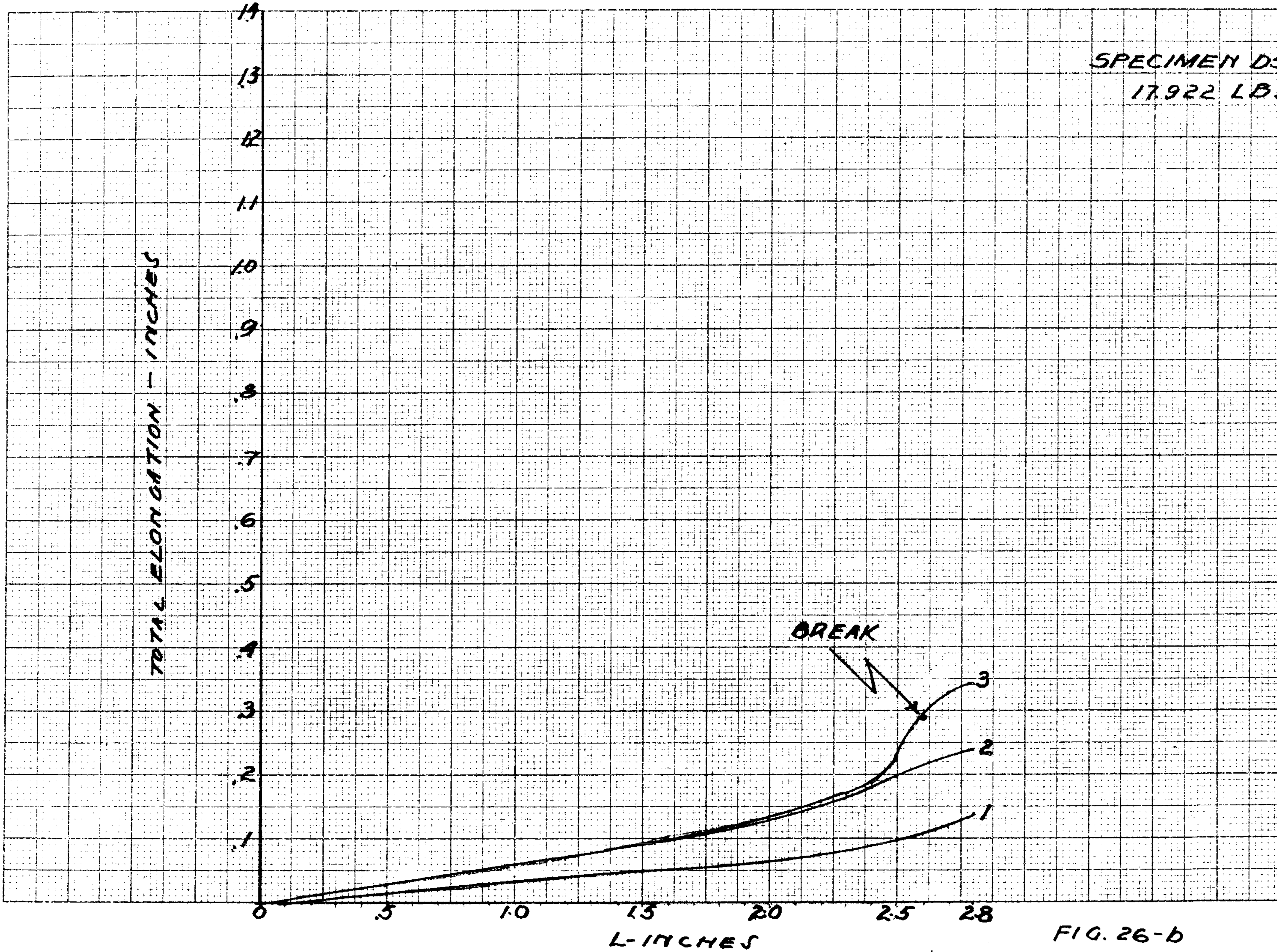
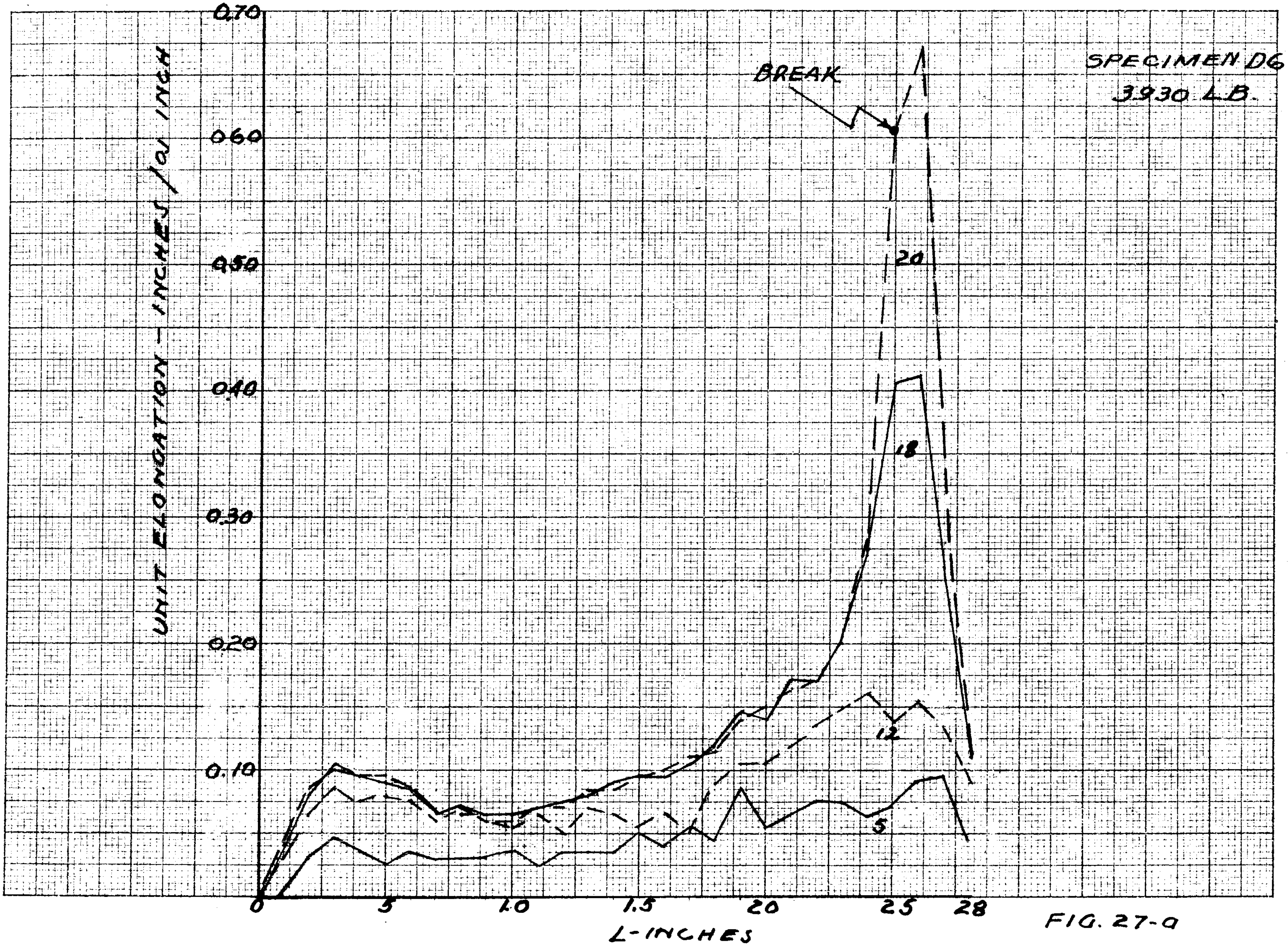

SPECIMEN D5
17.922 LB.
BREAK
UNIT ELONGATION - INCHES / A INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
.5
1.0
1.5
2.0
2.5
2.8
L-INCHES
1
2
3

FIG. 26-a



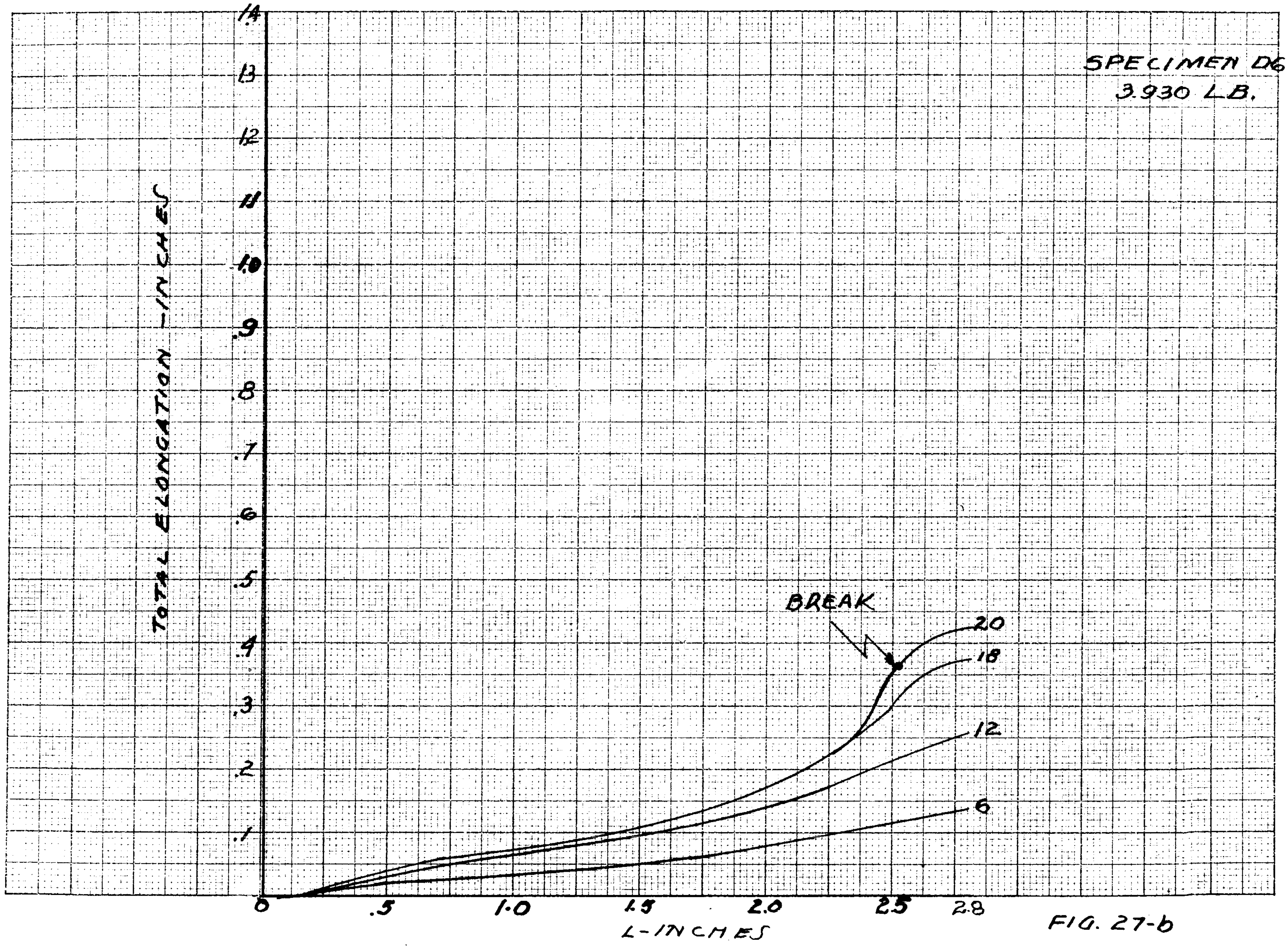
SPECIMEN D5
17.922 LB.
TOTAL ELONGATION - INCHES
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.5
1.0
1.5
2.0
2.5
2.8
L-INCHES
BREAK
1
2
3

FIG. 26-b



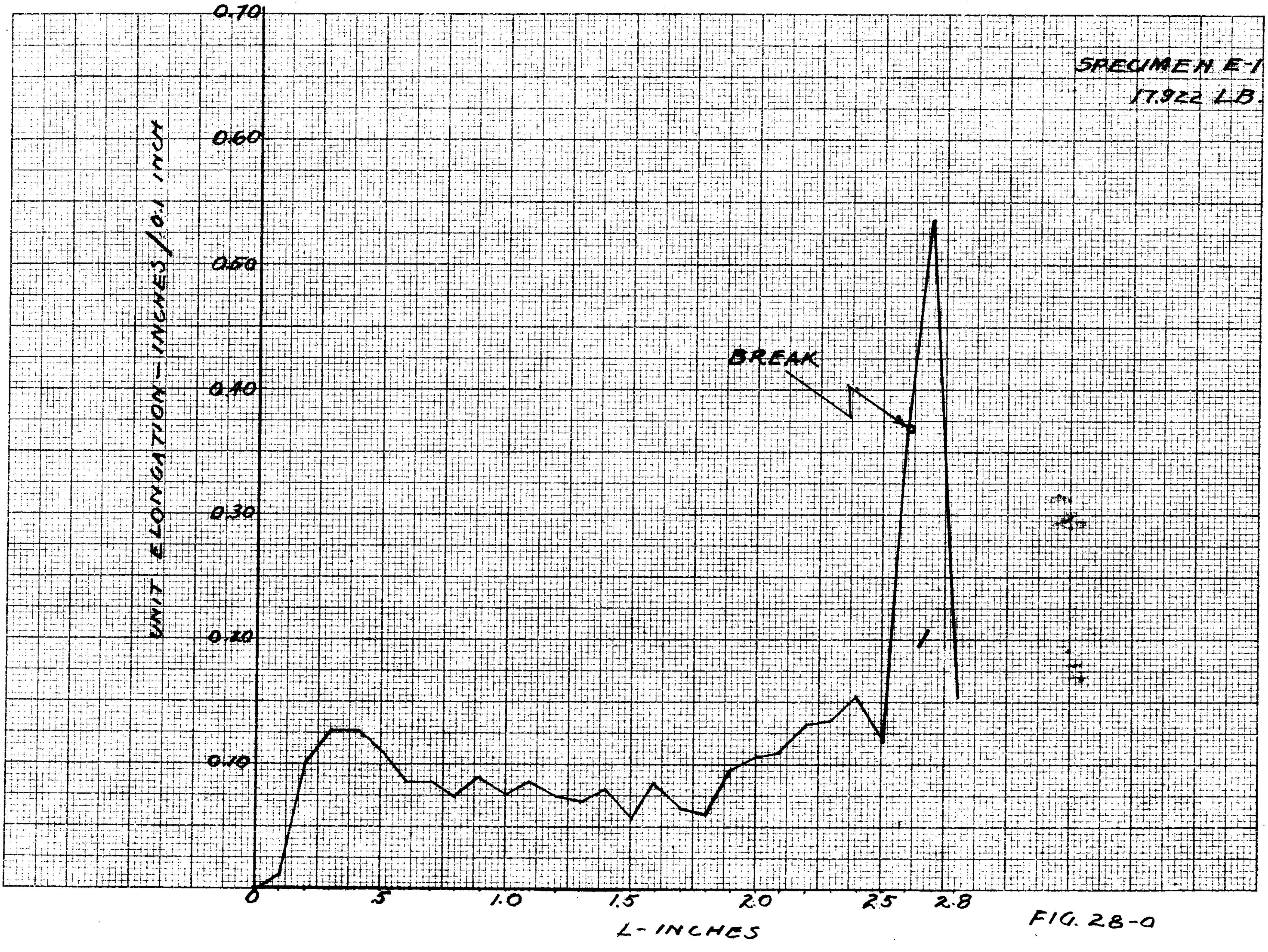
UNIT ELONGATION - INCHES /0.1 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
5
1.0
1.5
20
25
28
L-INCHES
BREAK
20
18
12
5
SPECIMEN D6
3930 LB.

FIG. 27-a



SPECIMEN D6
3.930 LB.
TOTAL ELONGATION - INCHES
L-INCHES
BREAK
20
18
12
6
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
.5
1.0
1.5
2.0
2.5
2.8

FIG. 27-b



SPECIMEN E-1
17.922 LB.
UNIT ELONGATION - INCHES/0.1 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
.5
1.0
1.5
2.0
2.5
2.8
BREAK
L-INCHES

FIG. 28-0

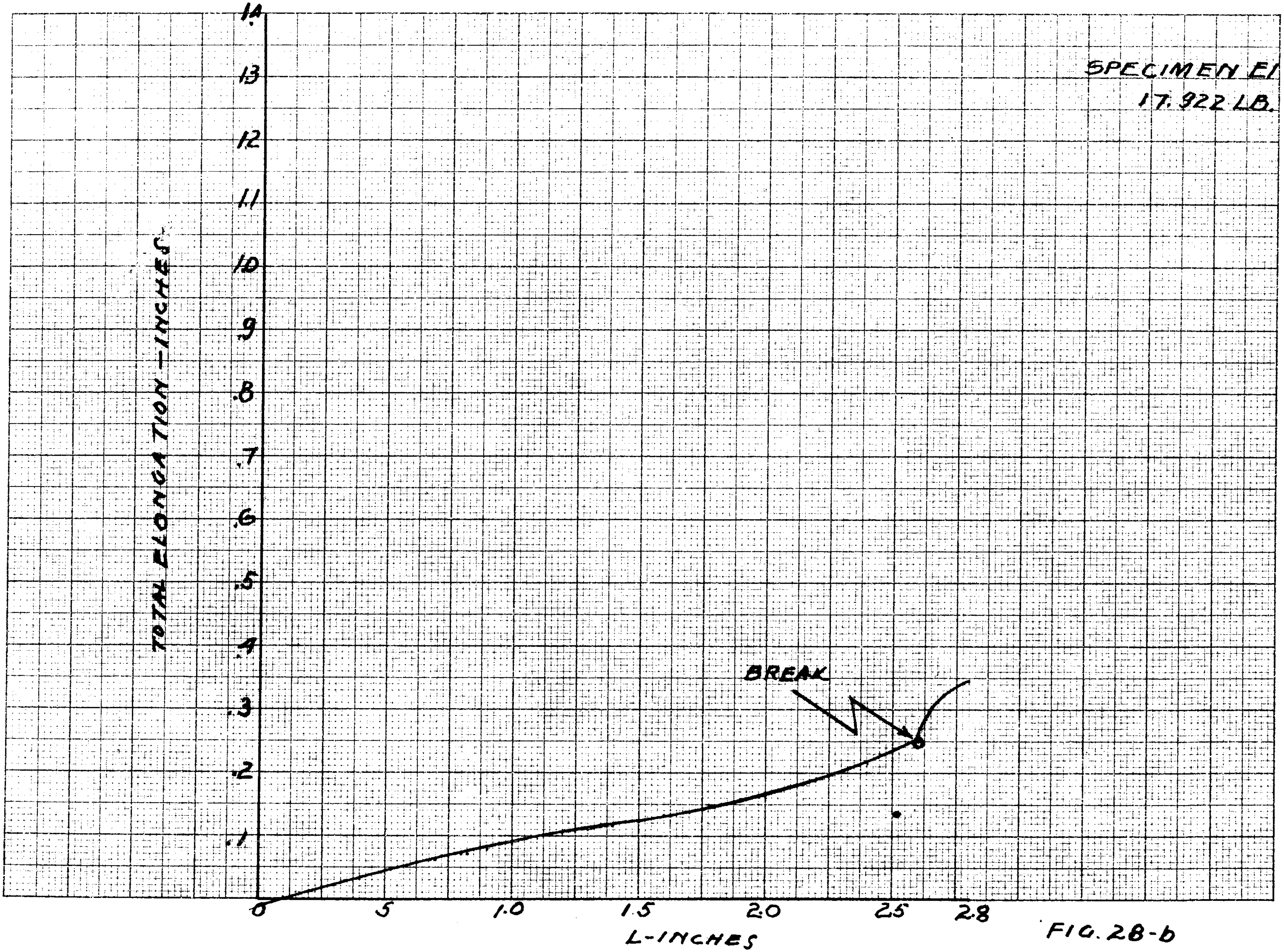

SPECIMEN E1
17.922 LB.
TOTAL ELONGATION - INCHES
.1
.2
.3
.4
.5
.6
.7
.8
.9
.10
.11
.12
.13
.14
0
5
1.0
1.5
2.0
2.5
2.8
L-INCHES
BREAK

FIG. 28-b

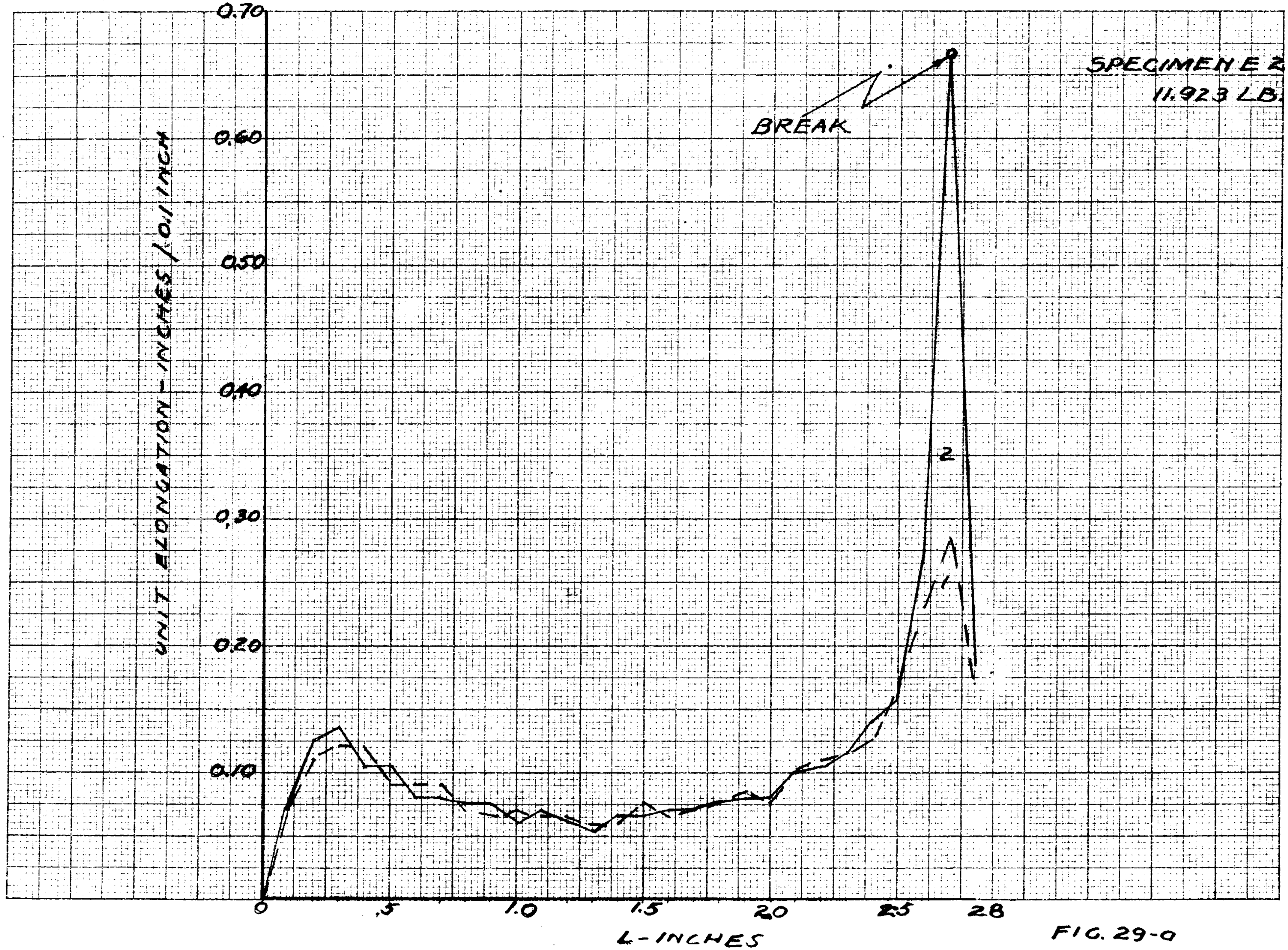

UNIT ELONGATION - INCHES / 0.1 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
.5
1.0
1.5
2.0
2.5
2.8
L - INCHES
SPECIMEN E 2
11.923 LB.
BREAK
2

FIG. 29-0

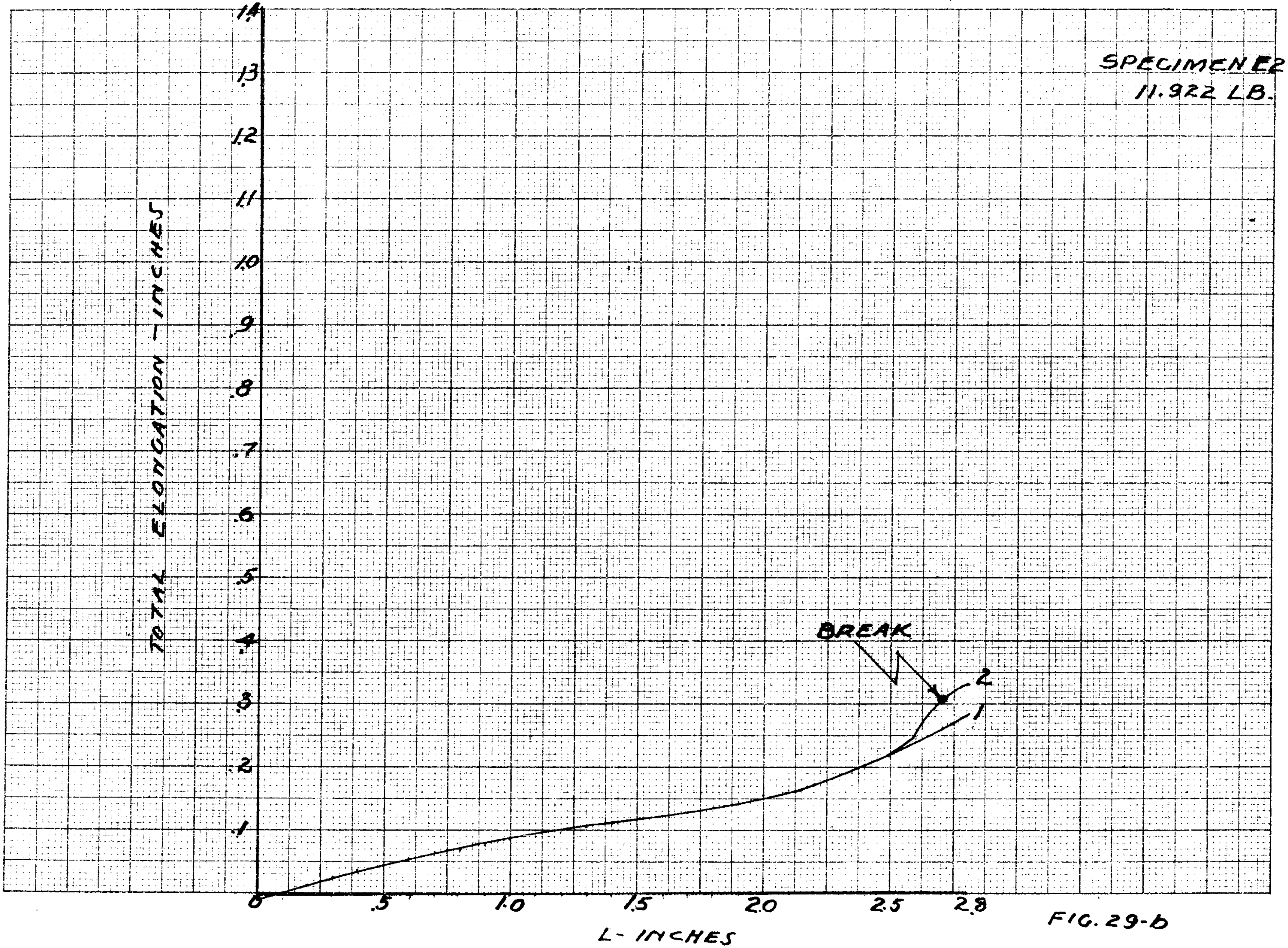

SPECIMEN E2
11.922 LB.
TOTAL ELONGATION - INCHES
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
.5
1.0
1.5
2.0
2.5
2.8
L - INCHES
BREAK
1
2

FIG. 29-b

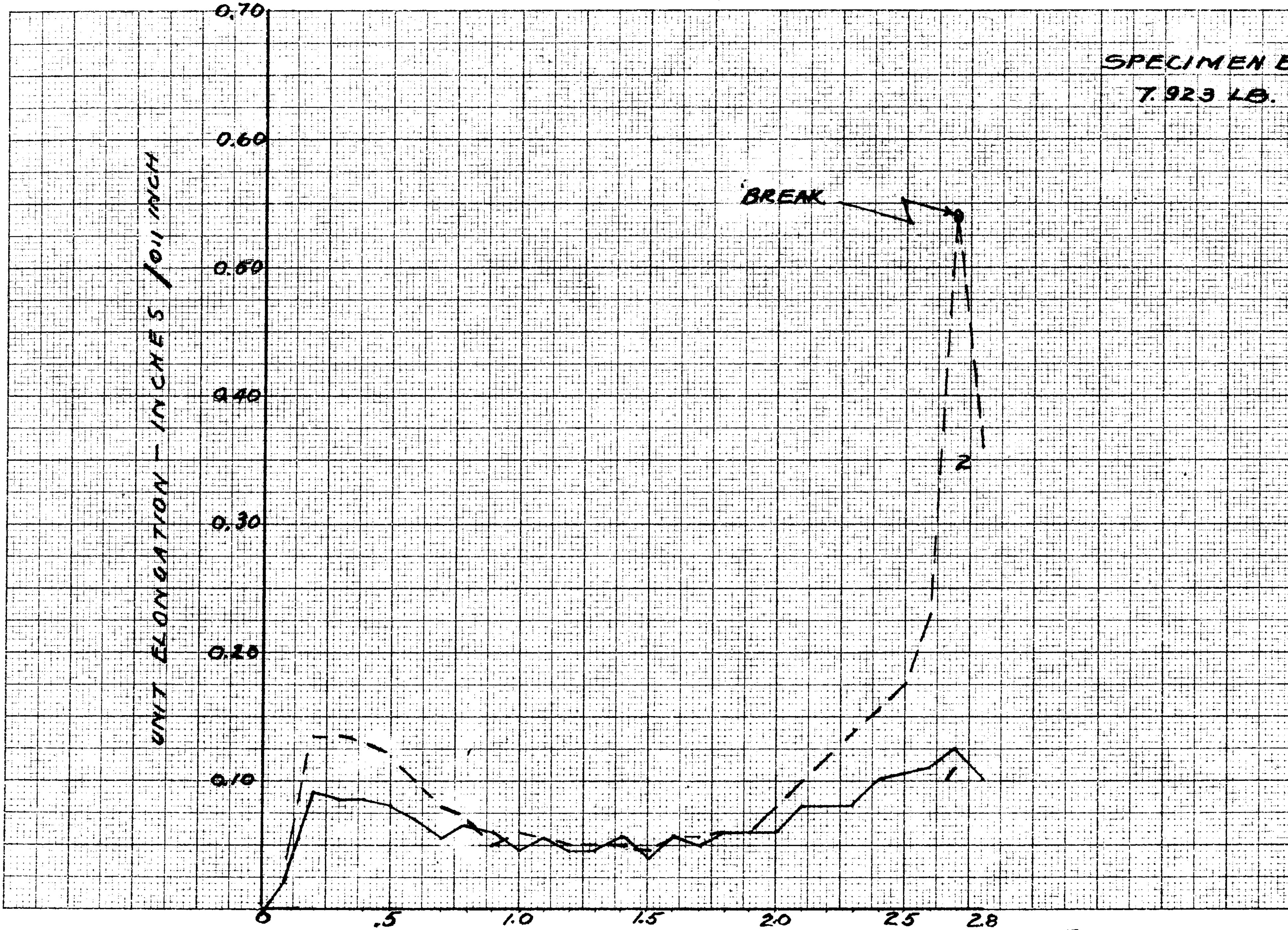

SPECIMEN E3
7.923 LB.
UNIT ELONGATION - INCHES / 011 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
BREAK
2
1
0
.5
1.0
1.5
2.0
2.5
2.8
L - INCHES

FIG. 30-a

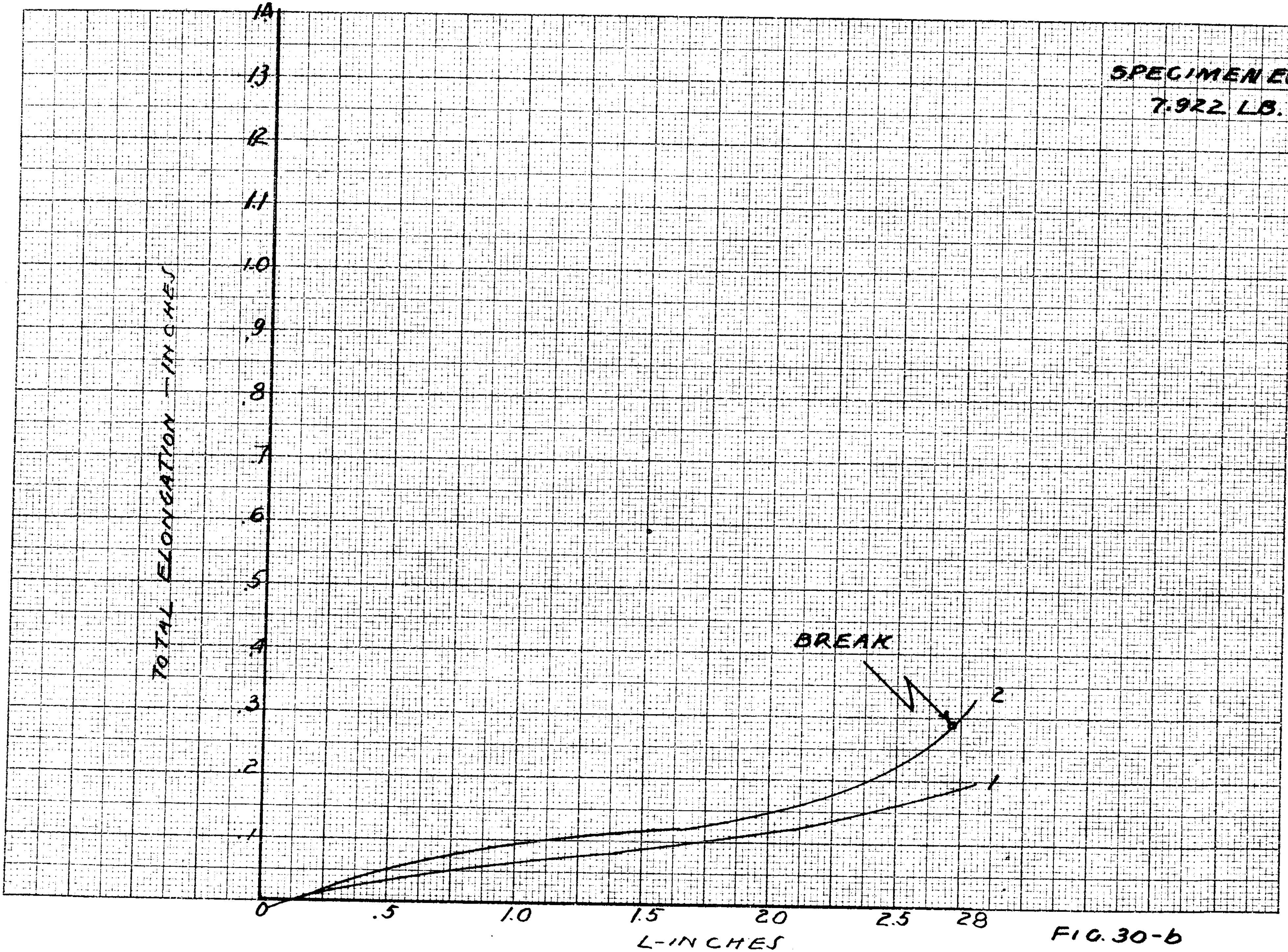

SPECIMEN E3
7.922 LB.
TOTAL ELONGATION — INCHES
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.5
1.0
1.5
2.0
2.5
2.8
L-INCHES
BREAK
1
2

FIG. 30-b

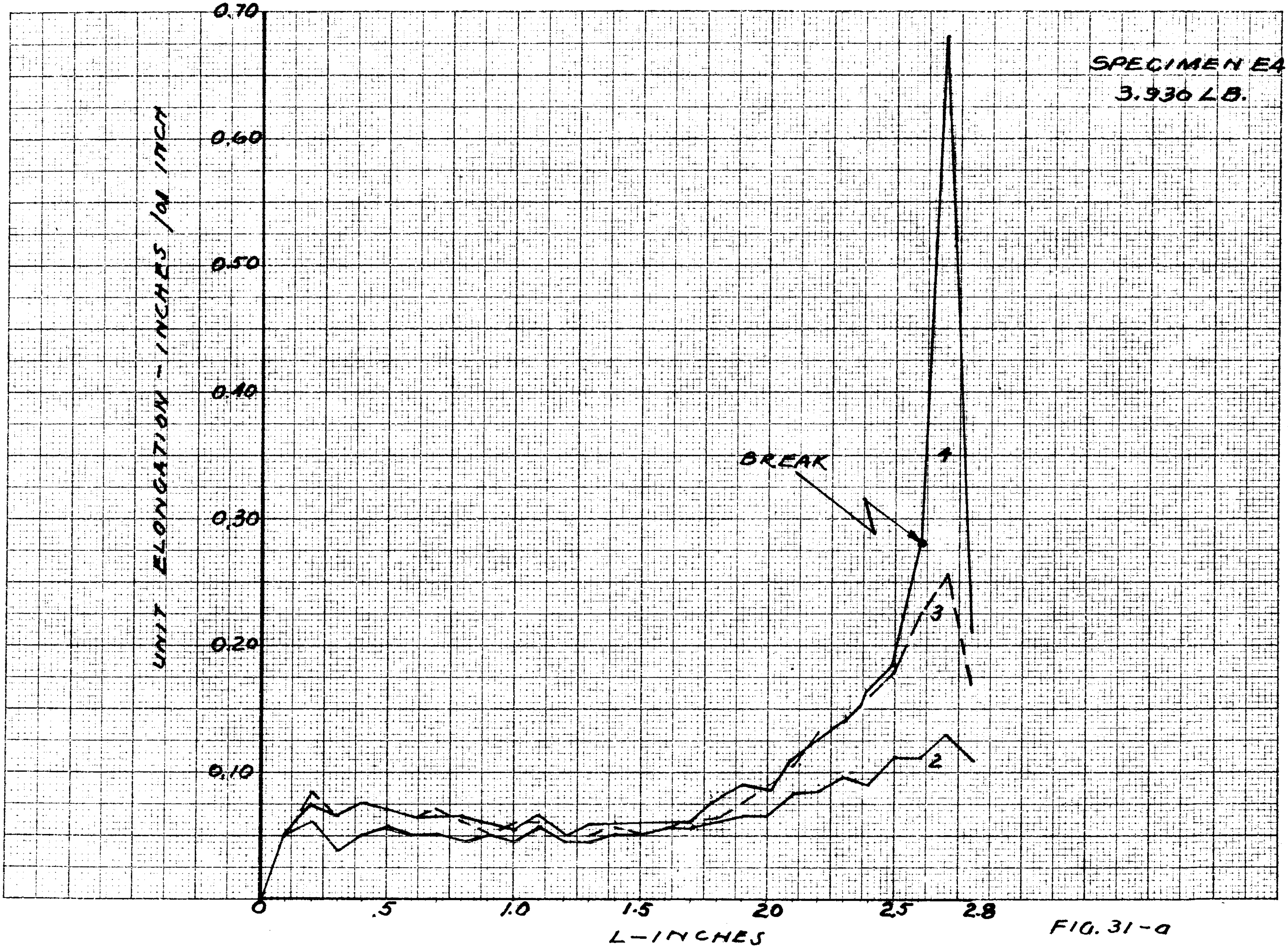

SPECIMEN E4
3.930 LB.
UNIT ELONGATION - INCHES /01 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
.5
1.0
1.5
20
2.5
2.8
L-INCHES
BREAK
1
2
3

FIG. 31-a

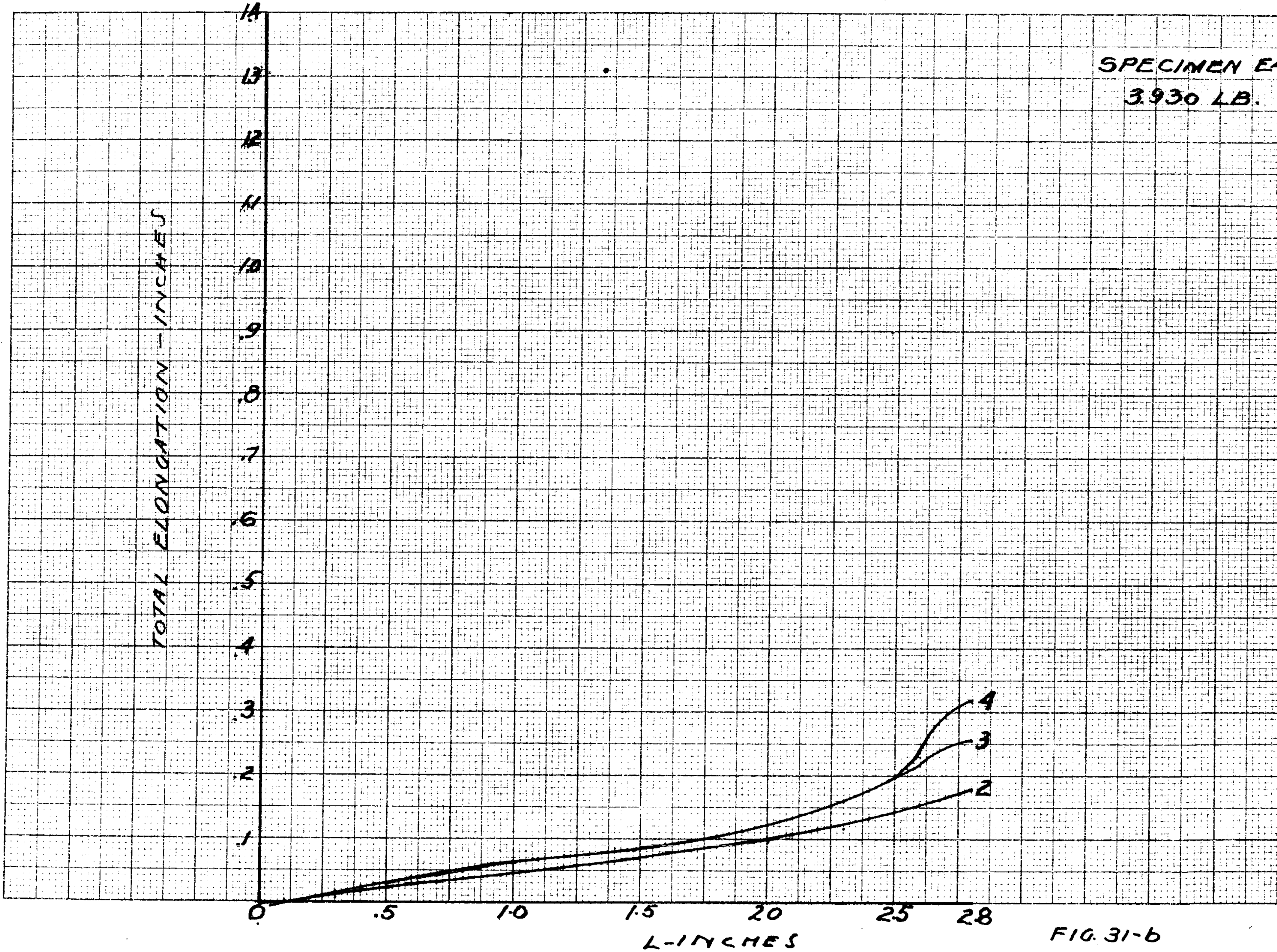

SPECIMEN E4
3930 LB.
TOTAL ELONGATION - INCHES
L-INCHES
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
.5
1.0
1.5
2.0
2.5
2.8
2
3
4

FIG. 31-b

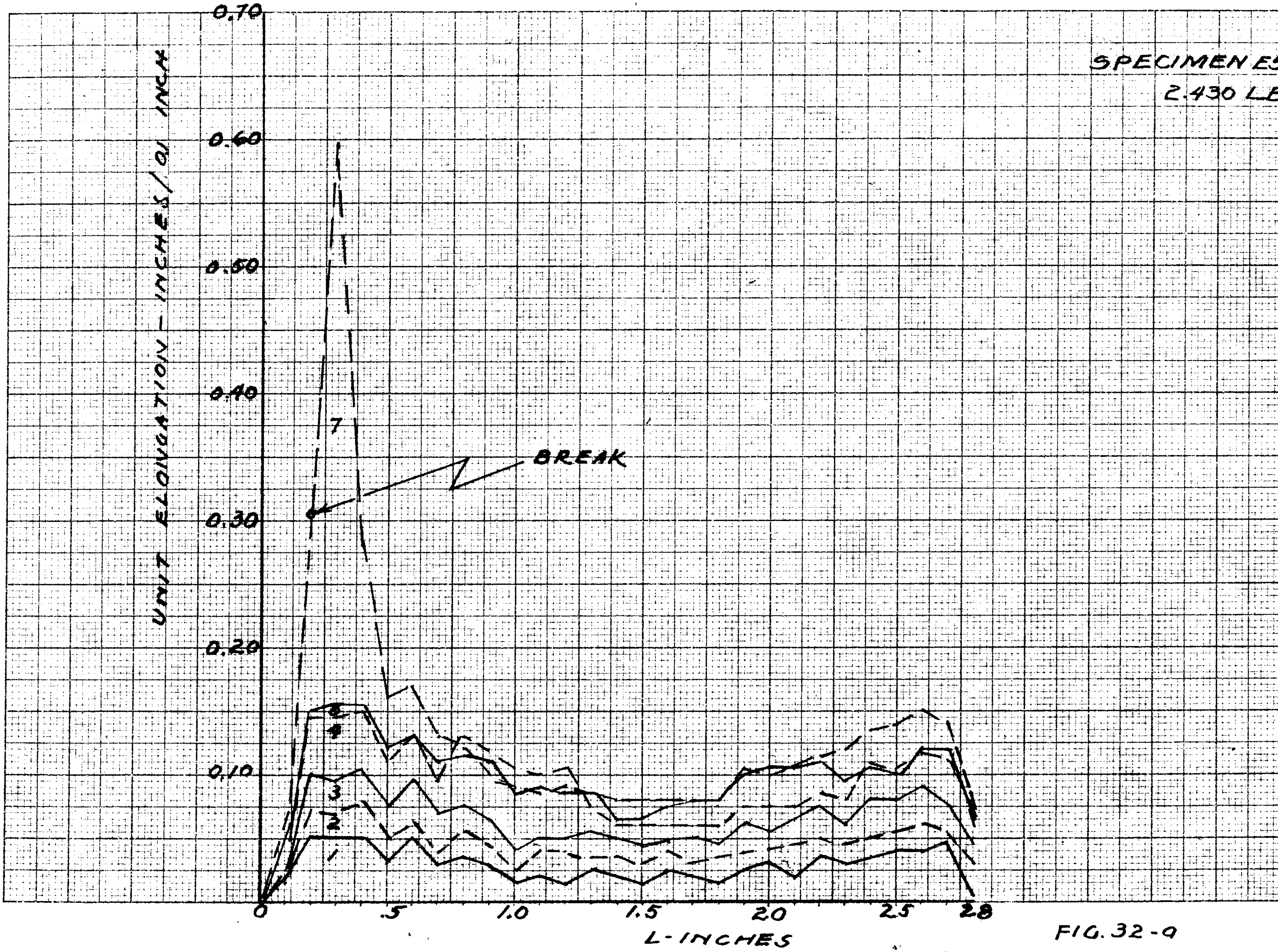

SPECIMEN E5
2.430 LB.
UNIT ELONGATION - INCHES/.01 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
7
BREAK
8
4
3
2
0
.5
1.0
1.5
2.0
2.5
2.8
L-INCHES

FIG. 32-a

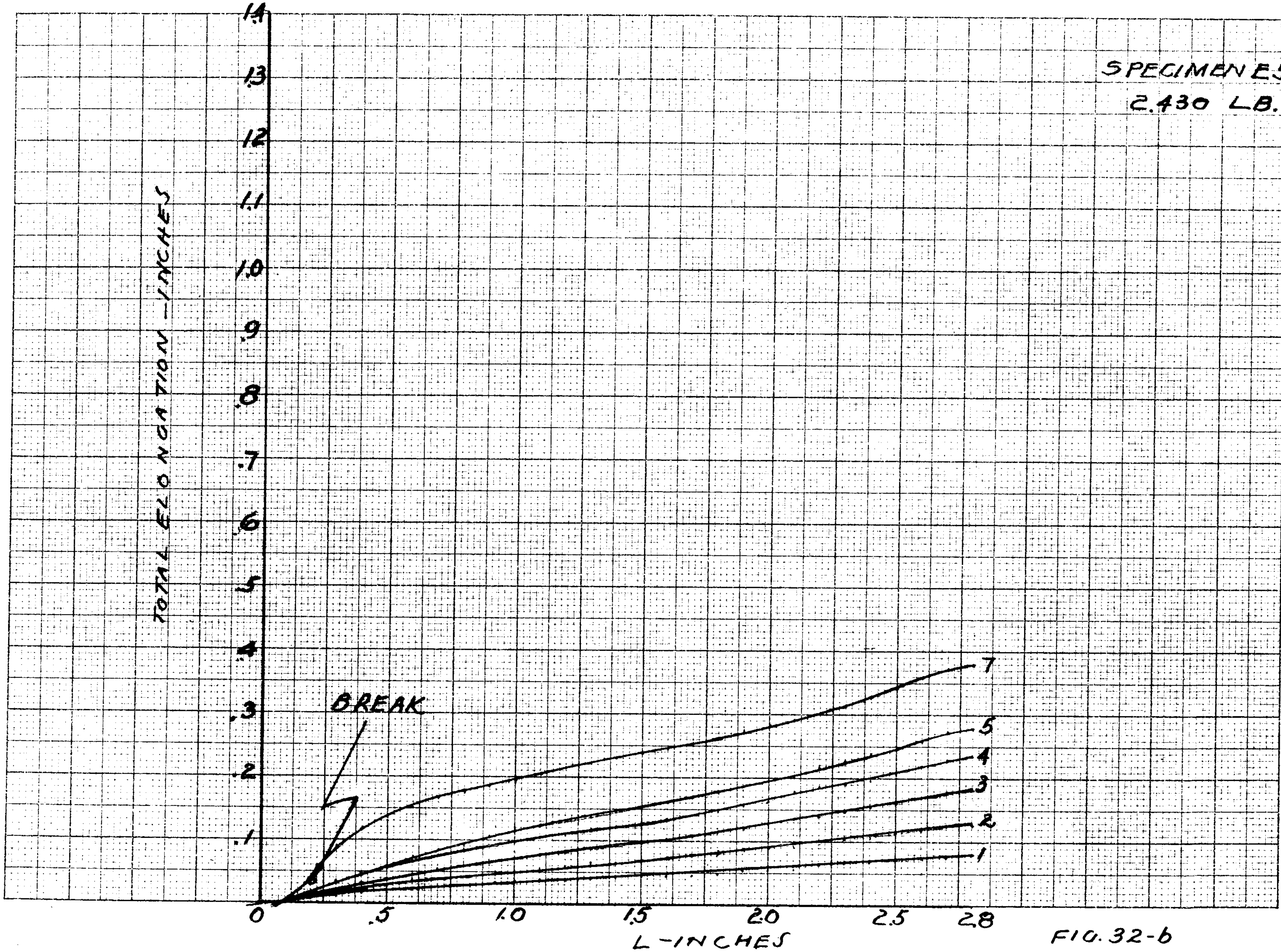

SPECIMEN E5
2.430 LB.
TOTAL ELONGATION - INCHES
L - INCHES
BREAK
0
.5
1.0
1.5
2.0
2.5
2.8
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1
2
3
4
5
7

FIG. 32-b

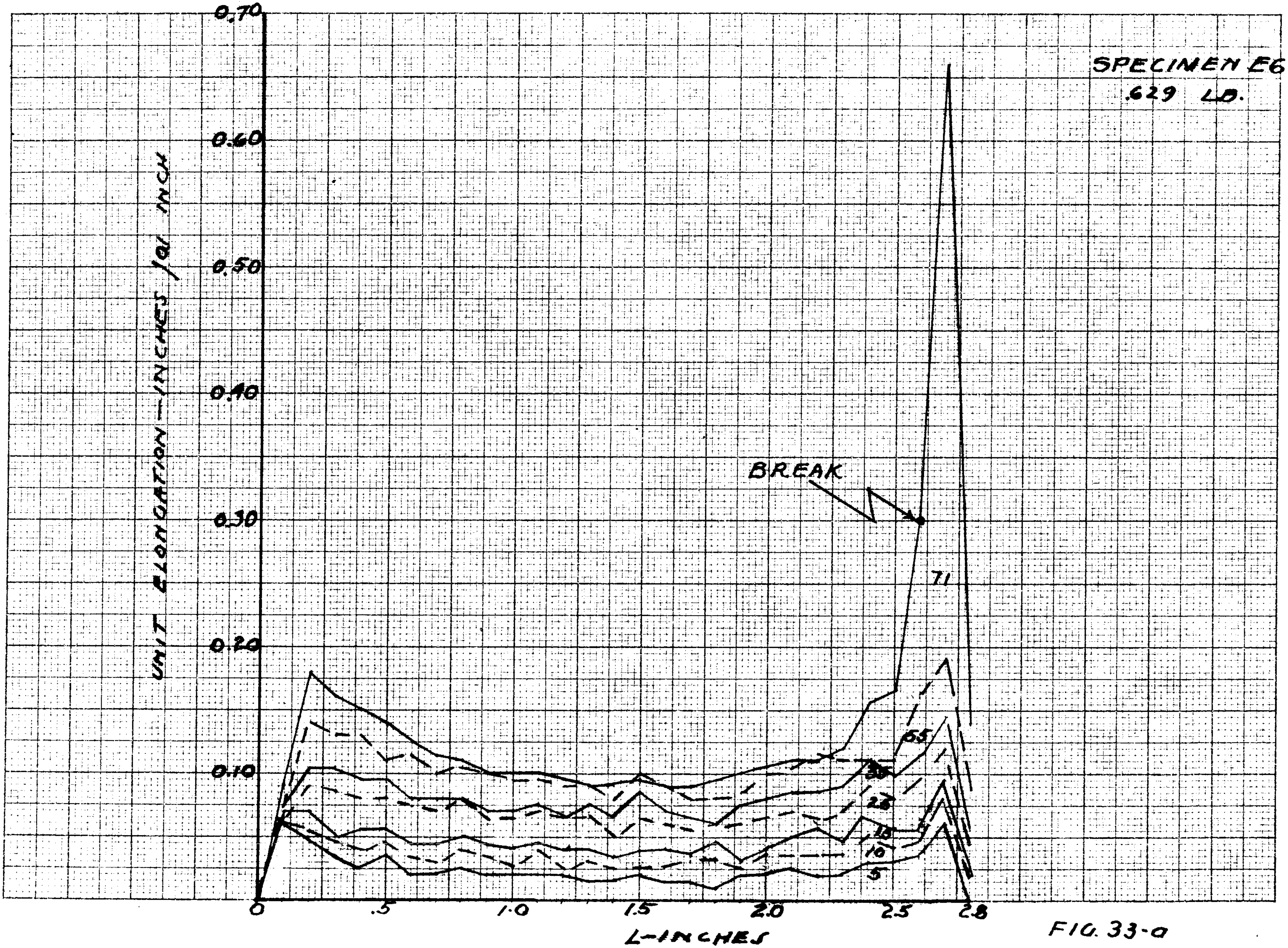

SPECIMEN E6
.629 LB.
UNIT ELONGATION—INCHES /01 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
.5
1.0
1.5
2.0
2.5
2.8
L—INCHES
BREAK
71
65
30
25
15
10
5

FIG. 33-a

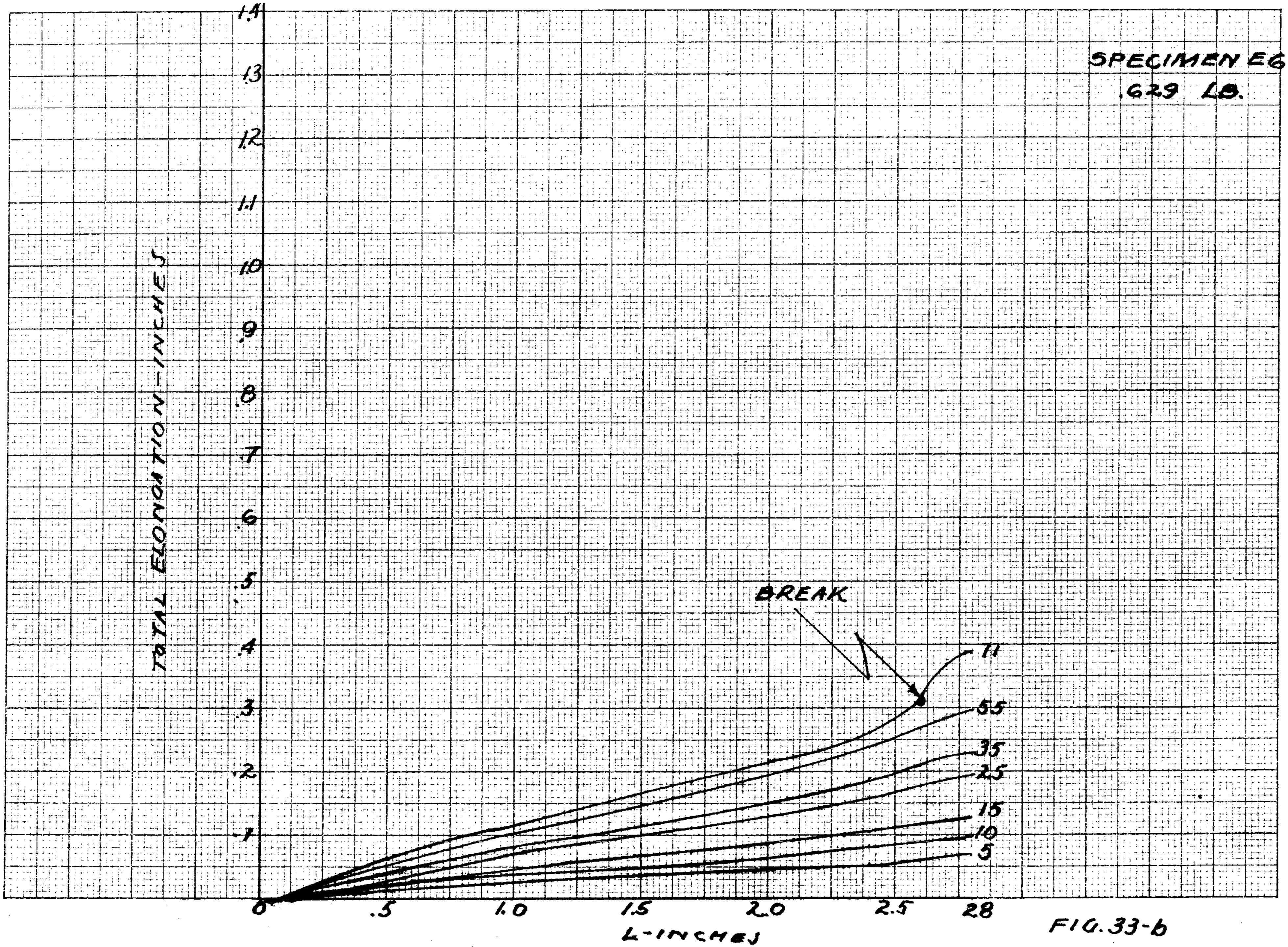

SPECIMEN E6
.629 LB.
TOTAL ELONGATION-INCHES
L-INCHES
BREAK
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
.5
1.0
1.5
2.0
2.5
28
71
55
35
25
15
10
5

FIG.33-b

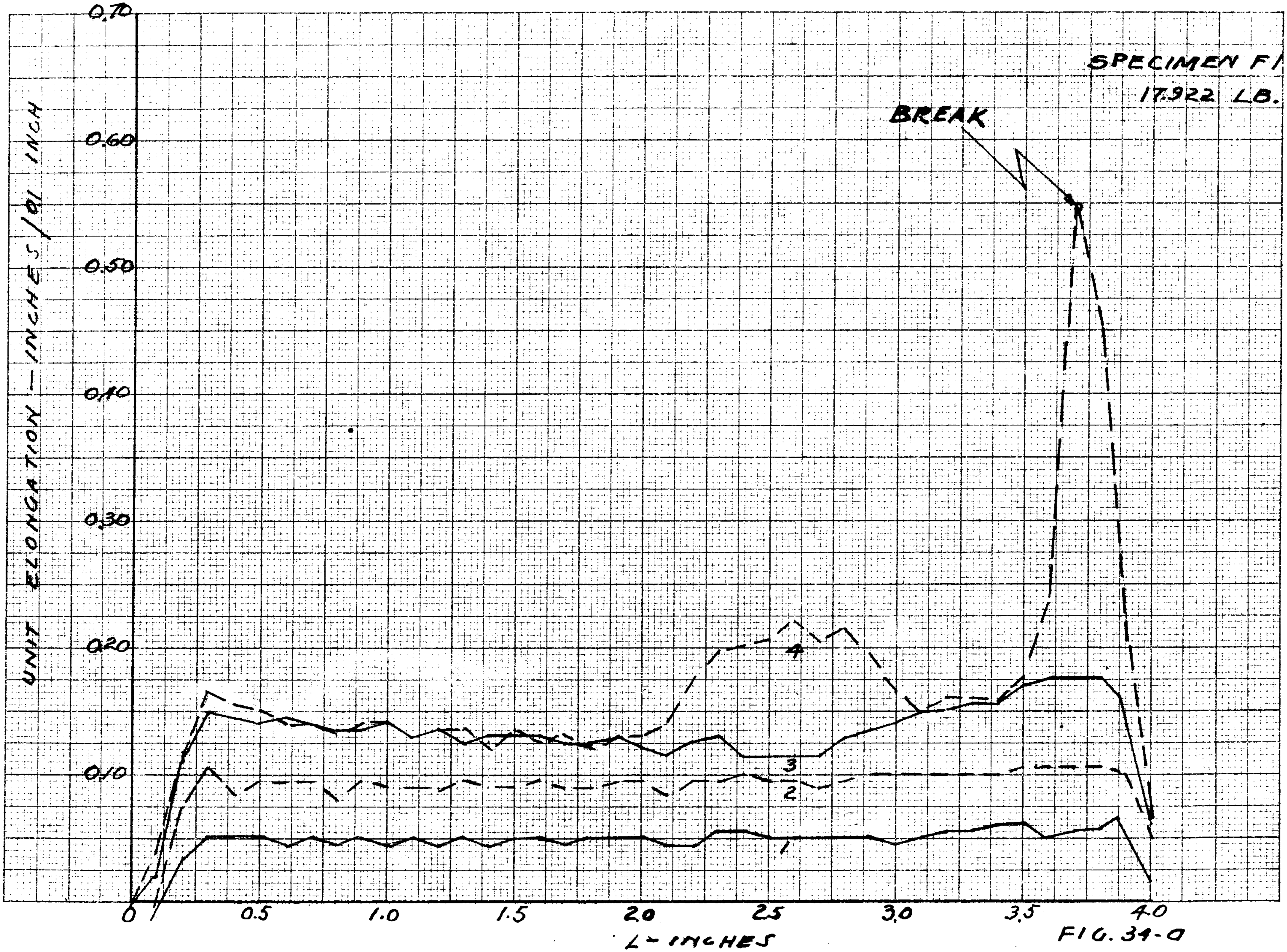
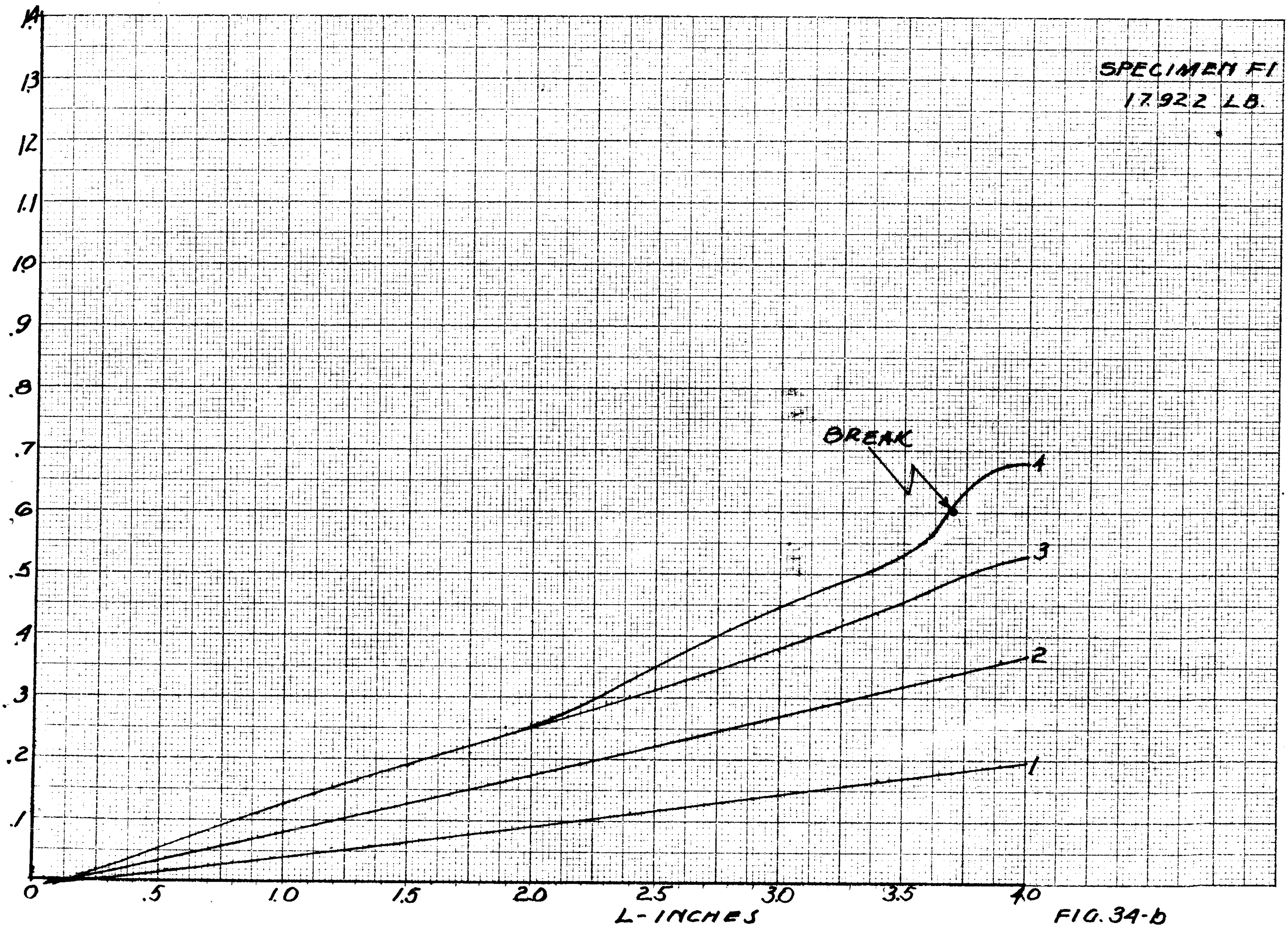

UNIT ELONGATION — INCHES/.01 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L - INCHES
SPECIMEN F1
17.922 LB.
BREAK
1
2
3
4

FIG. 34-D



SPECIMEN F1
17.922 LB.
BREAK
1
2
3
4
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L-INCHES

FIG. 34-b

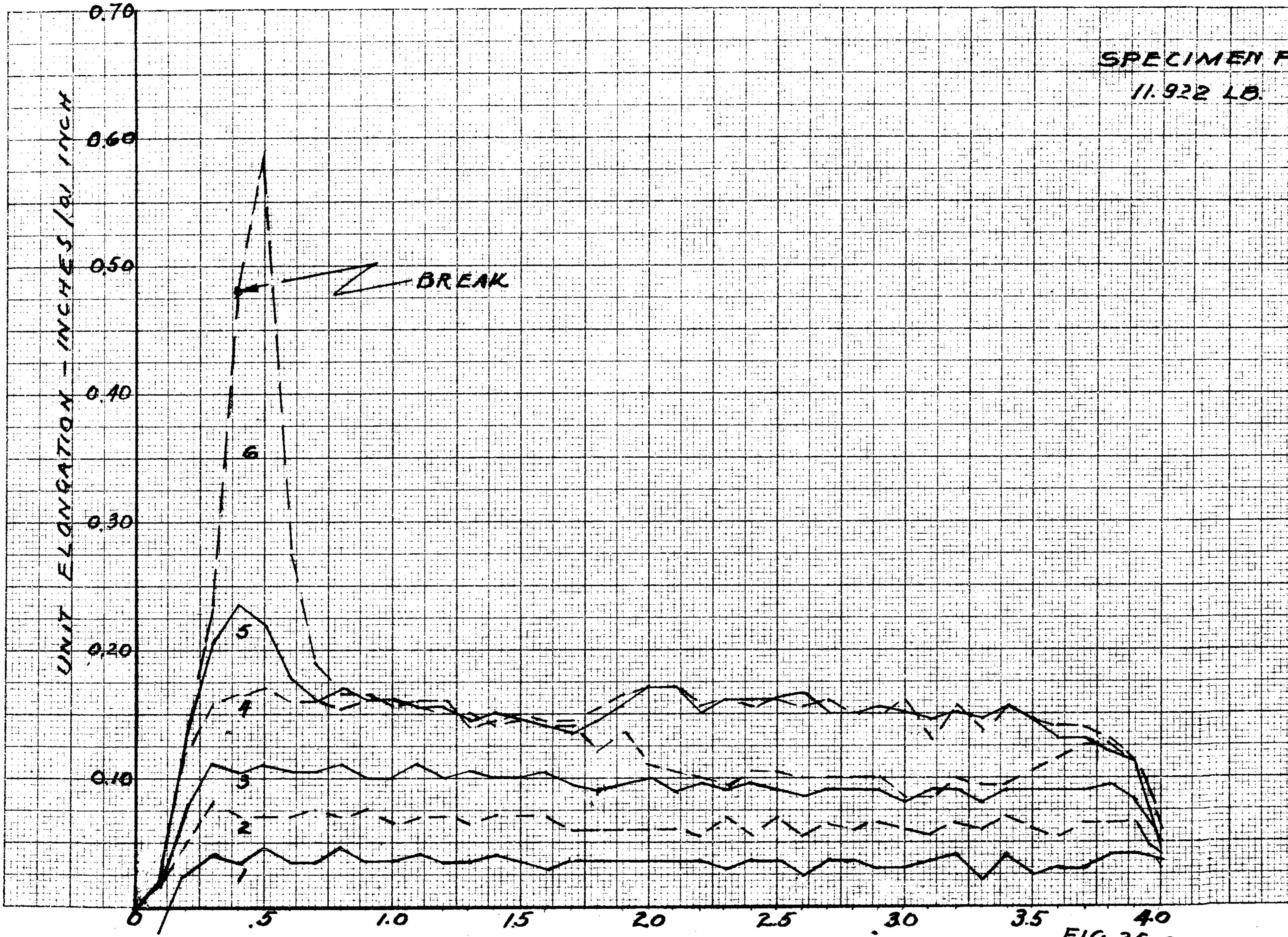

SPECIMEN F2
11.922 LB.
UNIT ELONGATION - INCHES/.01 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
BREAK
6
5
4
3
2
1
0
.5
1.0
1.5
2.0
2.5
.30
3.5
4.0
L-INCHES

FIG. 35-a

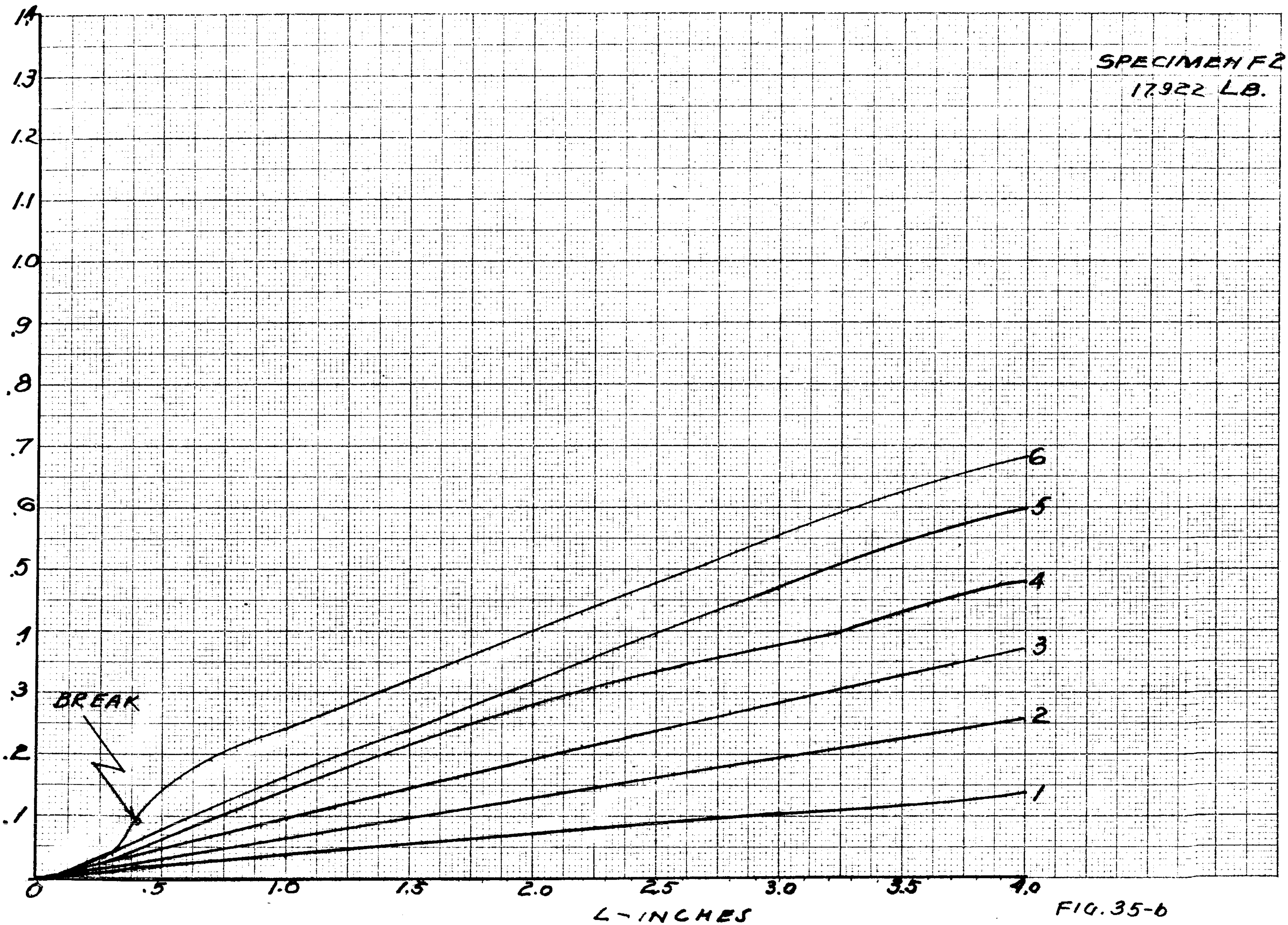
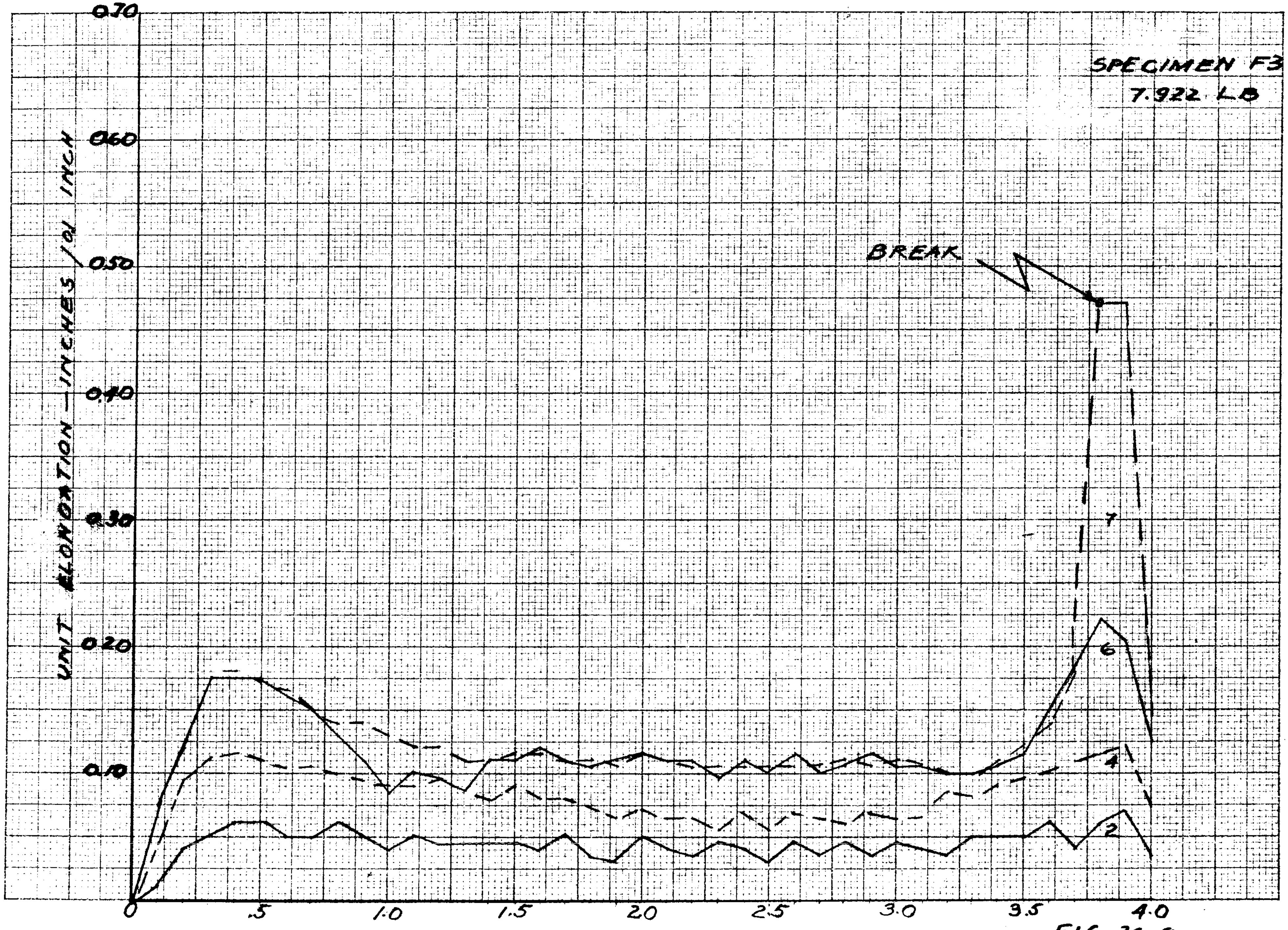
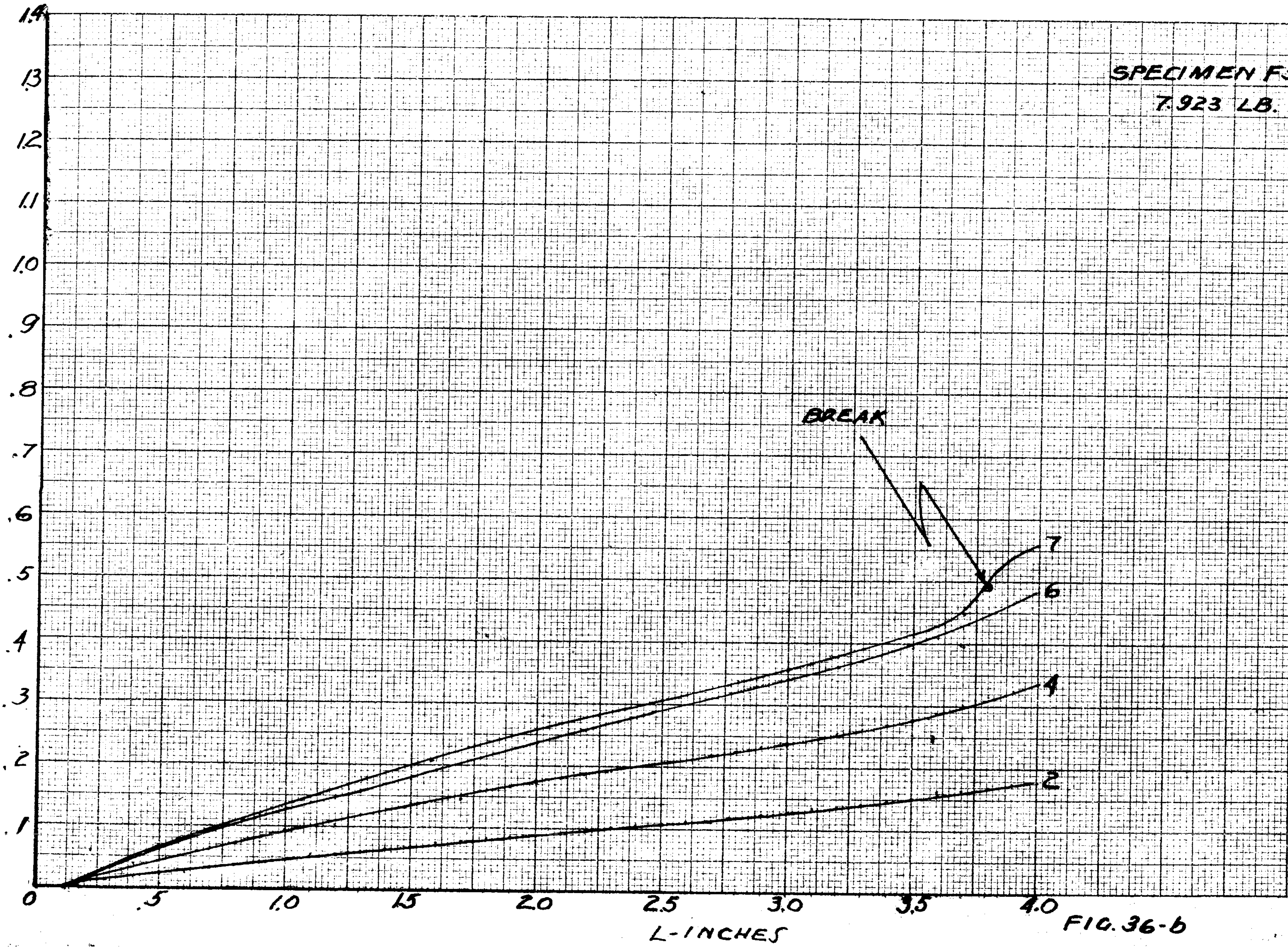

SPECIMEN F2
17922 LB.
BREAK
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
1
2
3
4
5
6
L - INCHES

FIG. 35-6



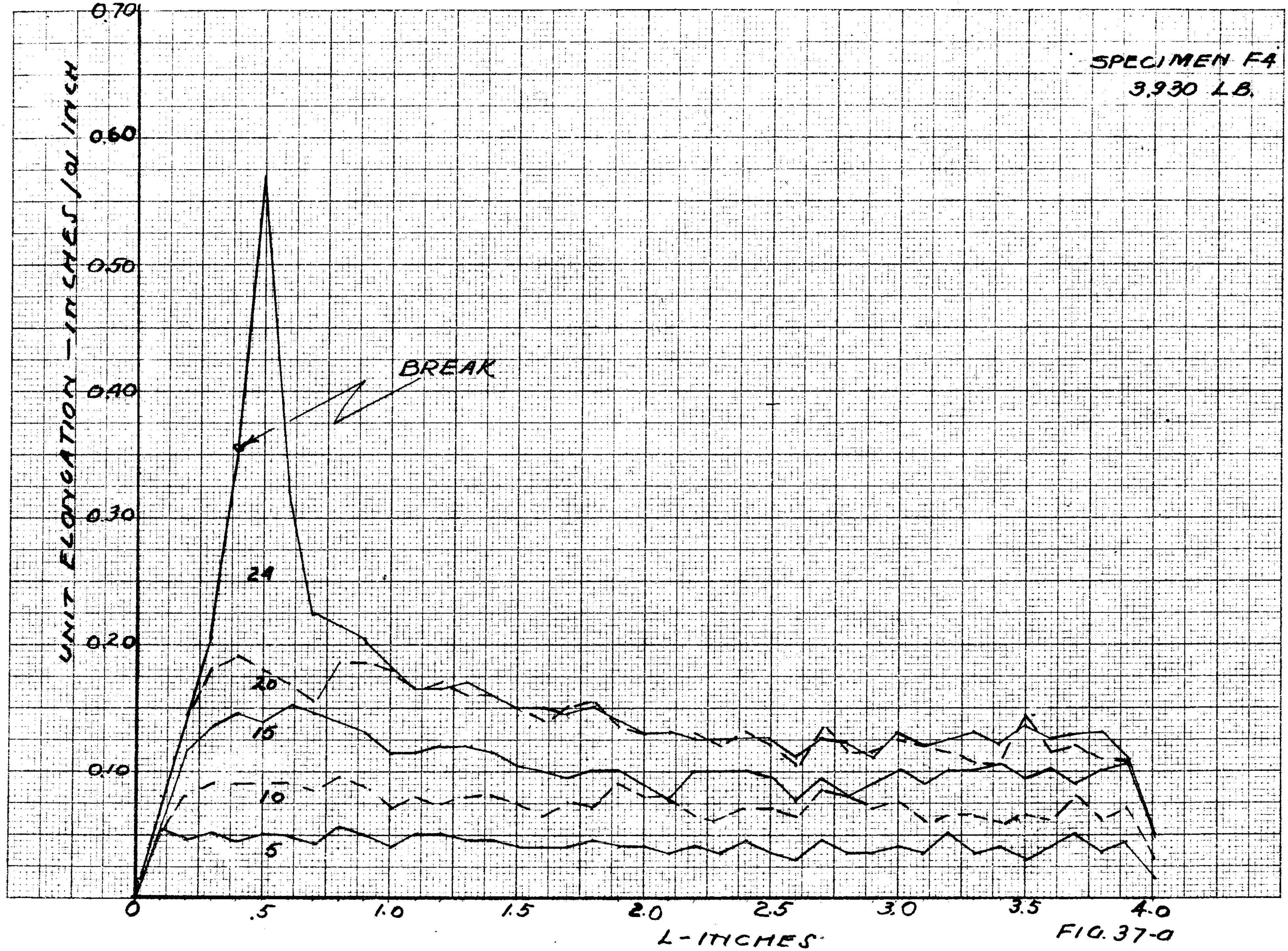
SPECIMEN F3
7.922 LB
BREAK
UNIT ELONGATION — INCHES /01 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L-INCHES
2
4
6
7

FIG. 36-4



SPECIMEN F3
7.923 LB.
BREAK
7
6
4
2
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L-INCHES

FIG. 36-b



SPECIMEN F4
3,930 LB.
BREAK
UNIT ELONGATION — INCHES/.01 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
24
20
15
10
5
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L-INCHES

FIG. 37-a

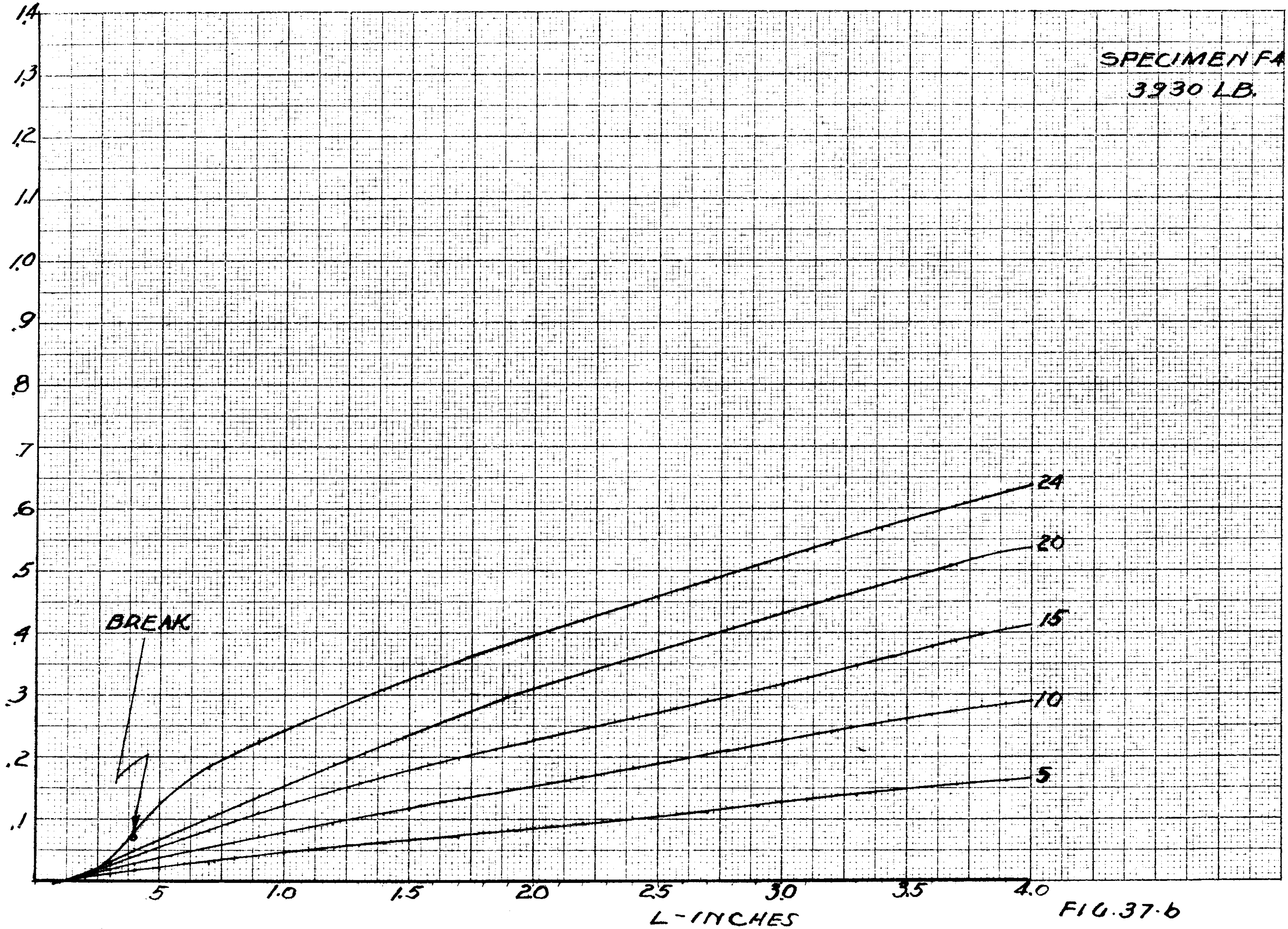
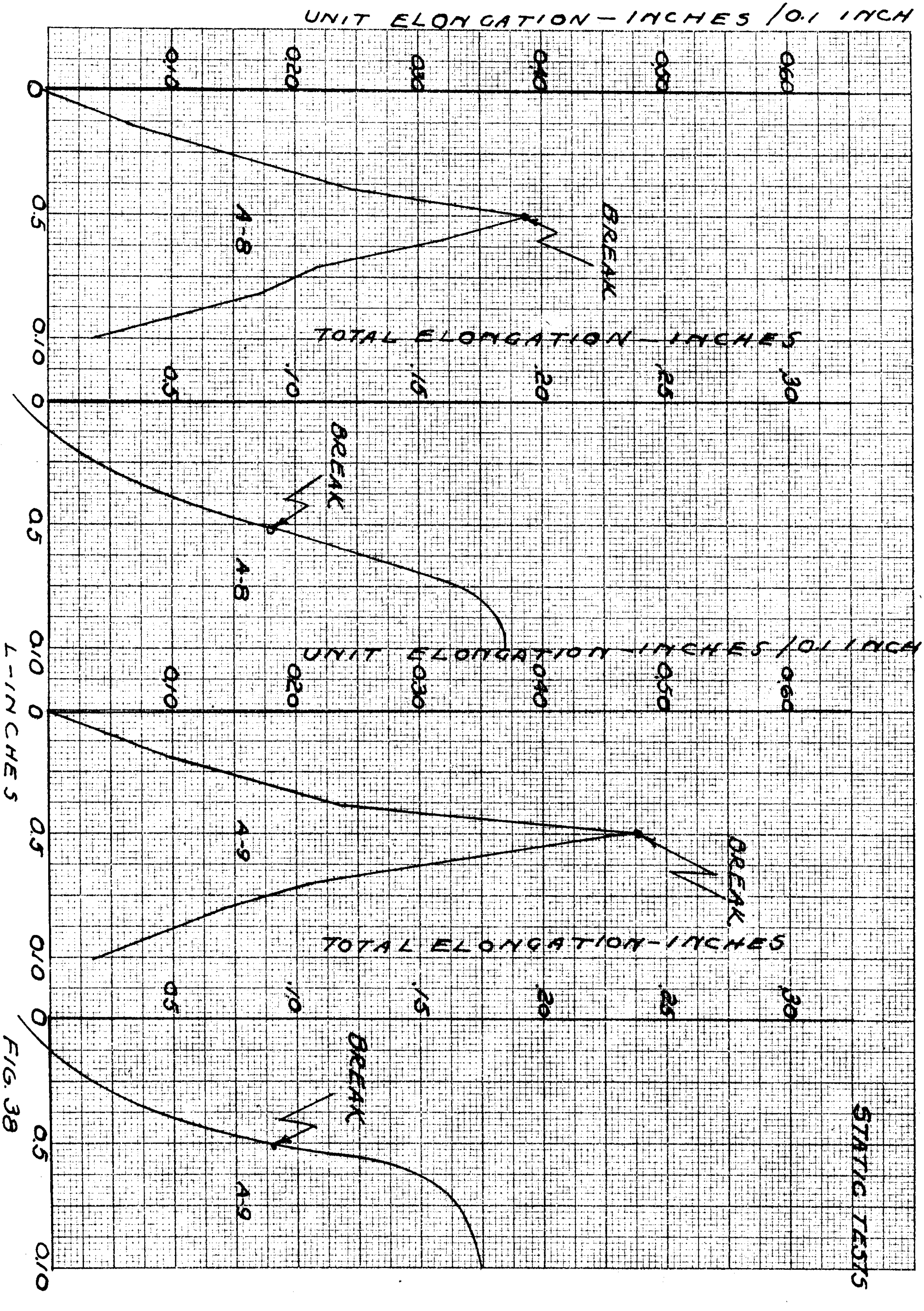

SPECIMEN F4
3930 LB.
BREAK
24
20
15
10
5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L-INCHES

FIG. 37-b



UNIT ELONGATION - INCHES /0.1 INCH
TOTAL ELONGATION - INCHES
UNIT ELONGATION - INCHES /0.1 INCH
TOTAL ELONGATION - INCHES
BREAK
A-8
A-9
L - INCHES
STATIC TESTS

FIG. 38

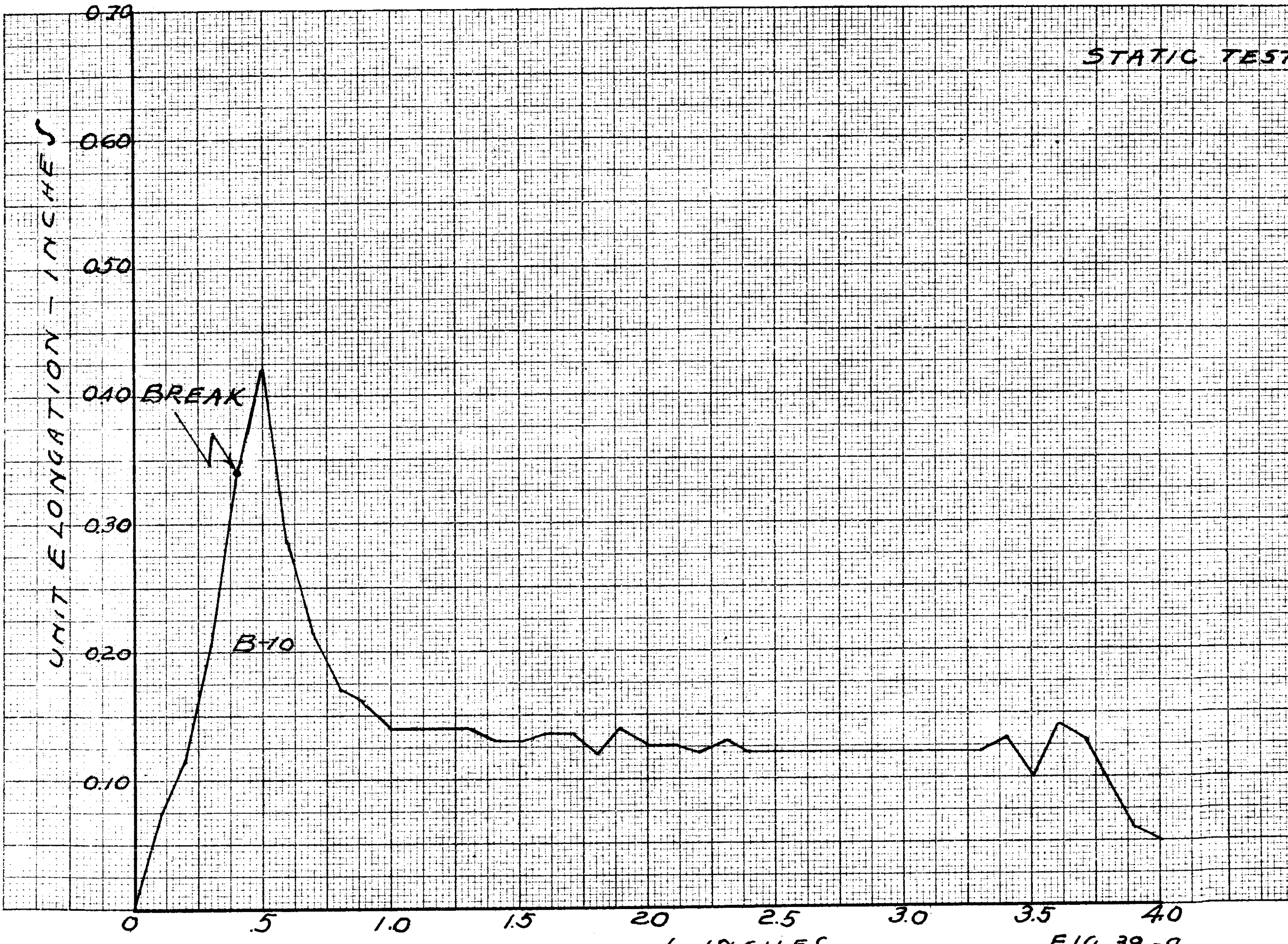

STATIC TEST
UNIT ELONGATION - INCHES
0.70
0.60
0.50
0.40
0.30
0.20
0.10
BREAK
B-10
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L-INCHES

FIG. 39-a

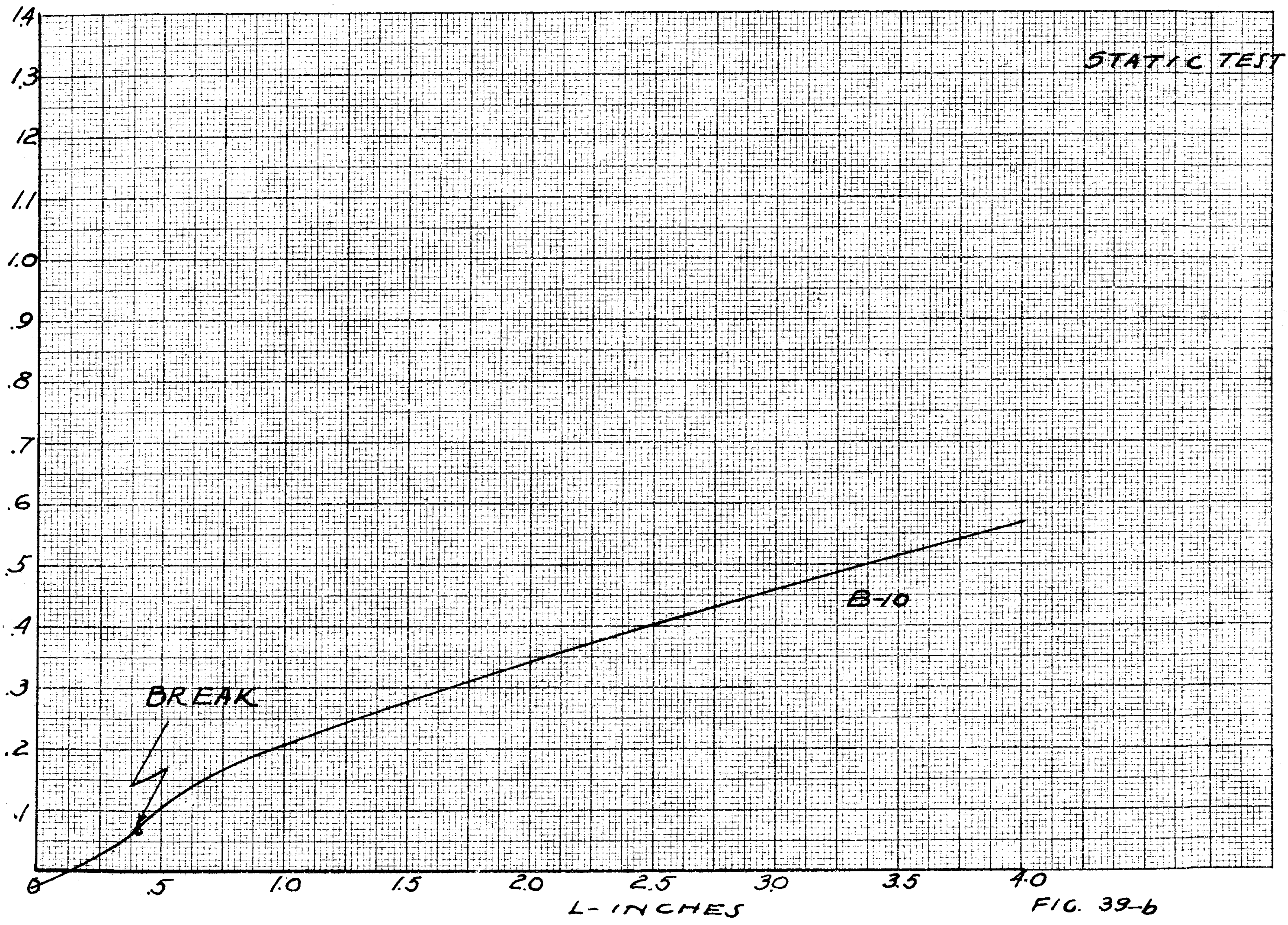

STATIC TEST
BREAK
B-10
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L - INCHES

FIG. 39-b

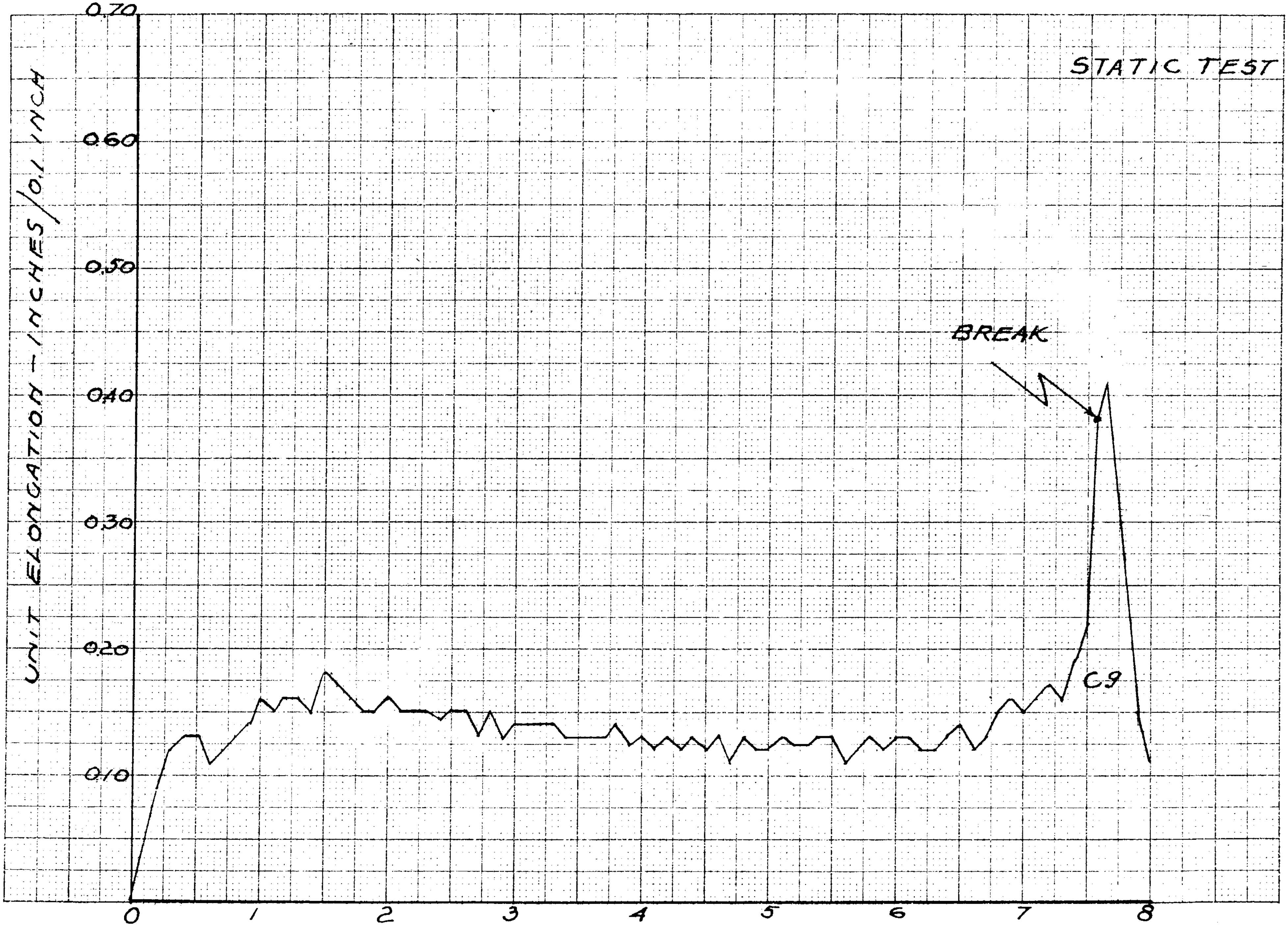
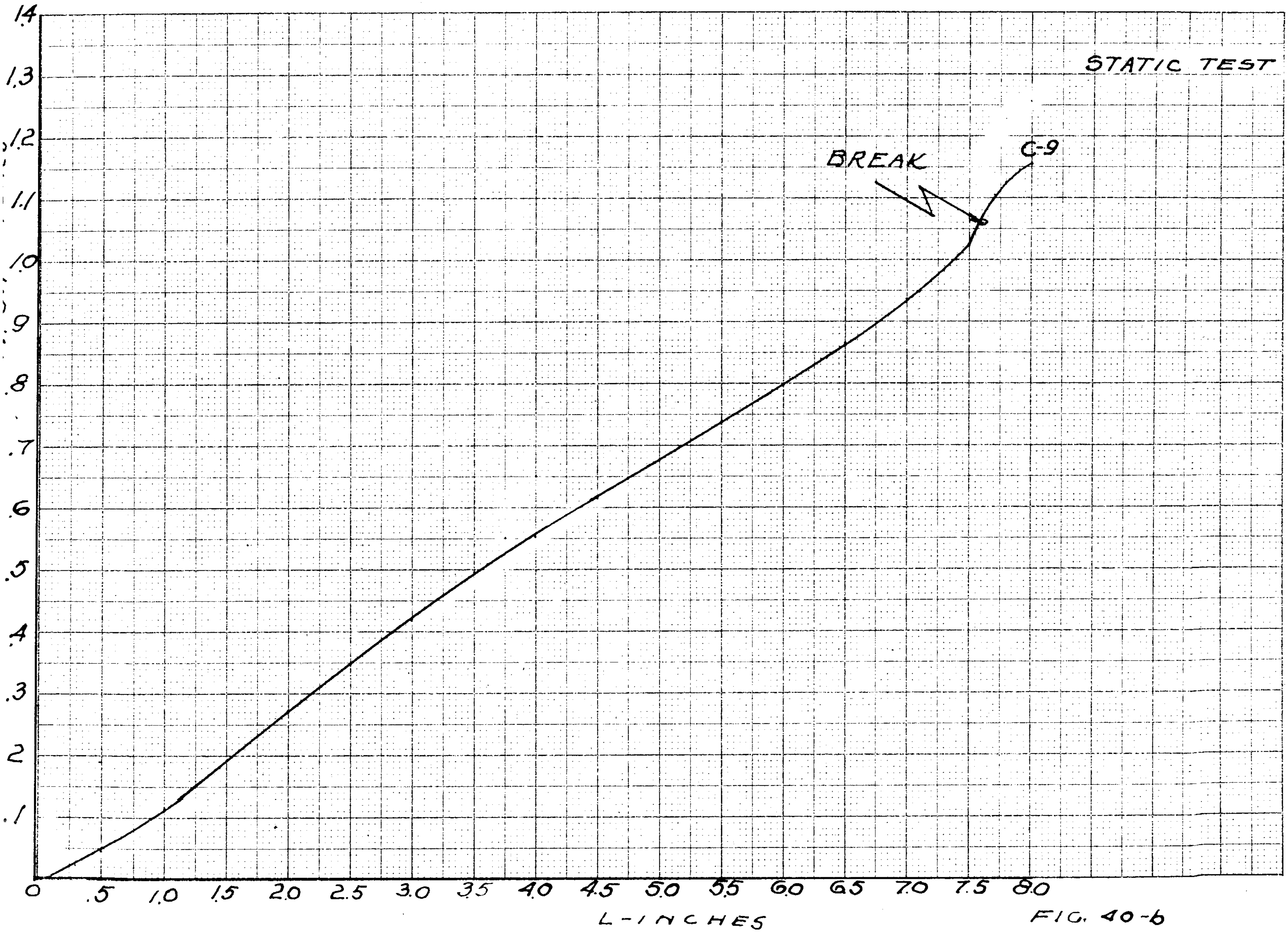

STATIC TEST
BREAK
C9
UNIT ELONGATION - INCHES/0.1 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
1
2
3
4
5
6
7
8
L-INCHES

FIG. 40-a



STATIC TEST
BREAK
C-9
14
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
2
.1
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
L-INCHES

FIG. 40-6

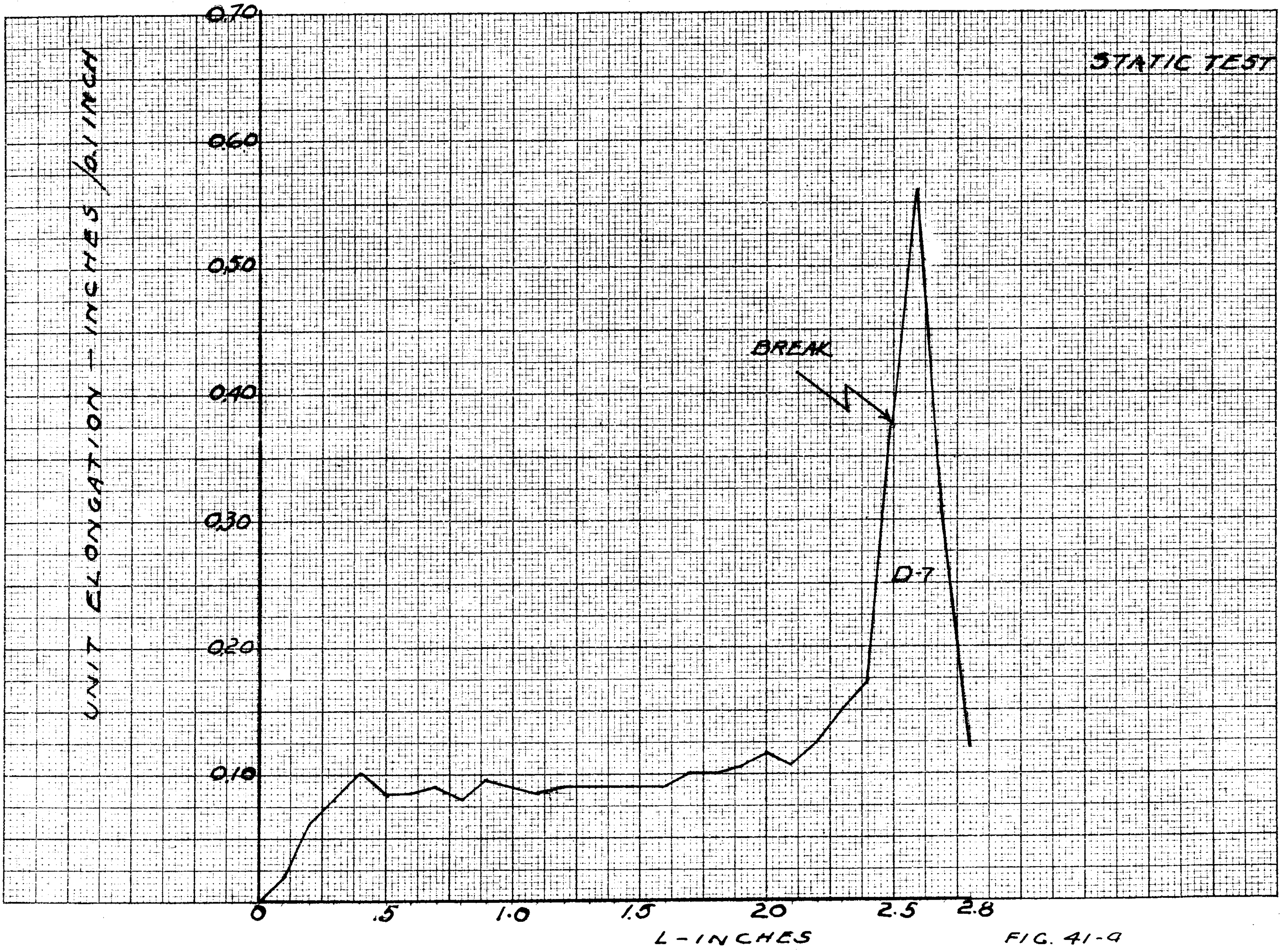

STATIC TEST
UNIT ELONGATION — INCHES /0.1 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
BREAK
D-7
0
.5
1.0
1.5
2.0
2.5
2.8
L-INCHES

FIG. 41-9

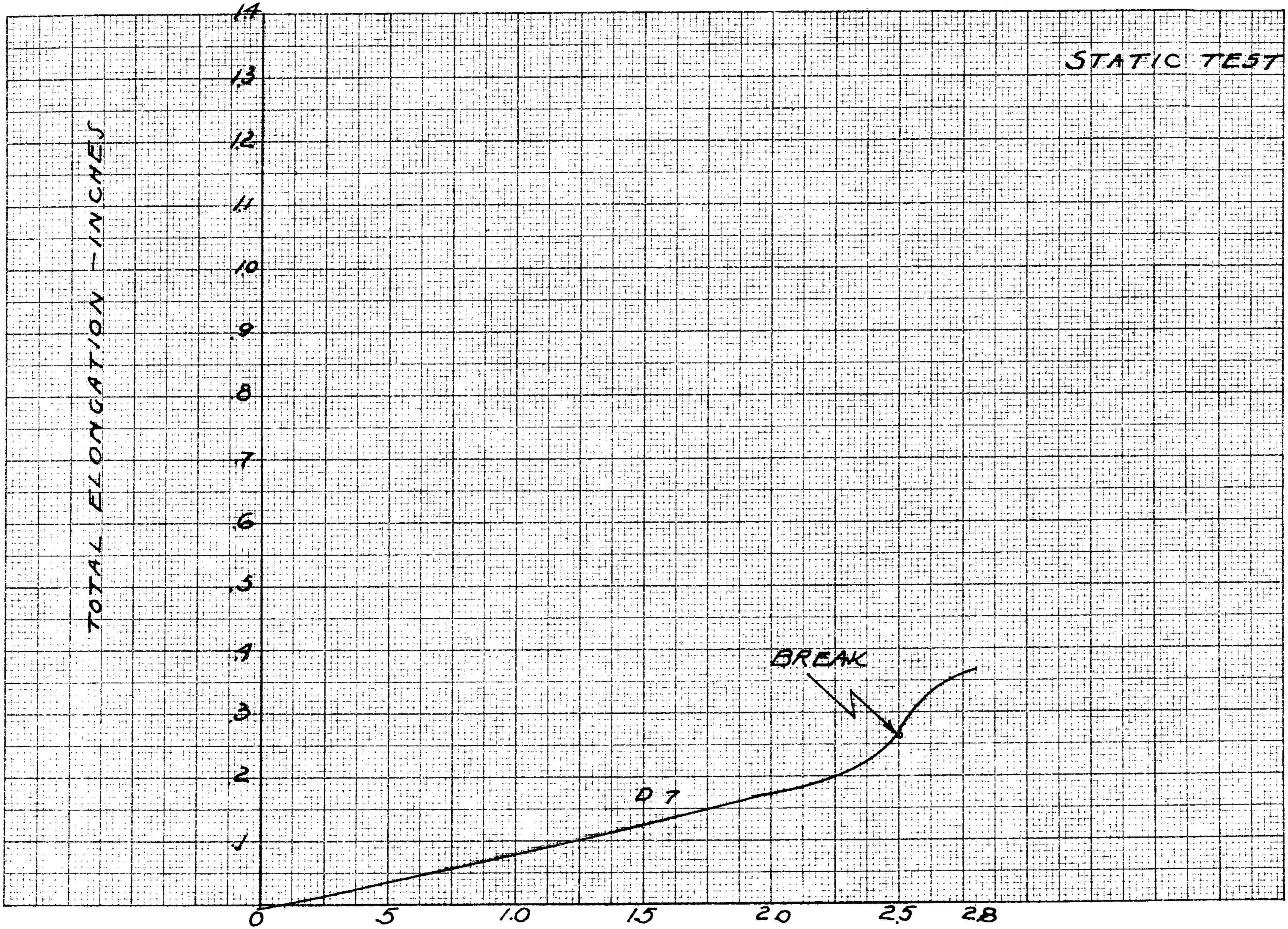

STATIC TEST
TOTAL ELONGATION - INCHES
L-INCHES
D 7
BREAK
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
5
1.0
1.5
2.0
2.5
2.8

FIG. 41-6

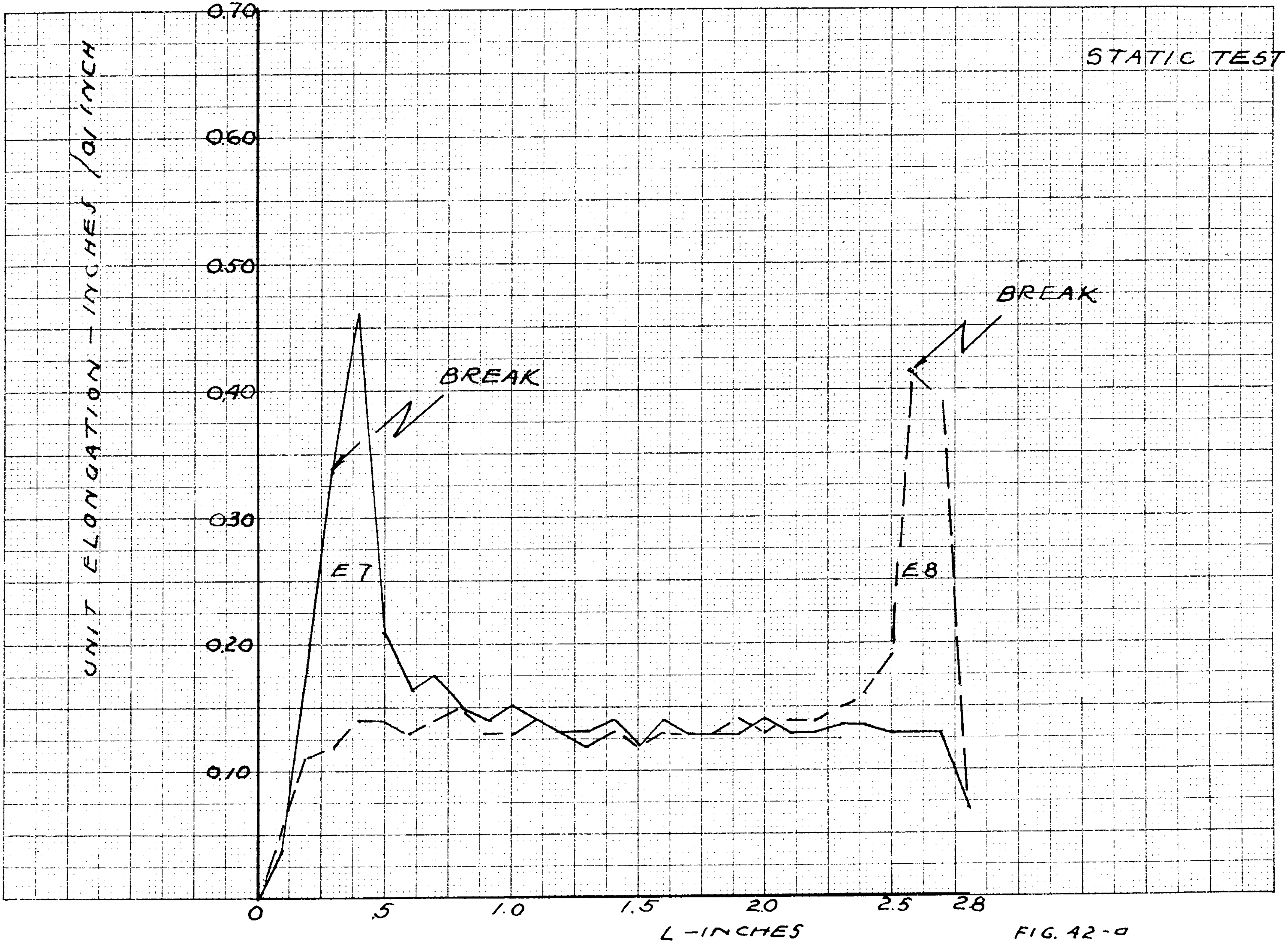

STATIC TEST
UNIT ELONGATION - INCHES /01 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
.5
1.0
1.5
2.0
2.5
2.8
L - INCHES
BREAK
BREAK
E7
E8

FIG. 42-a

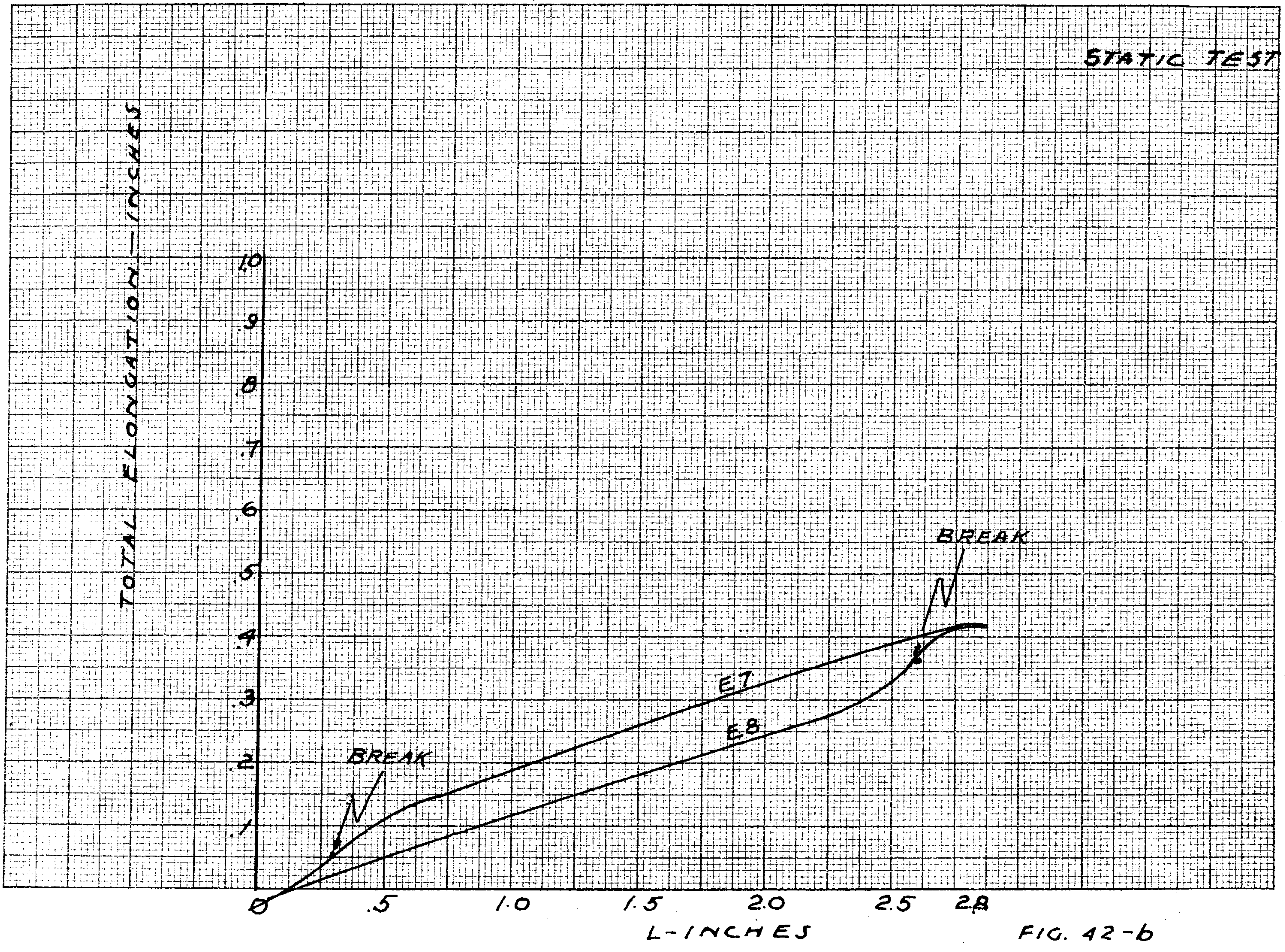

STATIC TEST
TOTAL ELONGATION — INCHES
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.5
1.0
1.5
2.0
2.5
2.8
L-INCHES
BREAK
BREAK
E7
E8

FIG. 42-b

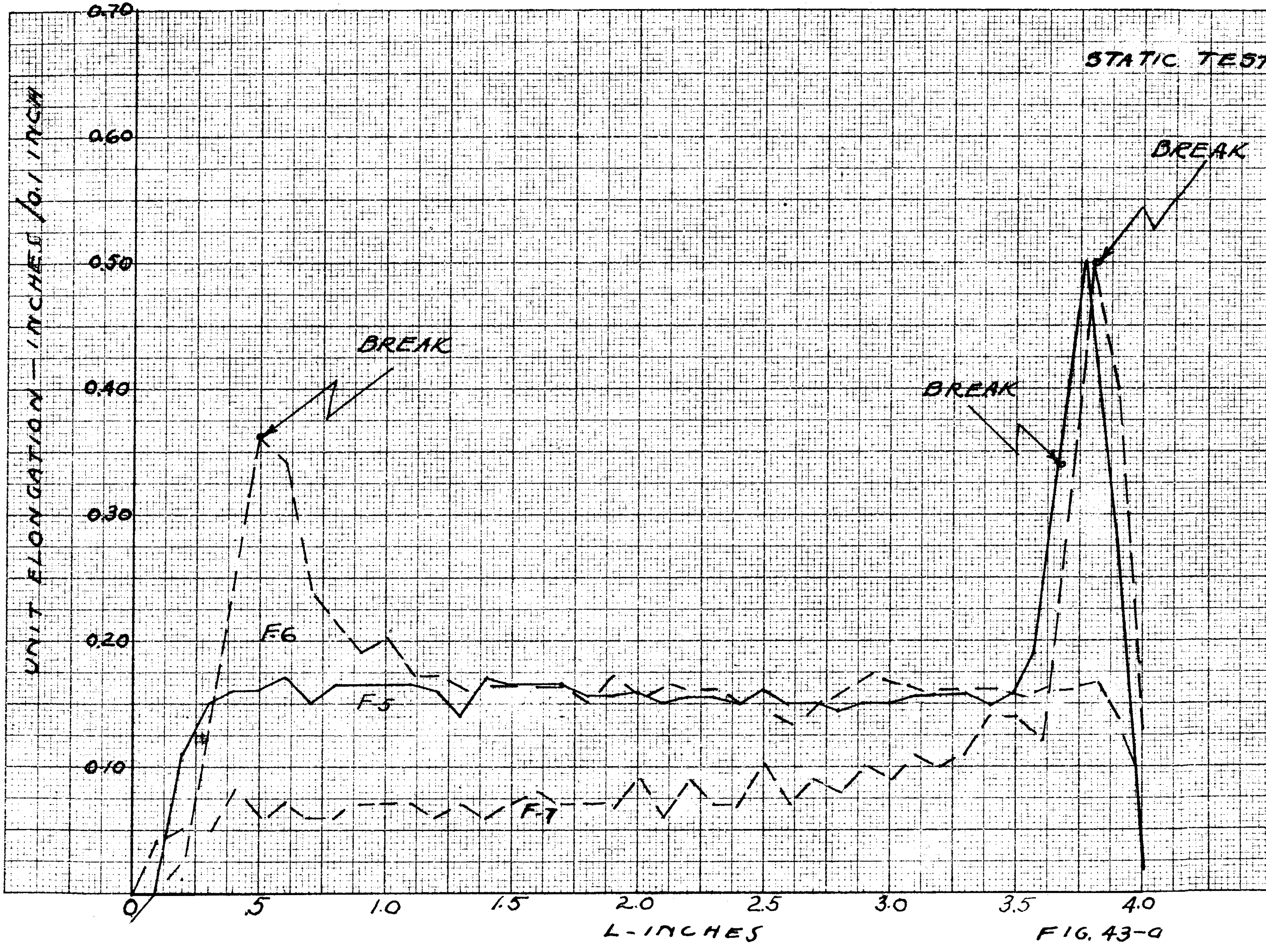
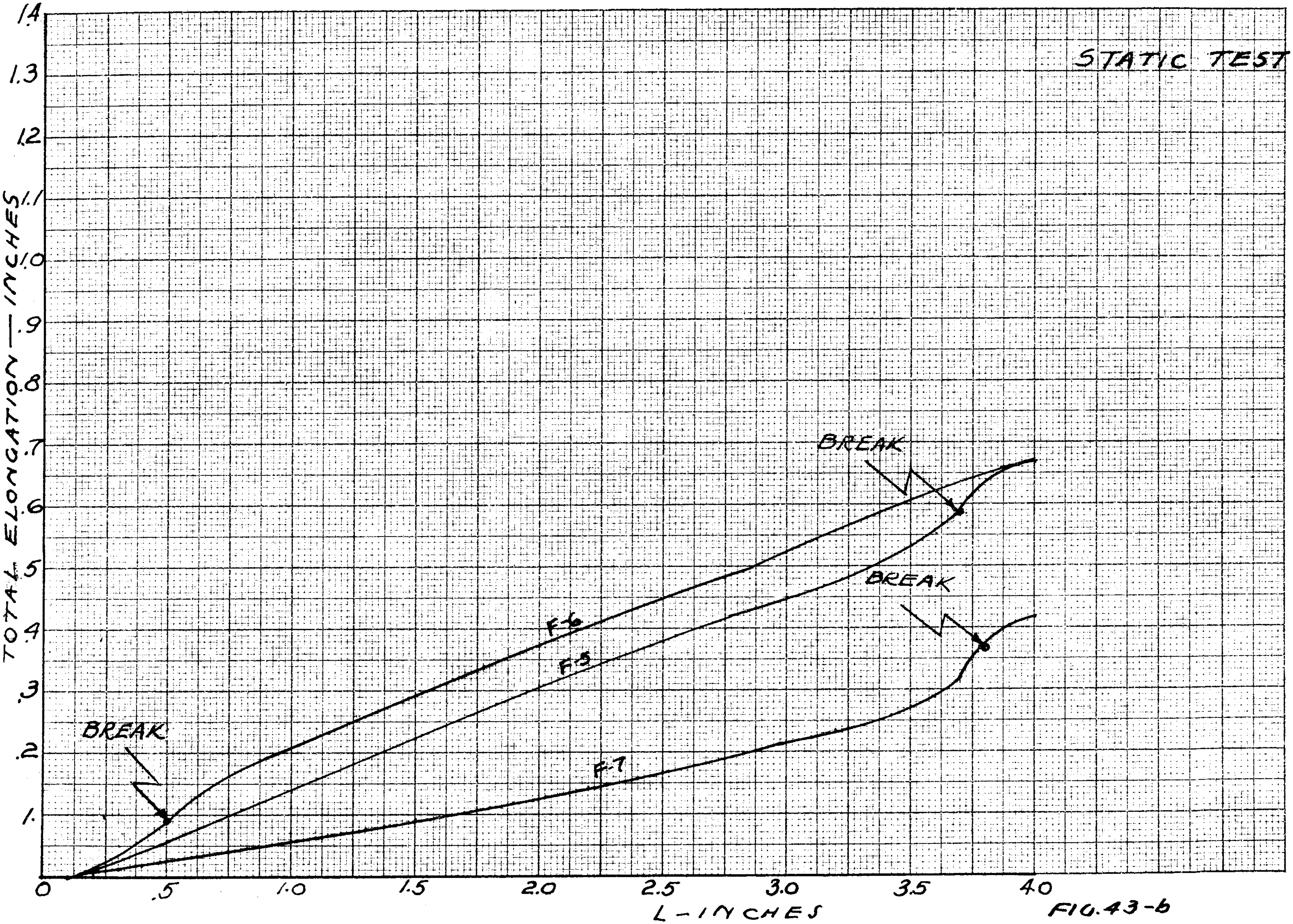

STATIC TEST
UNIT ELONGATION — INCHES /0.1 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L-INCHES
BREAK
BREAK
BREAK
F6
F5
F7

FIG. 43-a


STATIC TEST
TOTAL ELONGATION — INCHES
L - INCHES
BREAK
BREAK
BREAK
F-6
F-5
F-7
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
FIG. 43-b

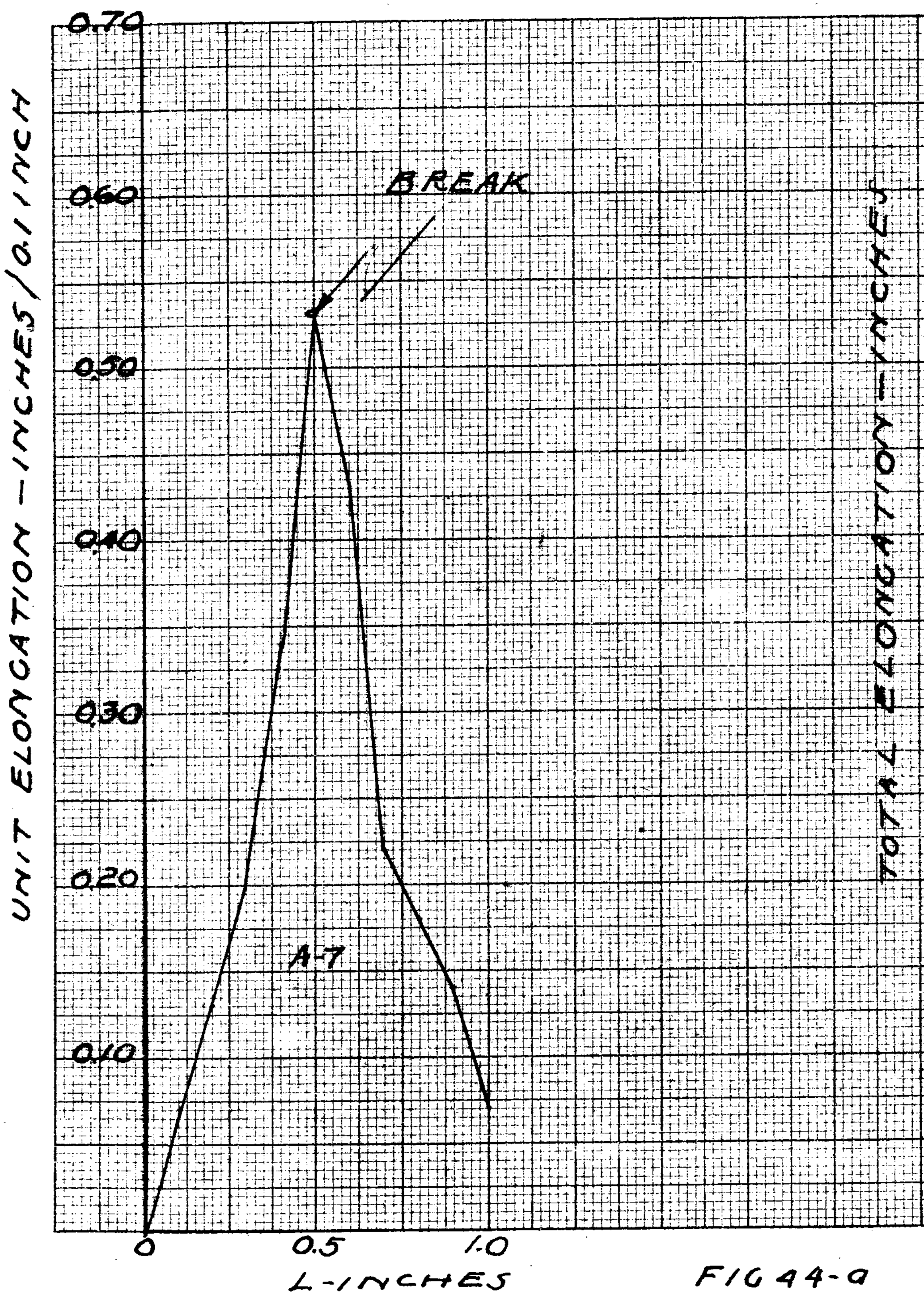


FIG 44-a

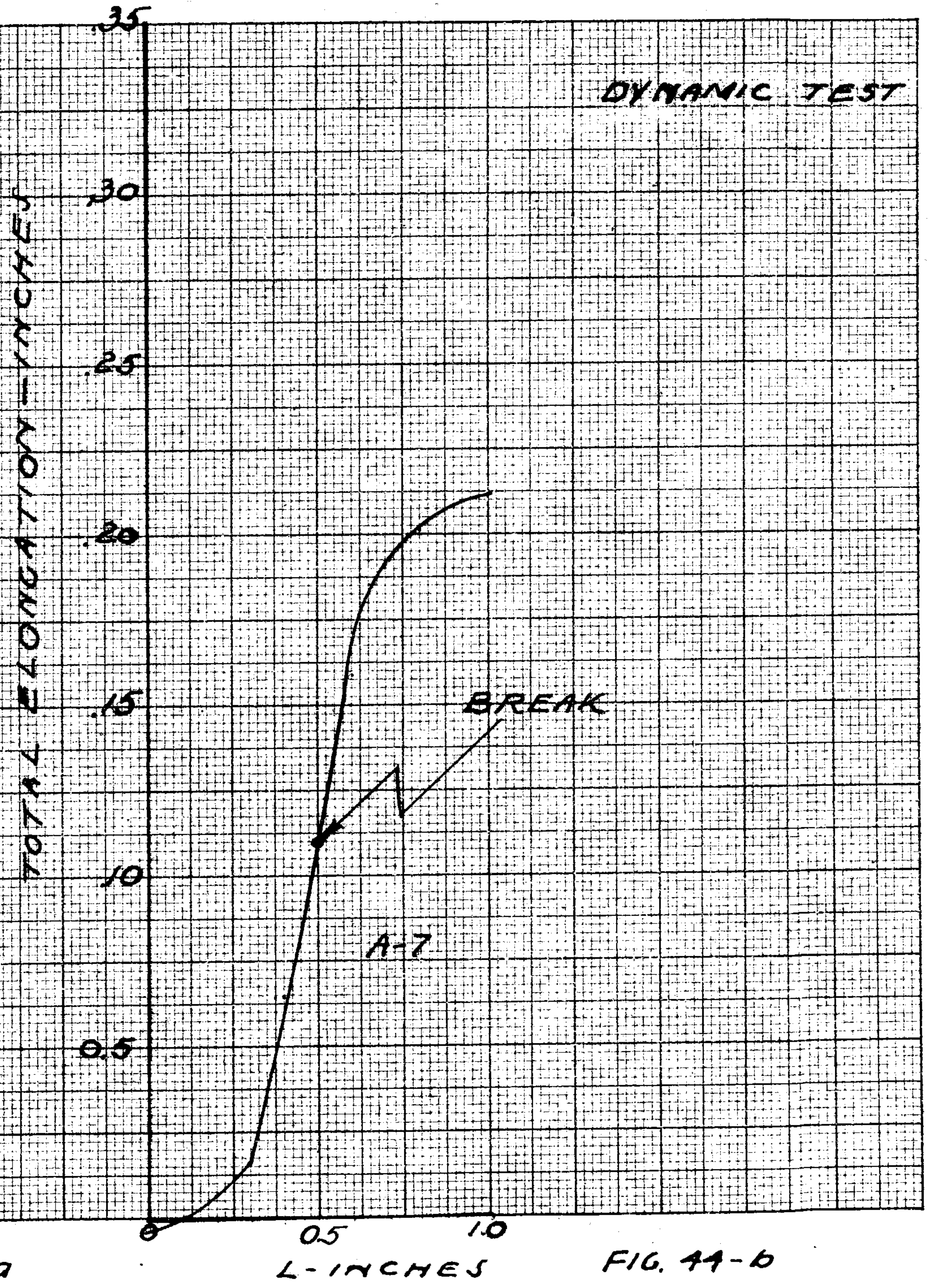


FIG. 44-b

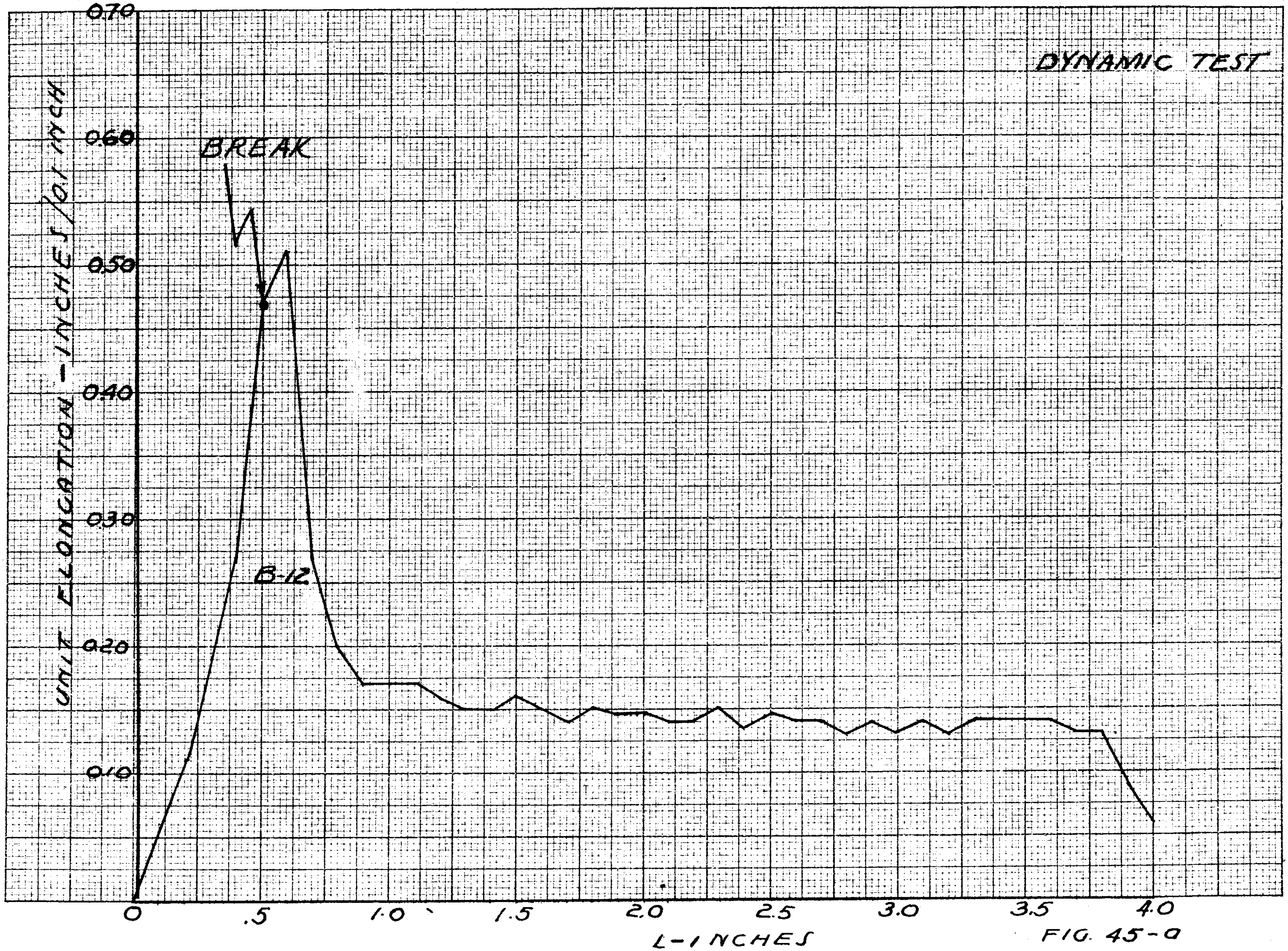

DYNAMIC TEST
UNIT ELONGATION - INCHES/0.1 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
BREAK
B-12
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L-INCHES

FIG. 45-a

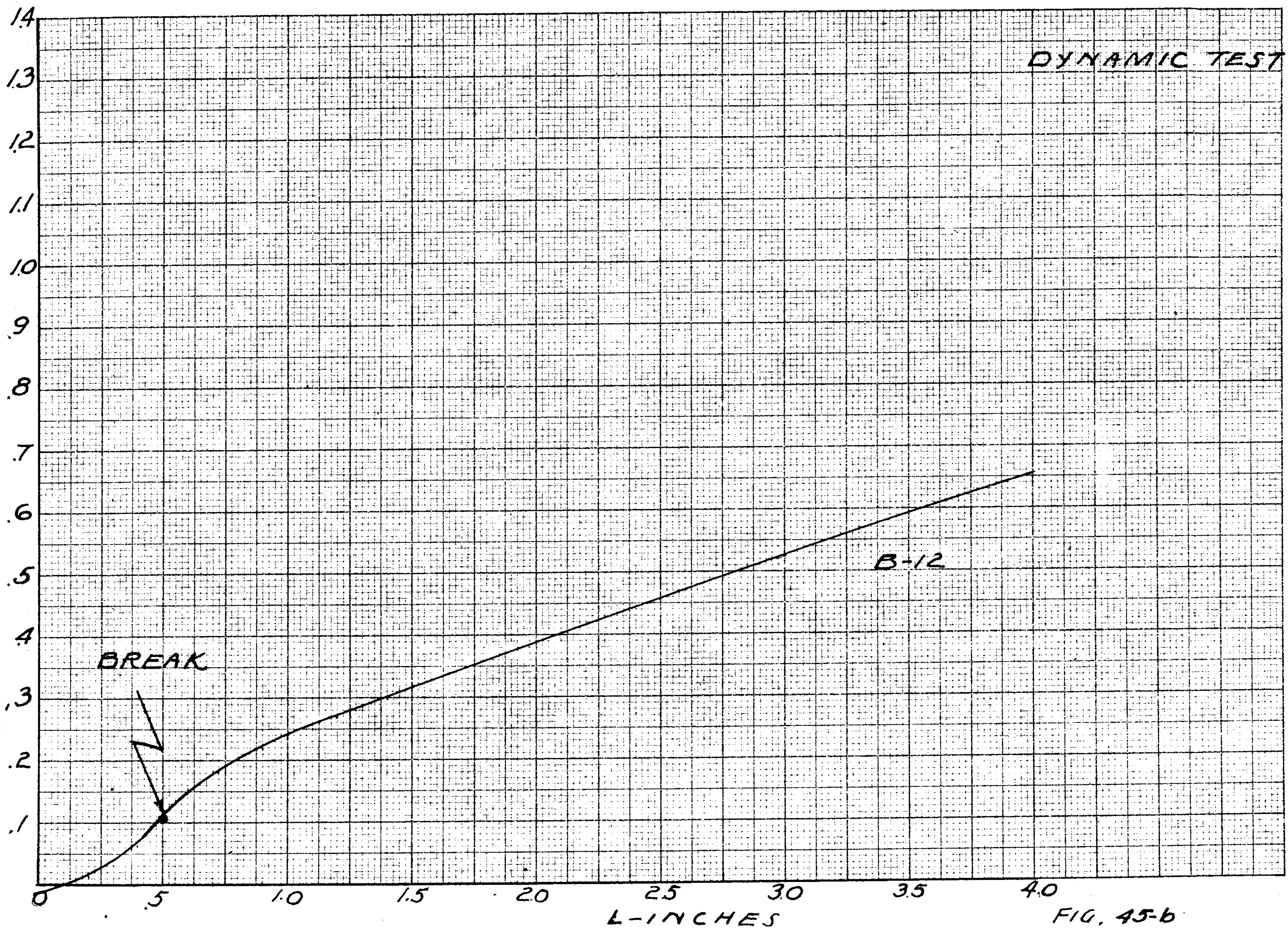
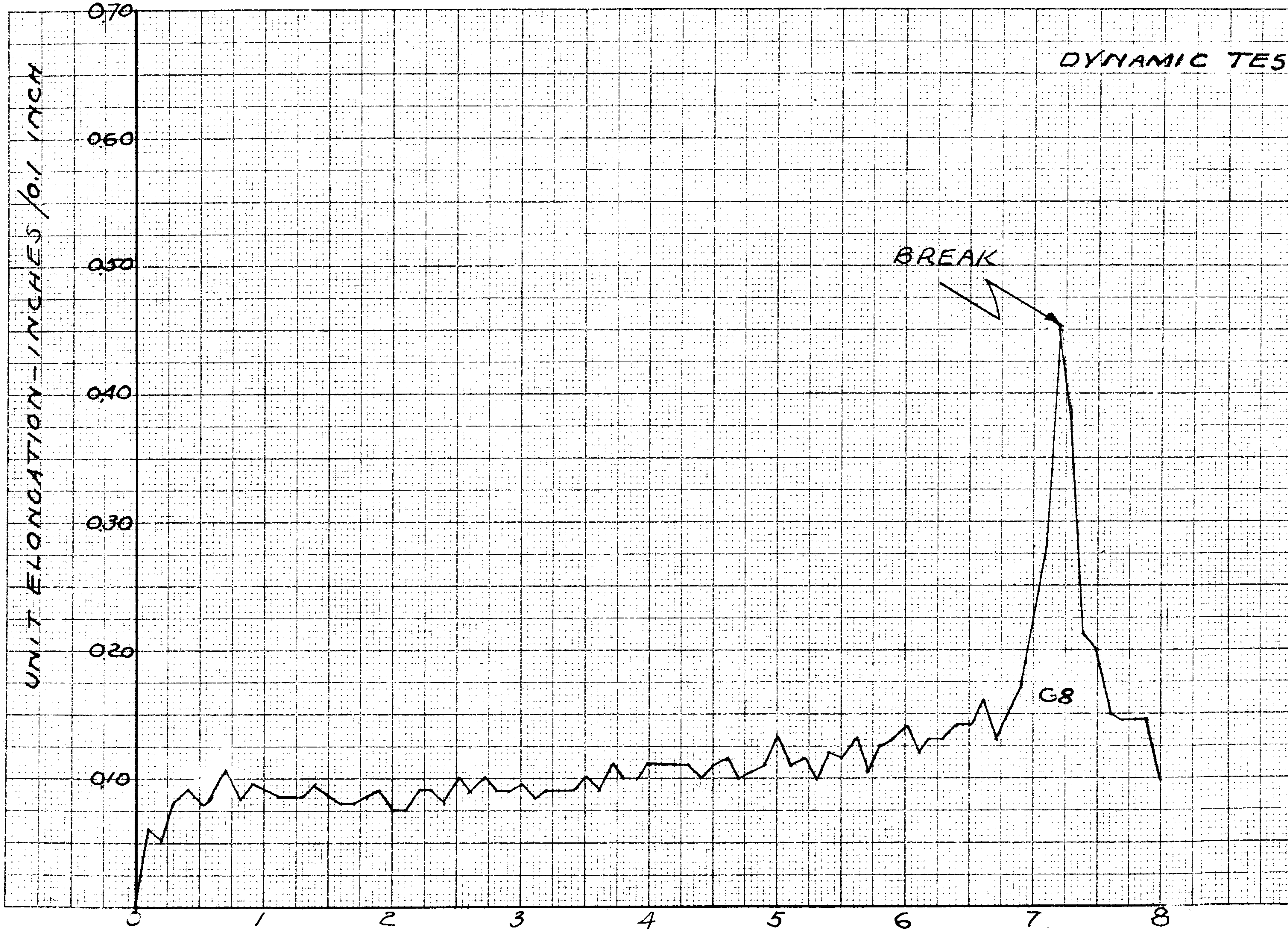

DYNAMIC TEST
BREAK
B-12
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L-INCHES

FIG. 45-b


DYNAMIC TEST
0.70
0.60
0.50
0.40
0.30
0.20
0.10
UNIT ELONGATION—INCHES/0.1 INCH
BREAK
G8
0
1
2
3
4
5
6
7
8
L-INCHES
FIG. 46-a

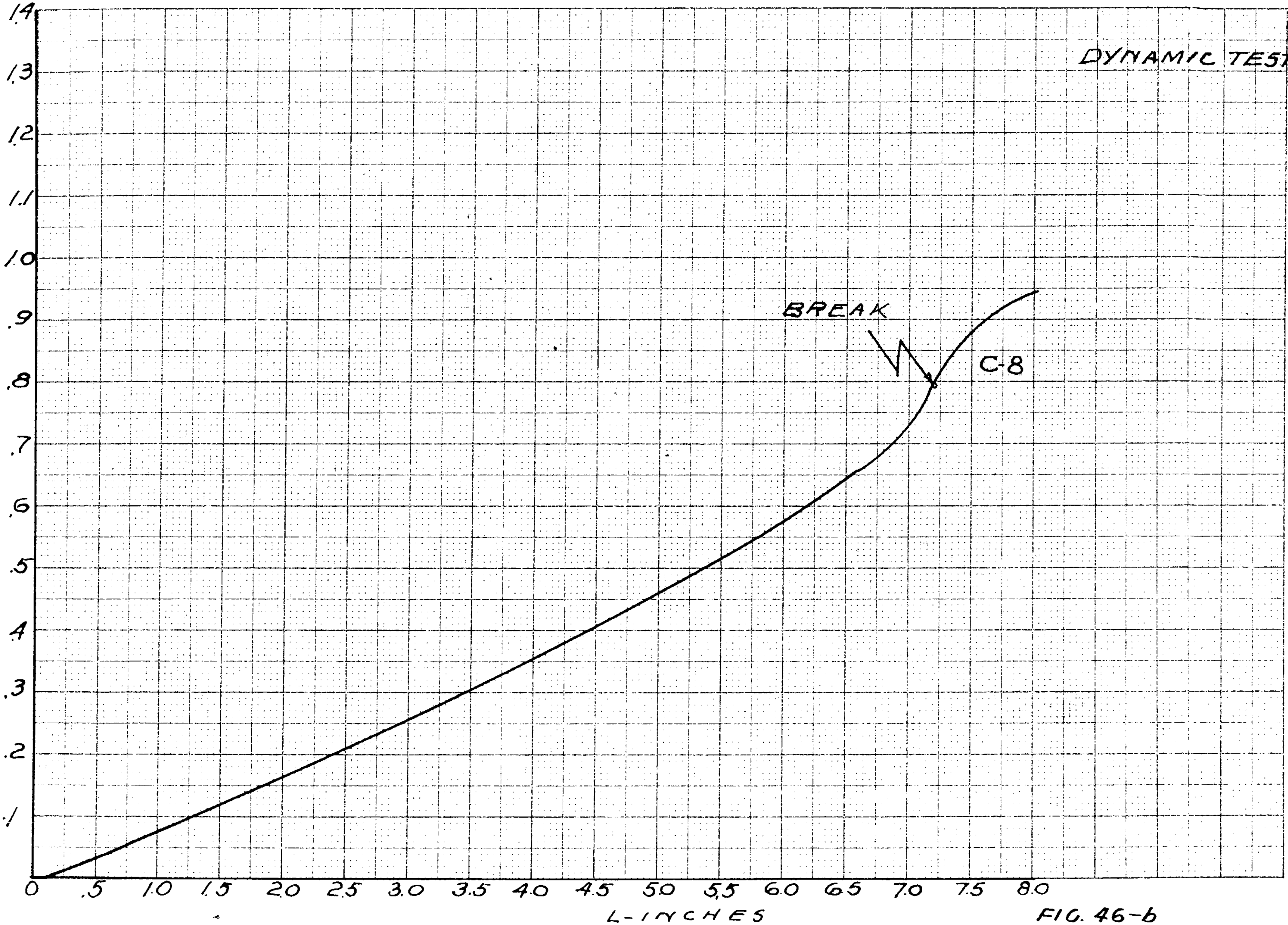
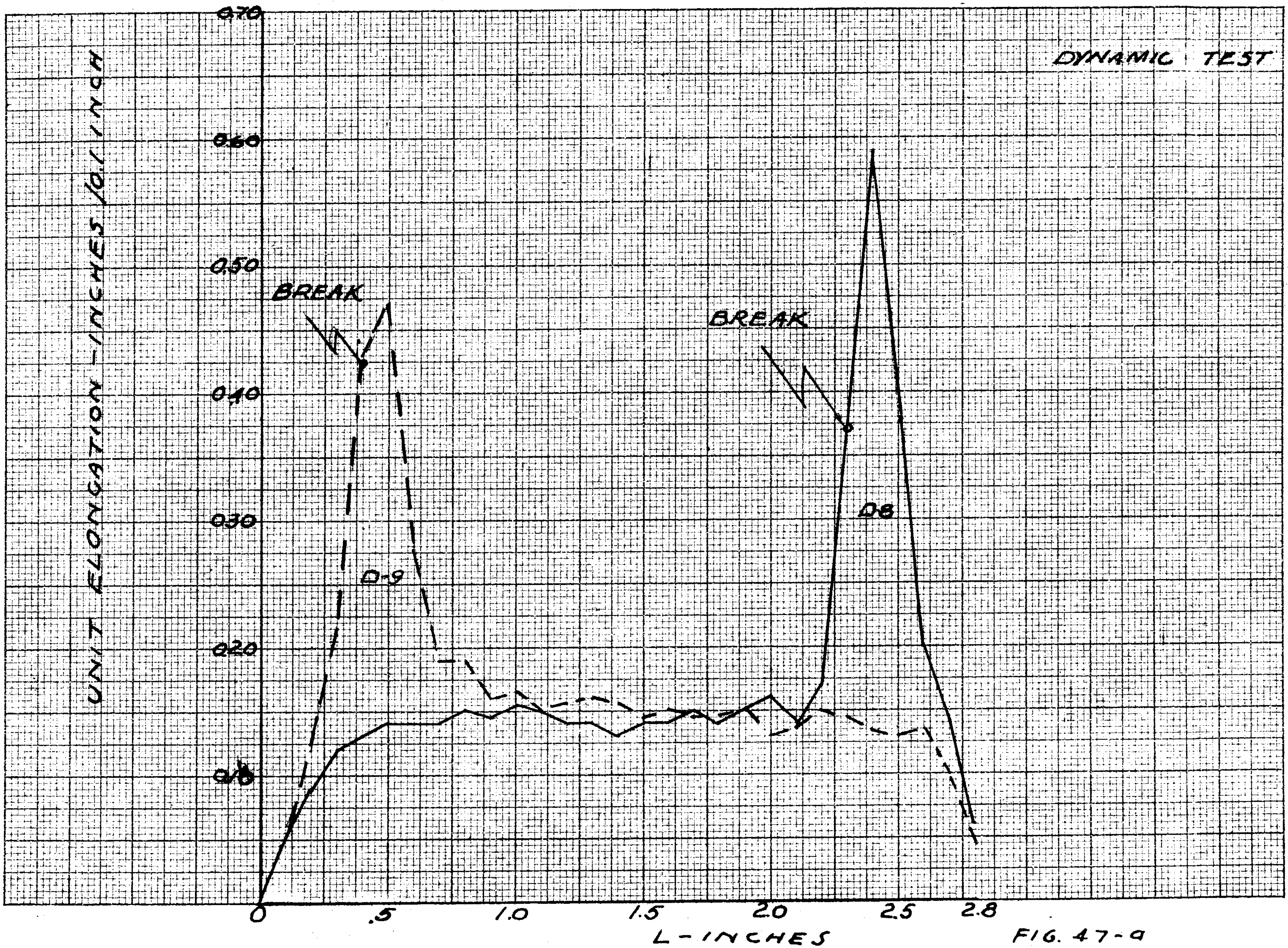

DYNAMIC TEST
BREAK
C-8
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
L-INCHES

FIG. 46-b



DYNAMIC TEST
UNIT ELONGATION - INCHES /0.1 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
BREAK
BREAK
D-9
D8
0
.5
1.0
1.5
2.0
2.5
2.8
L - INCHES

FIG. 47-a

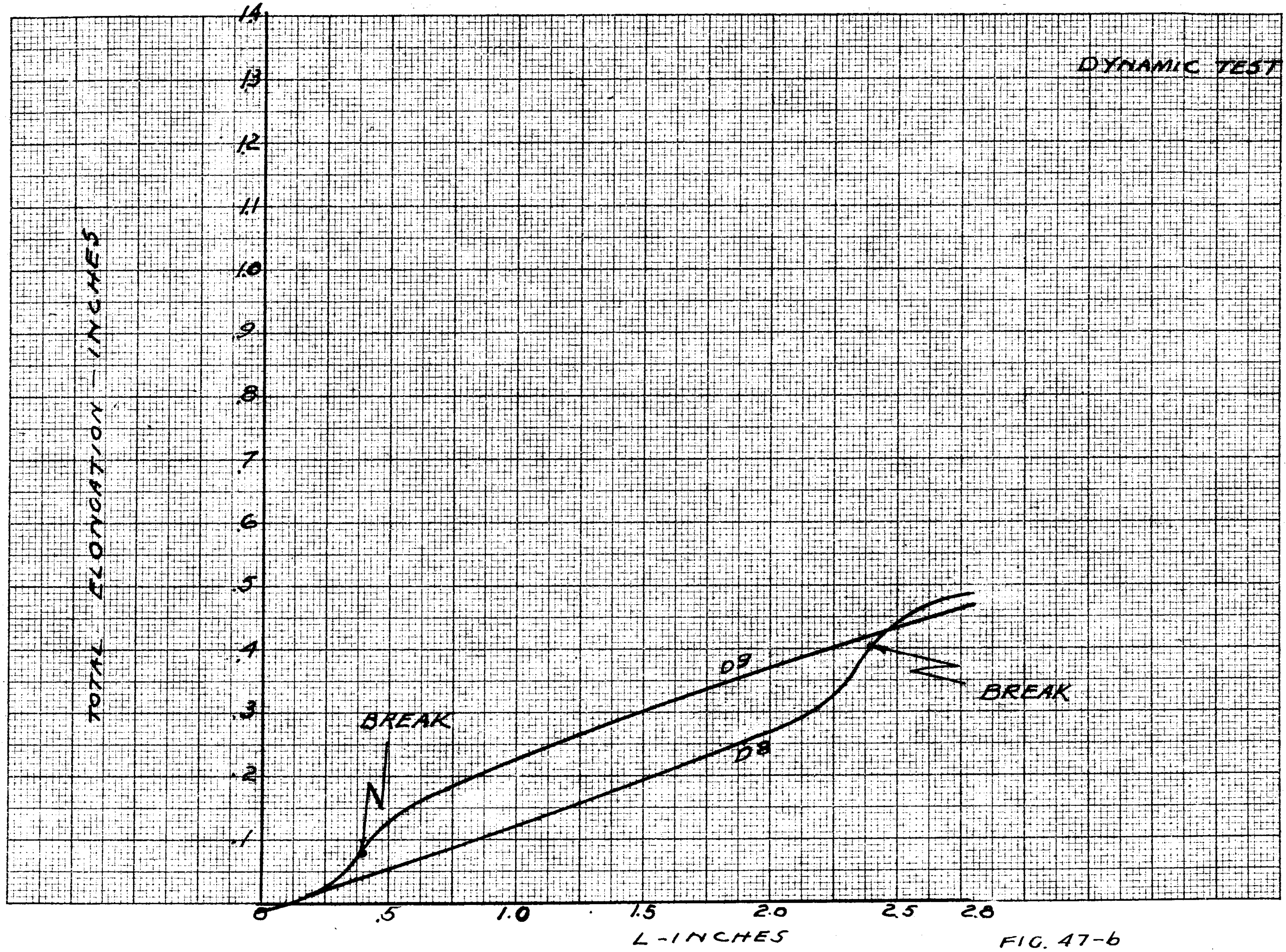
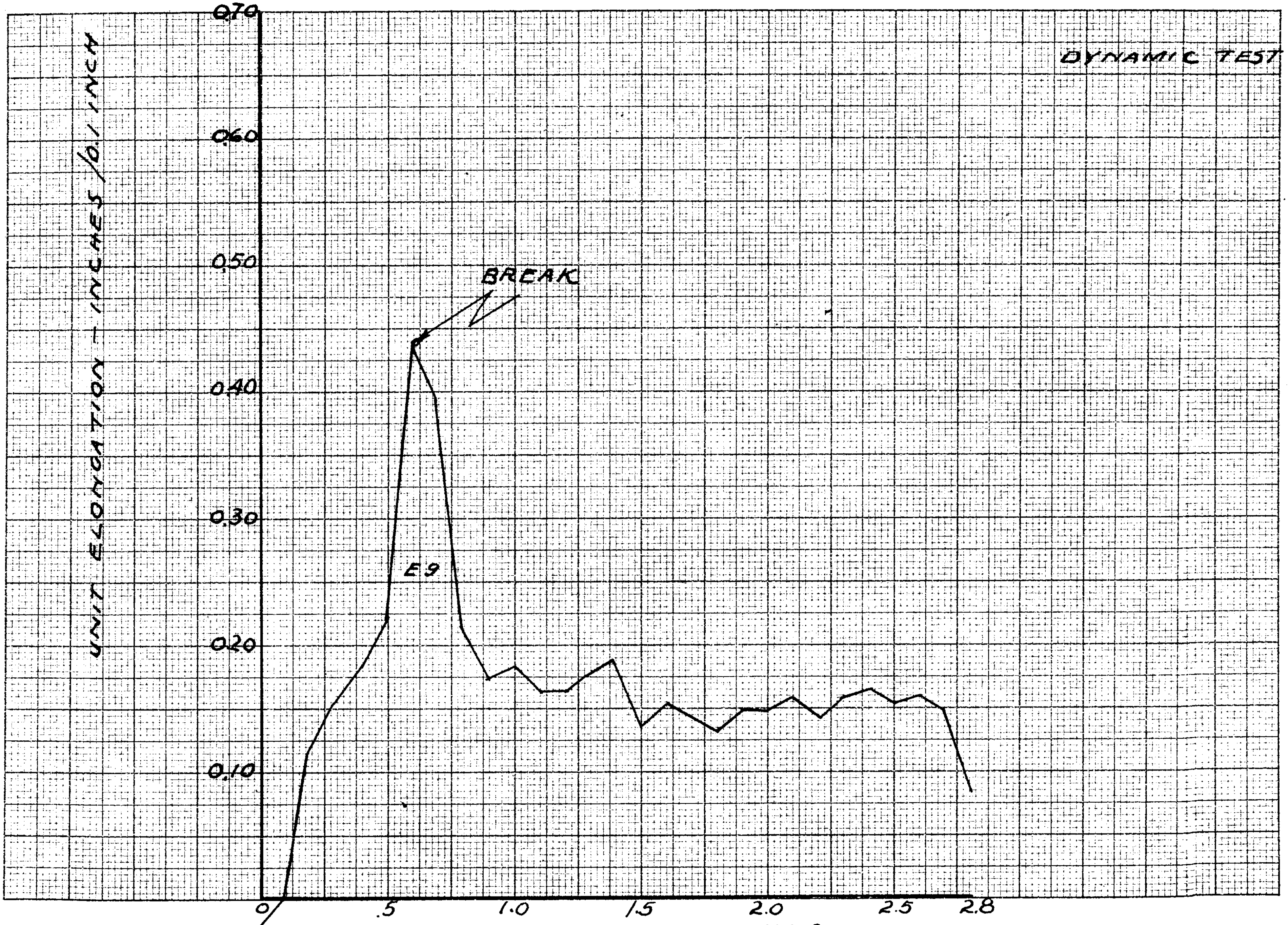

DYNAMIC TEST
TOTAL ELONGATION - INCHES
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
.5
1.0
1.5
2.0
2.5
2.8
L-INCHES
BREAK
D9
D8
BREAK

FIG. 47-6



DYNAMIC TEST
UNIT ELONGATION - INCHES /0.1 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
BREAK
E9
0
.5
1.0
1.5
2.0
2.5
2.8
L-INCHES

FIG. 48-a

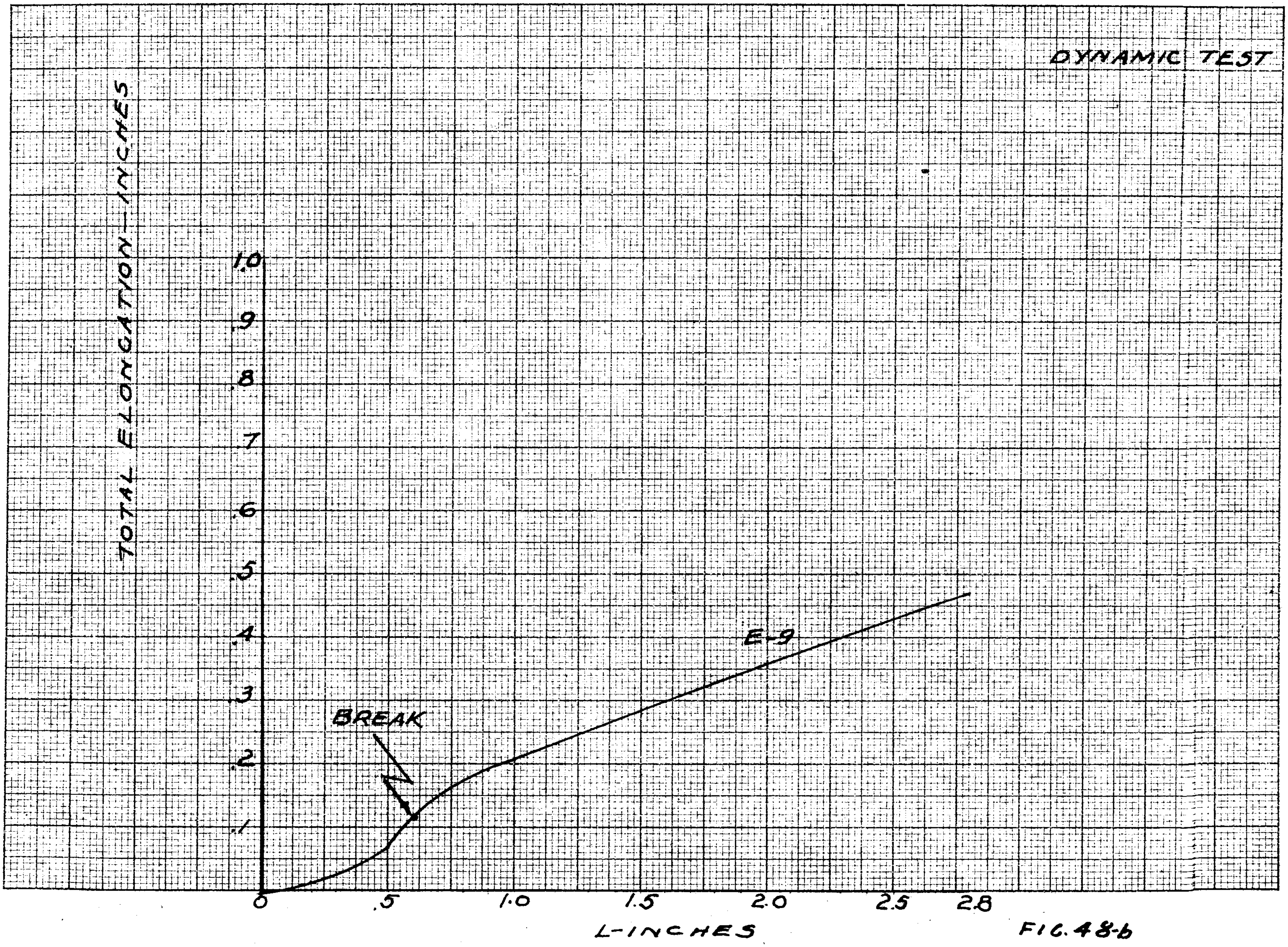

DYNAMIC TEST
TOTAL ELONGATION—INCHES
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.5
1.0
1.5
2.0
2.5
2.8
BREAK
E-9
L-INCHES

FIG. 48-b

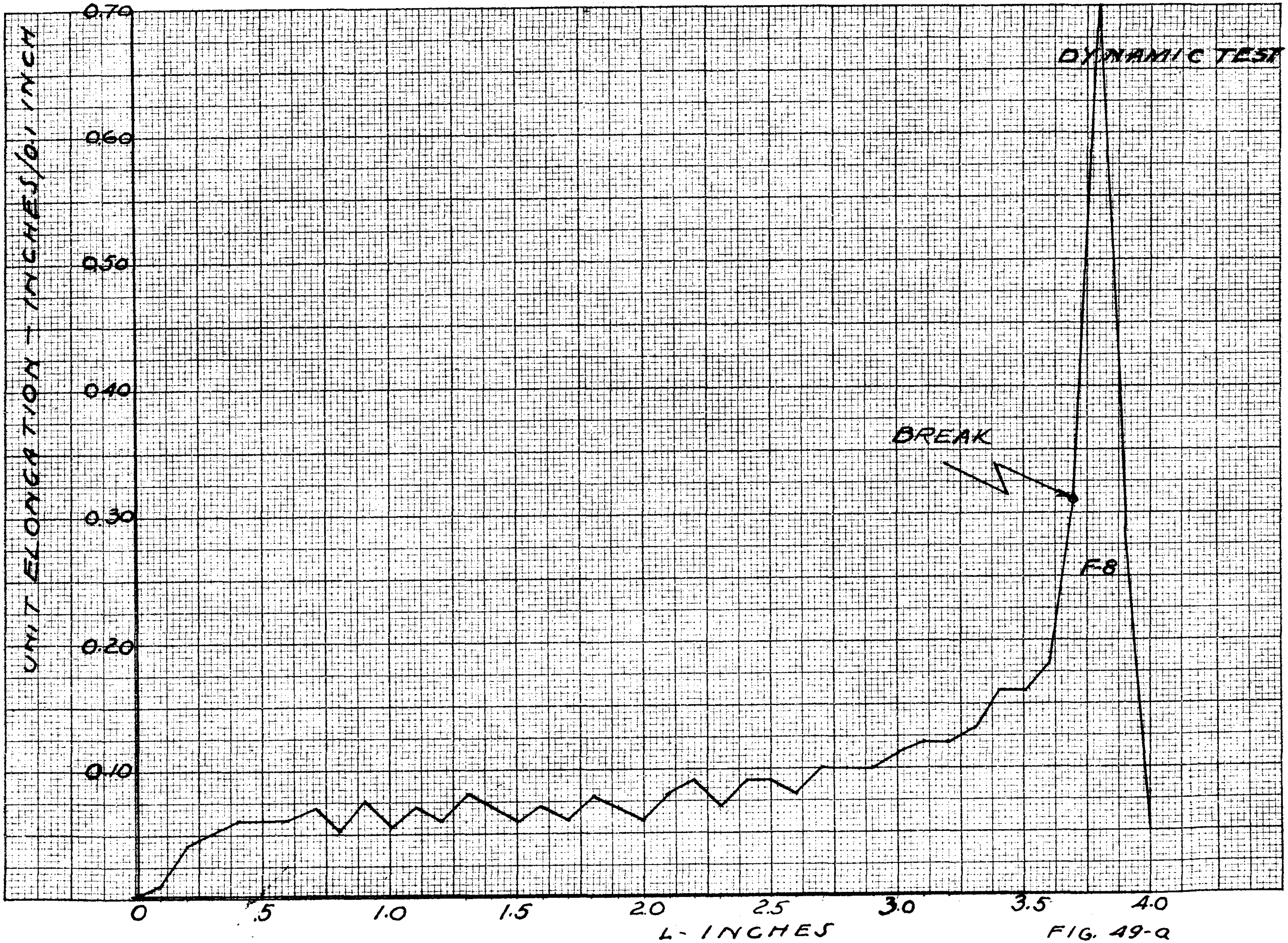
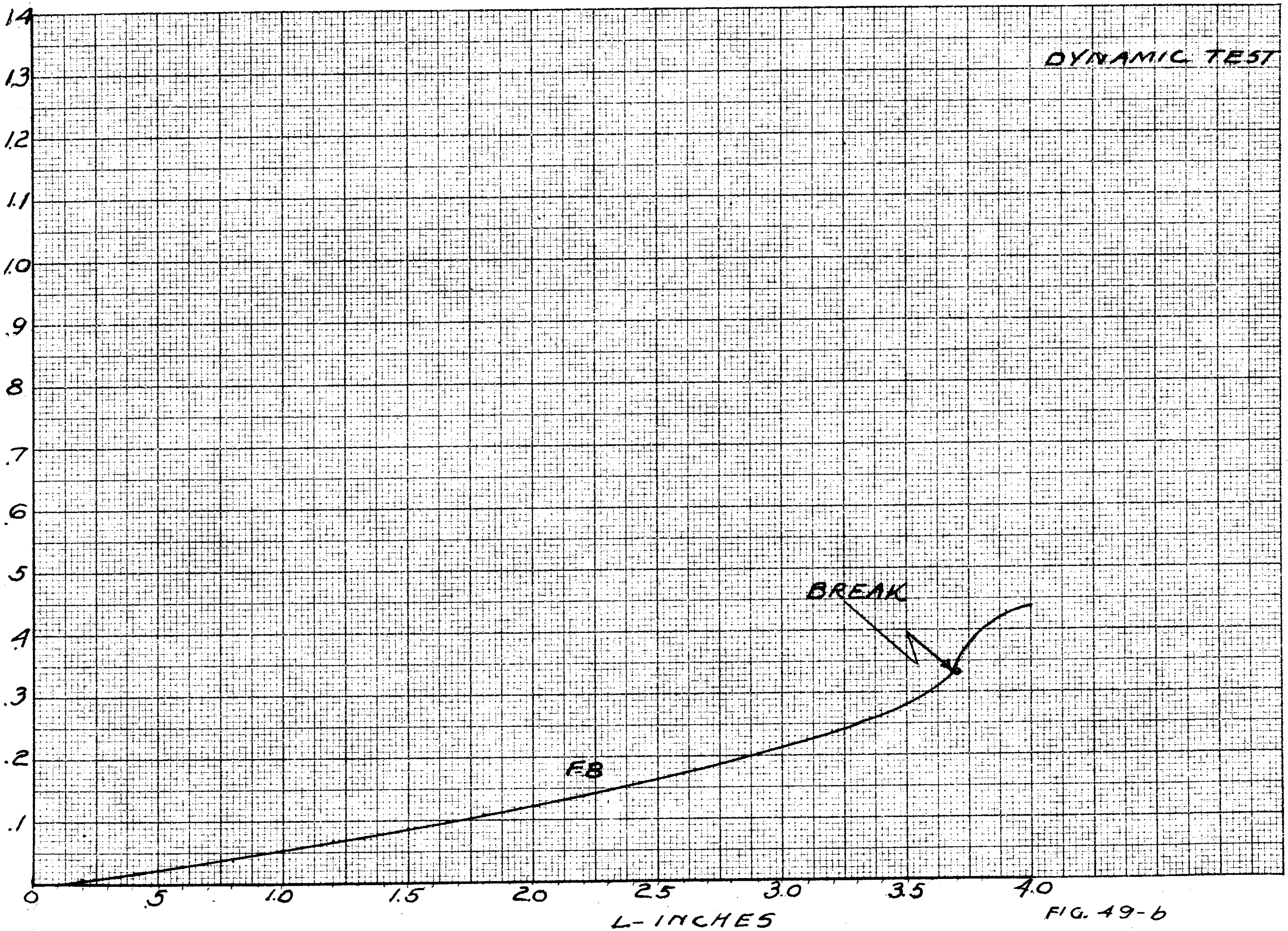
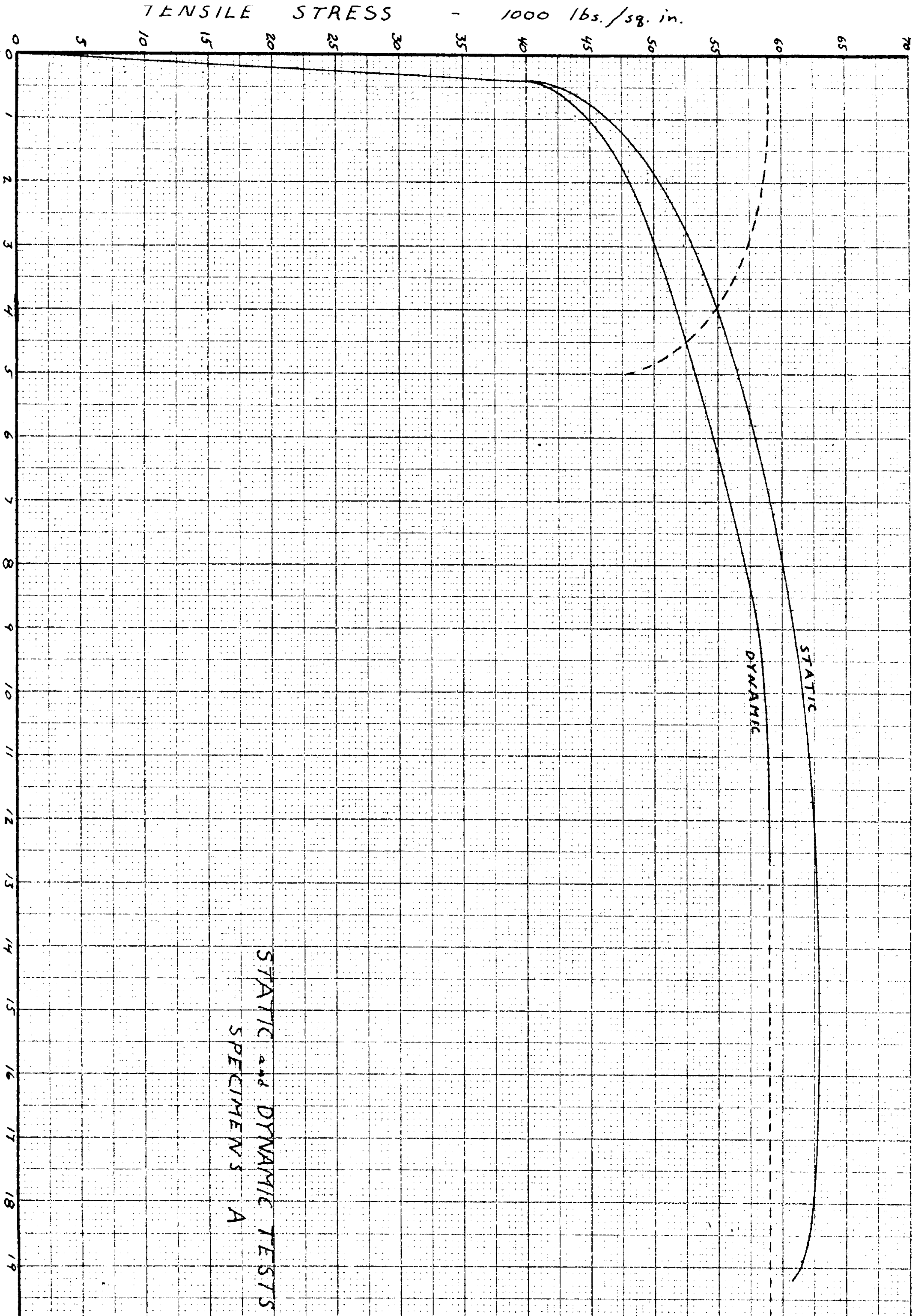

UNIT ELONGATION - INCHES/0.1 INCH
0.70
0.60
0.50
0.40
0.30
0.20
0.10
DYNAMIC TEST
BREAK
F-8
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
L - INCHES

FIG. 49-a



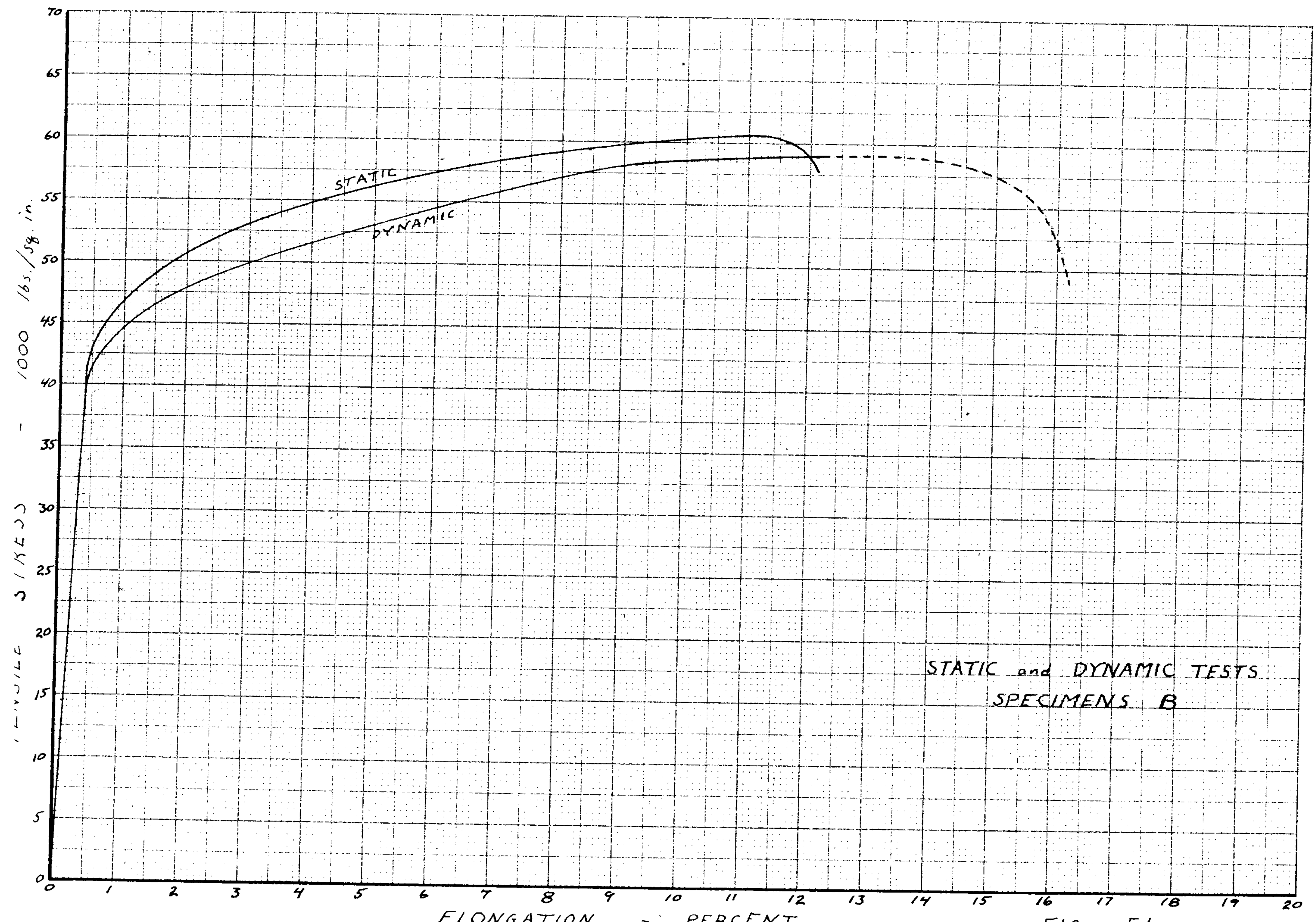
DYNAMIC TEST
BREAK
FB
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
.1
.2
.3
.4
.5
.6
.7
8
.9
1.0
1.1
1.2
1.3
1.4
L-INCHES

FIG. 49-6



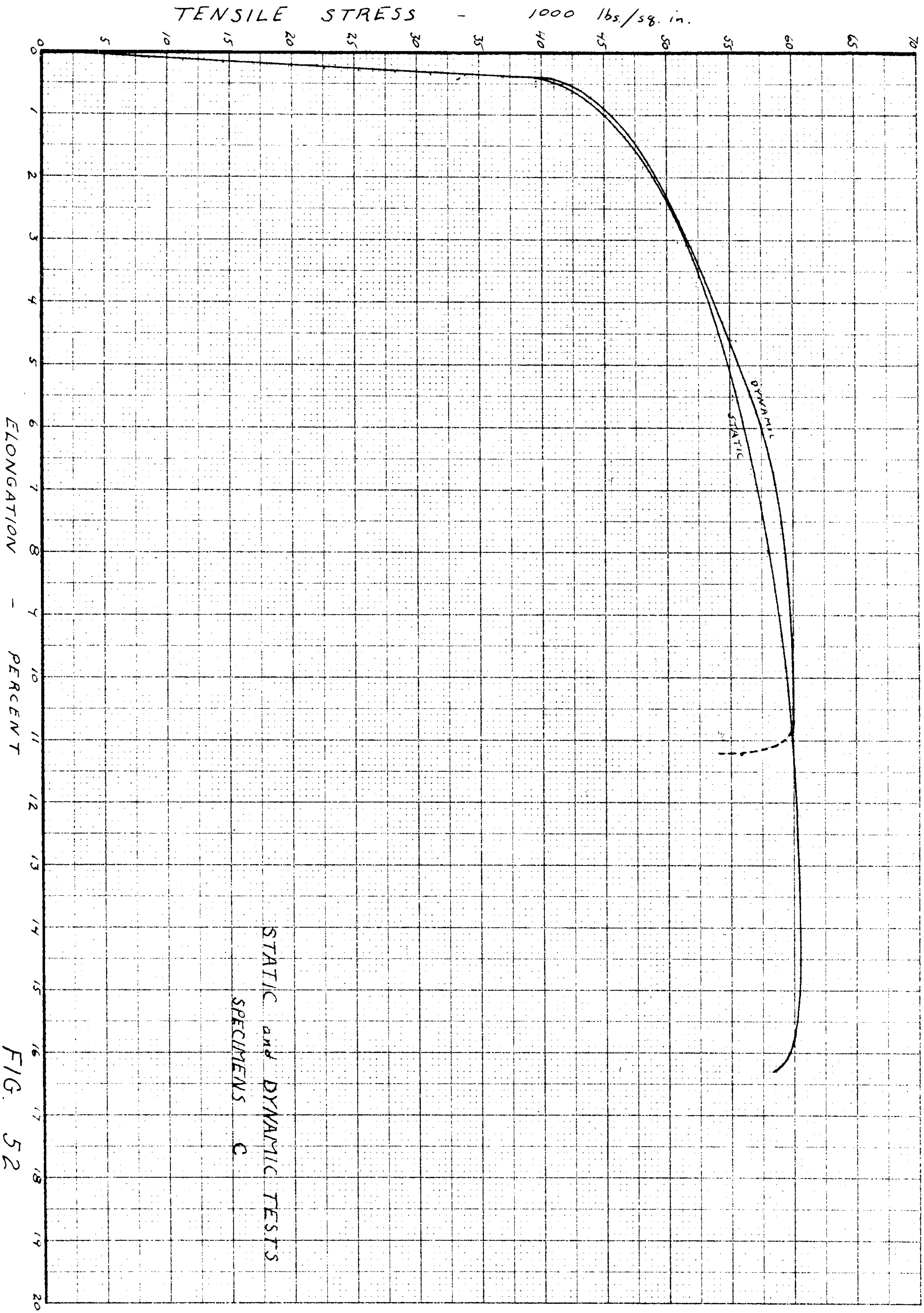
STATIC and DYNAMIC TESTS
SPECIMENS A

FIG. 50



TENSILE STRESS - 1000 lbs./sq. in.
ELONGATION - PERCENT
STATIC
DYNAMIC
STATIC and DYNAMIC TESTS
SPECIMENS B

FIG. 51



STATIC and DYNAMIC TESTS

SPECIMENS C

FIG. 52

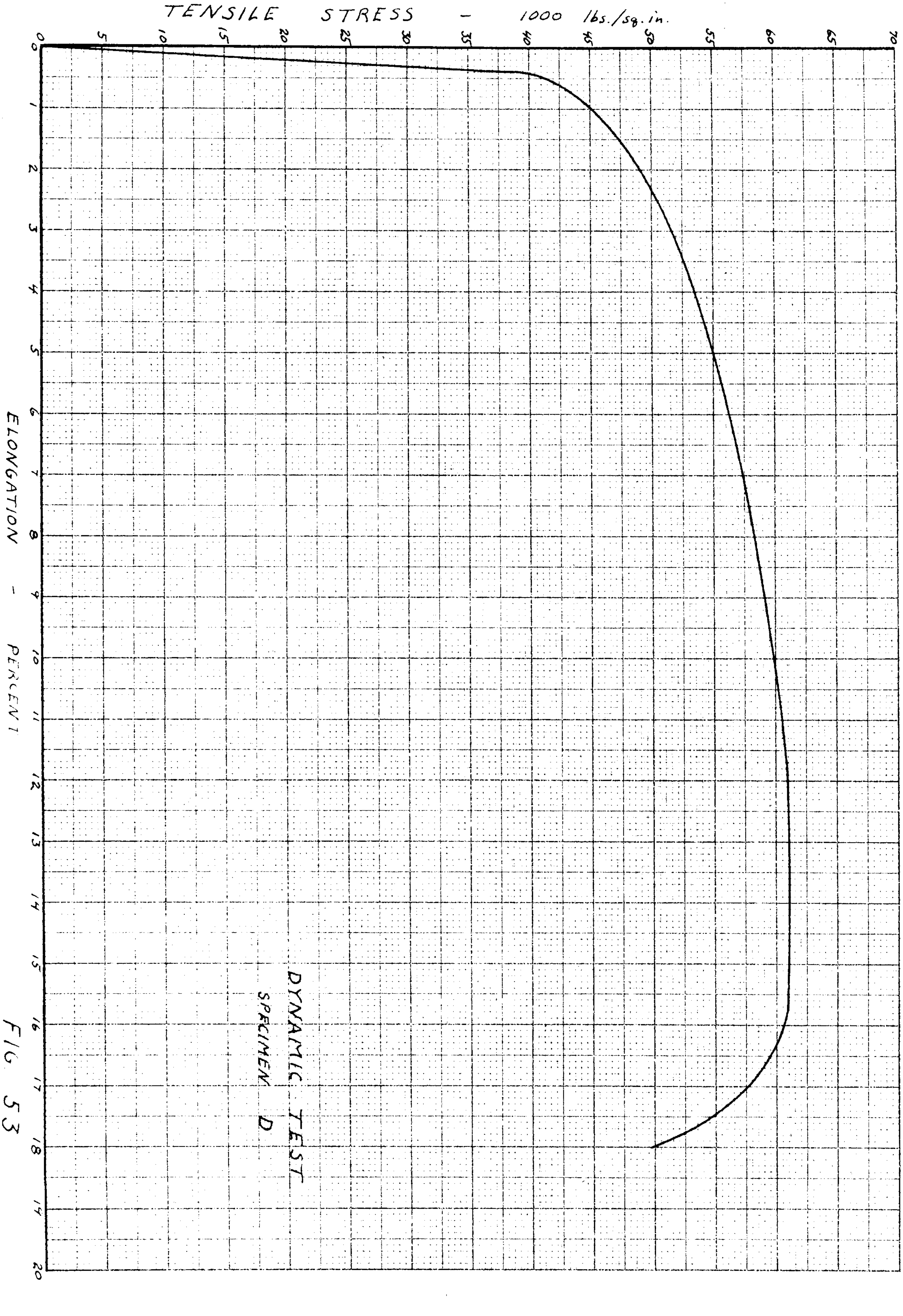
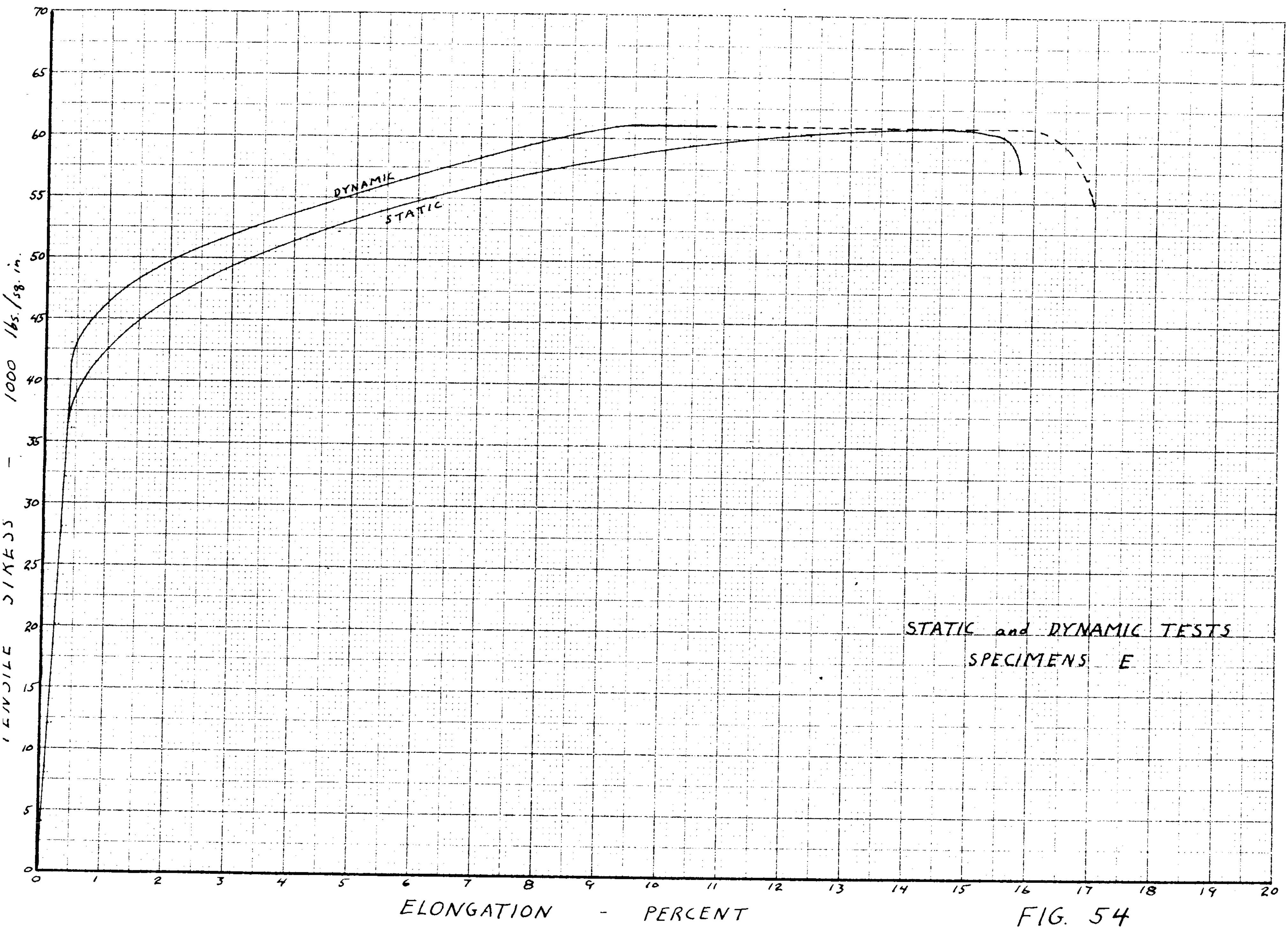

TENSILE STRESS - 1000 lbs./sq.in.
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
ELONGATION - PERCENT
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
DYNAMIC TEST
SPECIMEN D

FIG. 53



TENSILE STRESS - 1000 lbs./sq. in.
DYNAMIC
STATIC
STATIC and DYNAMIC TESTS
SPECIMENS E
ELONGATION - PERCENT

FIG. 54

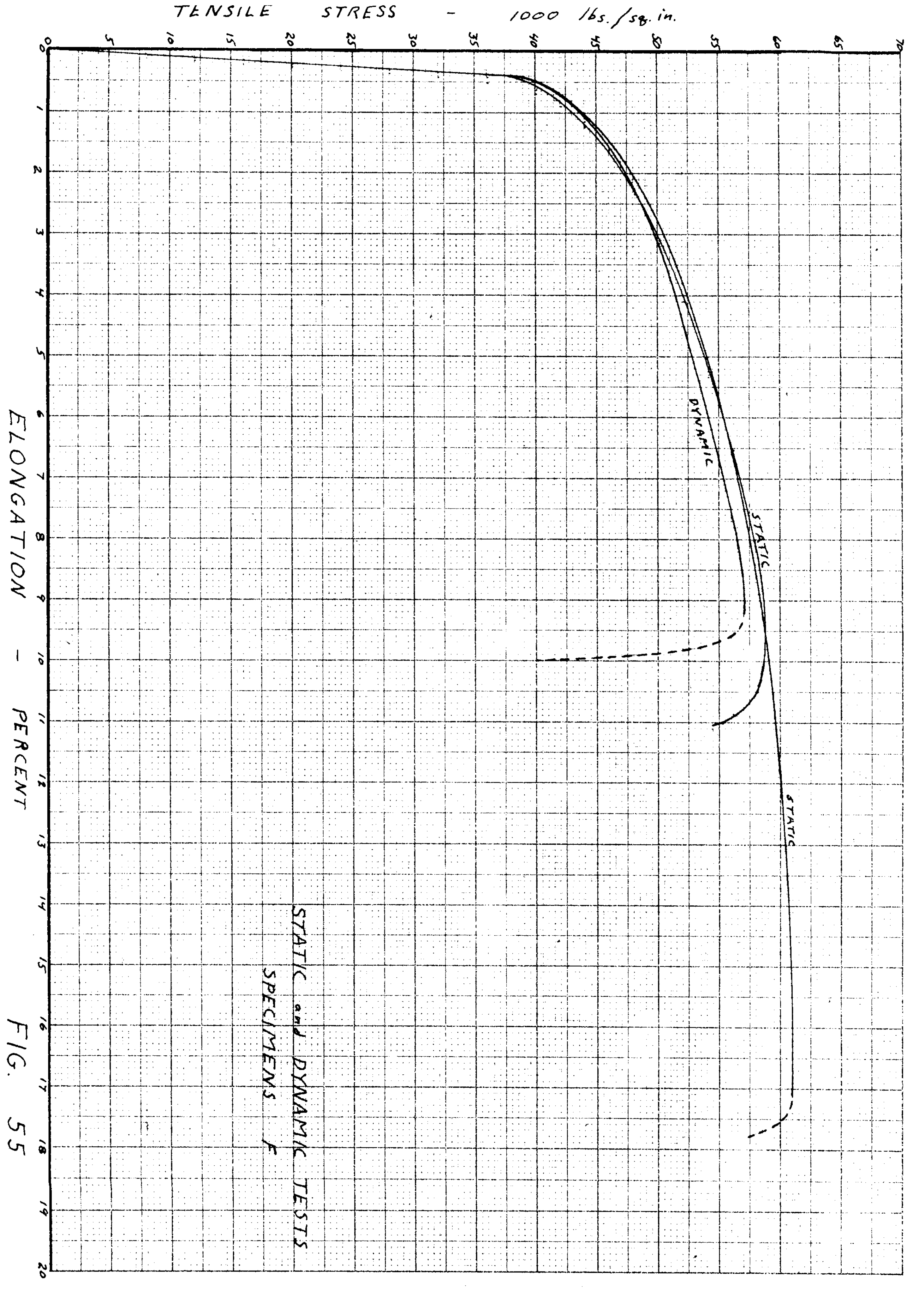
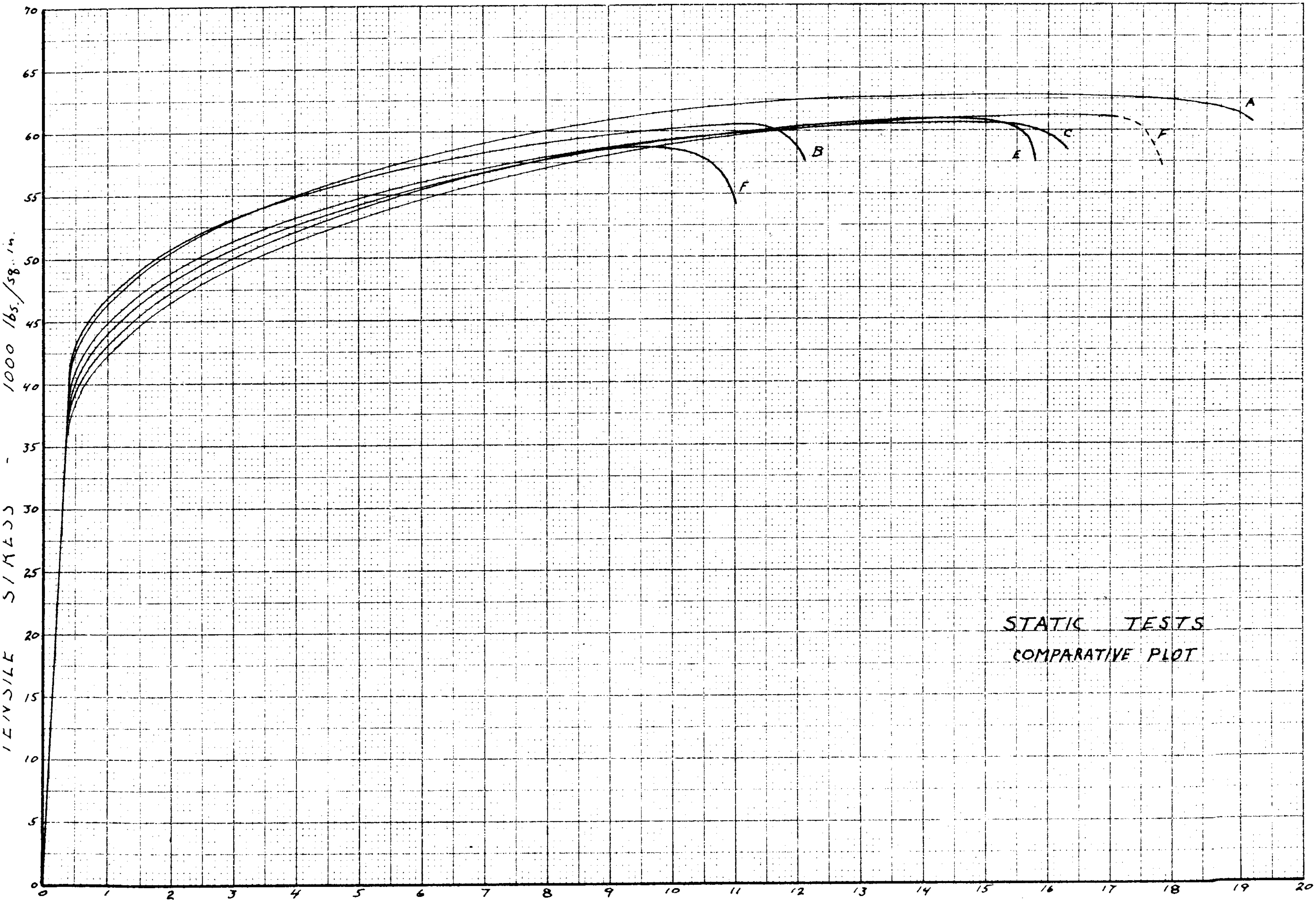
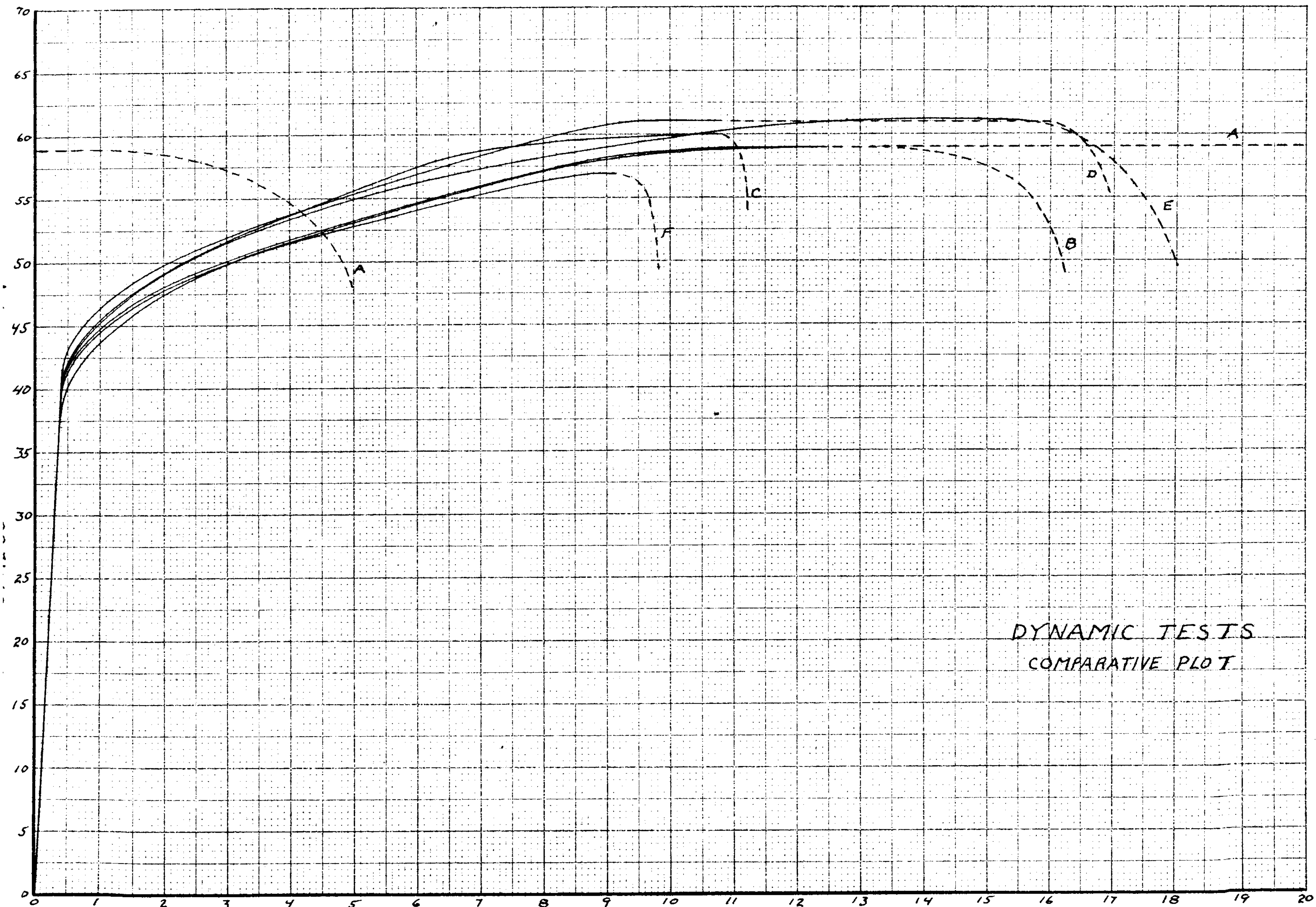

TENSILE STRESS - 1000 lbs./sq. in.
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
ELONGATION - PERCENT
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
DYNAMIC
STATIC
STATIC
STATIC and DYNAMIC TESTS
SPECIMENS F

FIG. 55



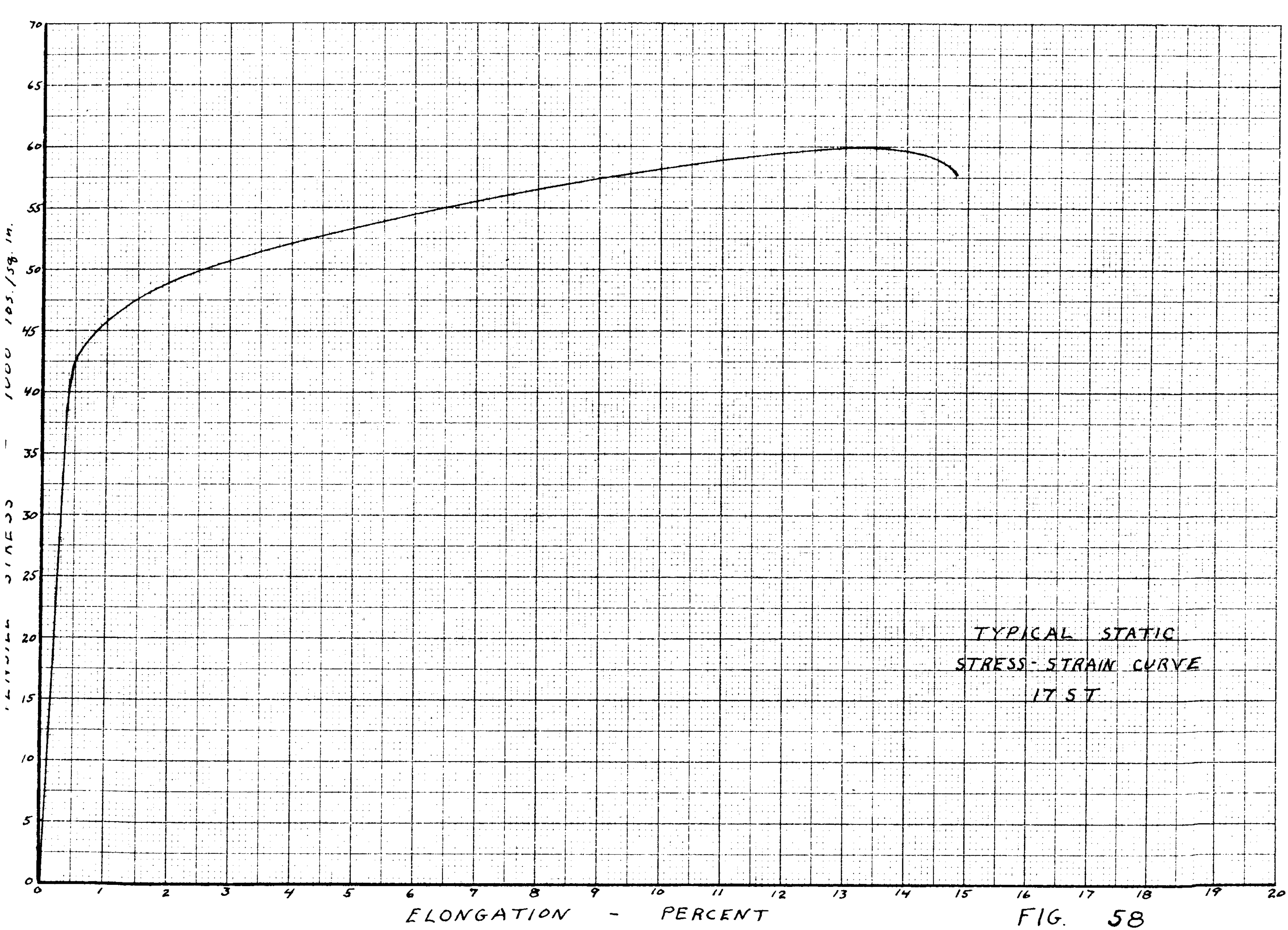
TENSILE STRESS - 1000 lbs./sq. in.
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
ELONGATION - PERCENT
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
A
B
C
E
F
F
STATIC TESTS
COMPARATIVE PLOT

FIG. 56



ELONGATION - PERCENT

FIG. 57



TENSILE STRESS - 1000 lbs./sq. in.
ELONGATION - PERCENT
TYPICAL STATIC
STRESS-STRAIN CURVE
17 ST

FIG. 58

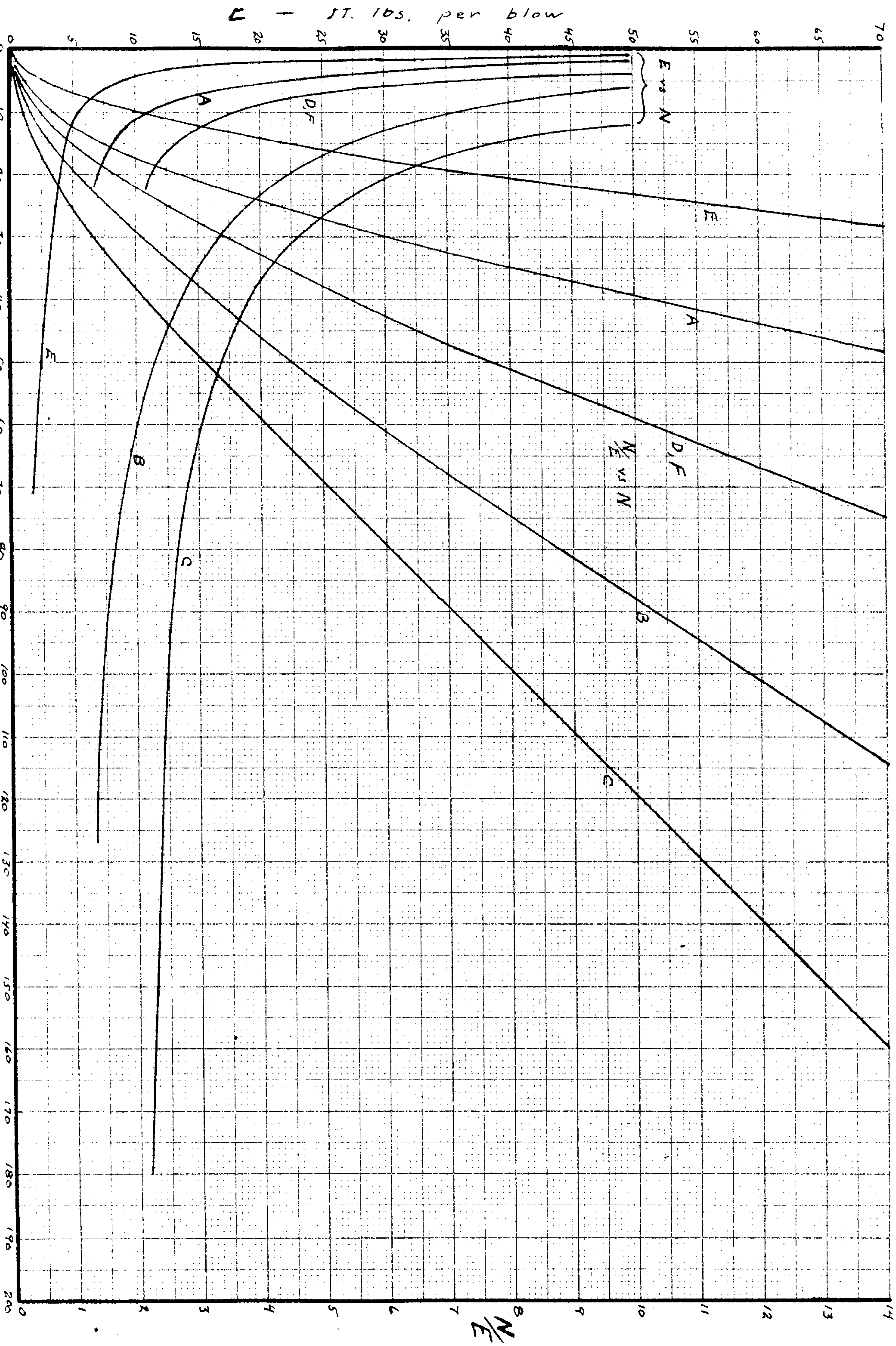


FIG. 59

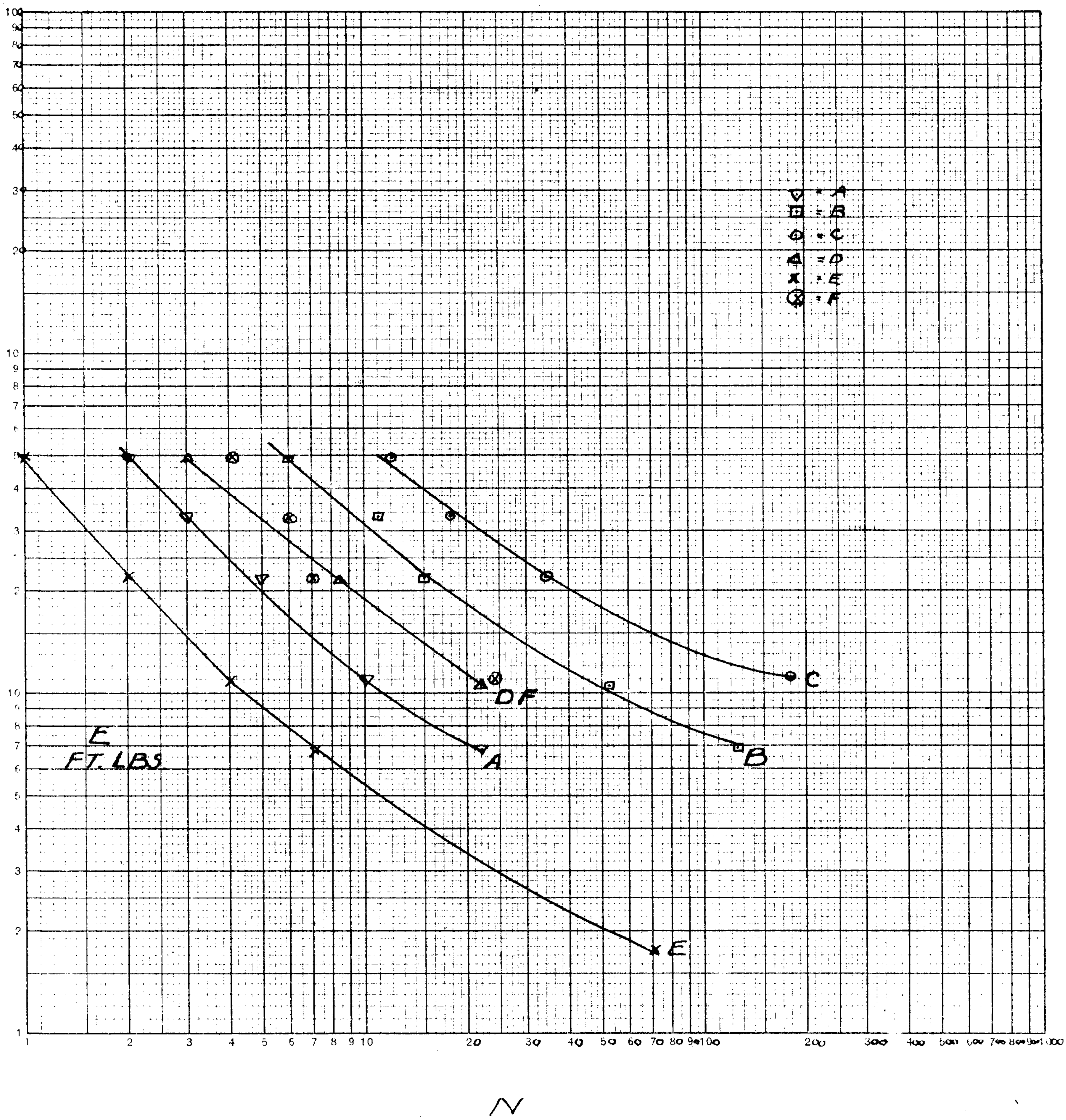


FIG. 60

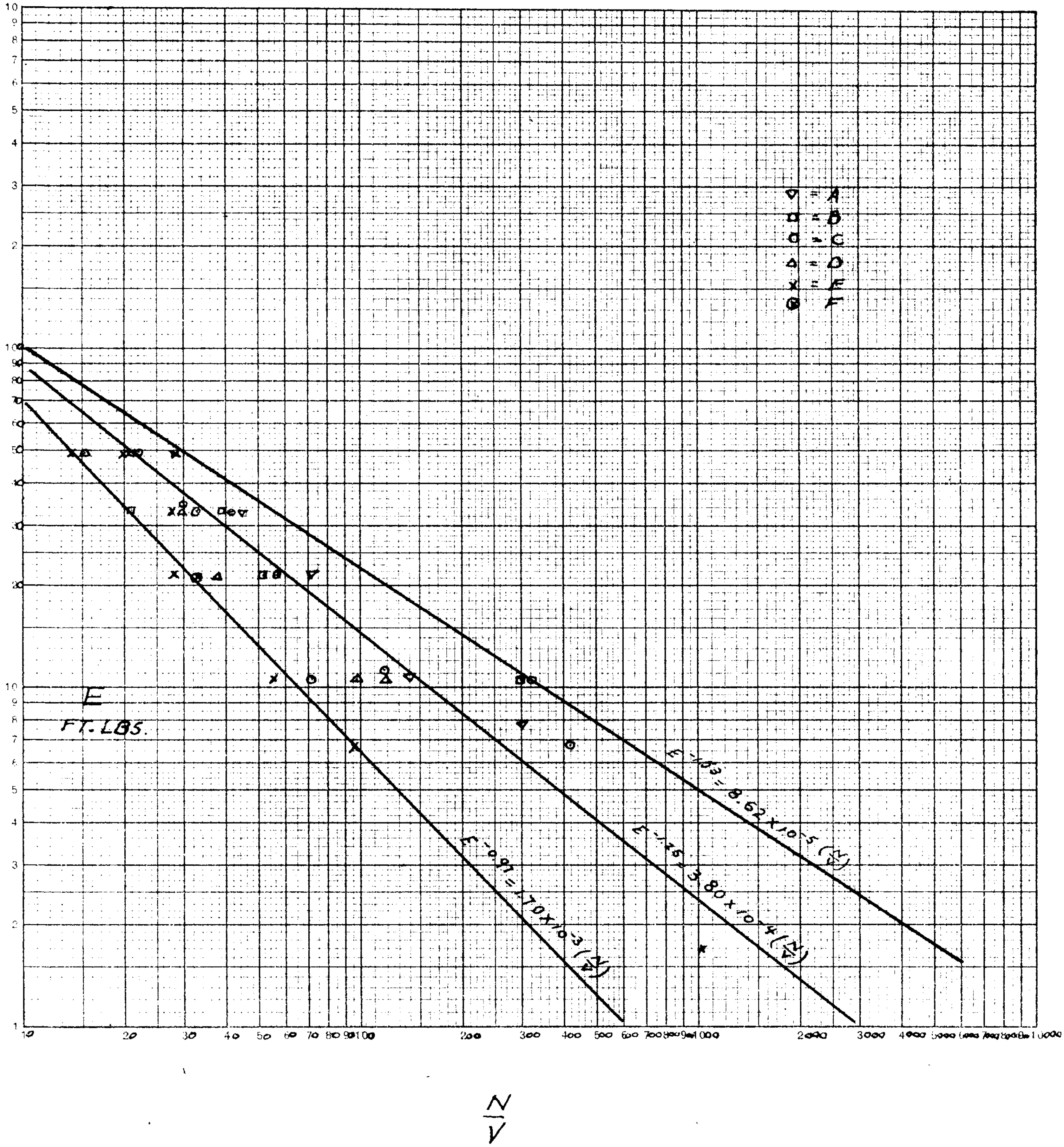
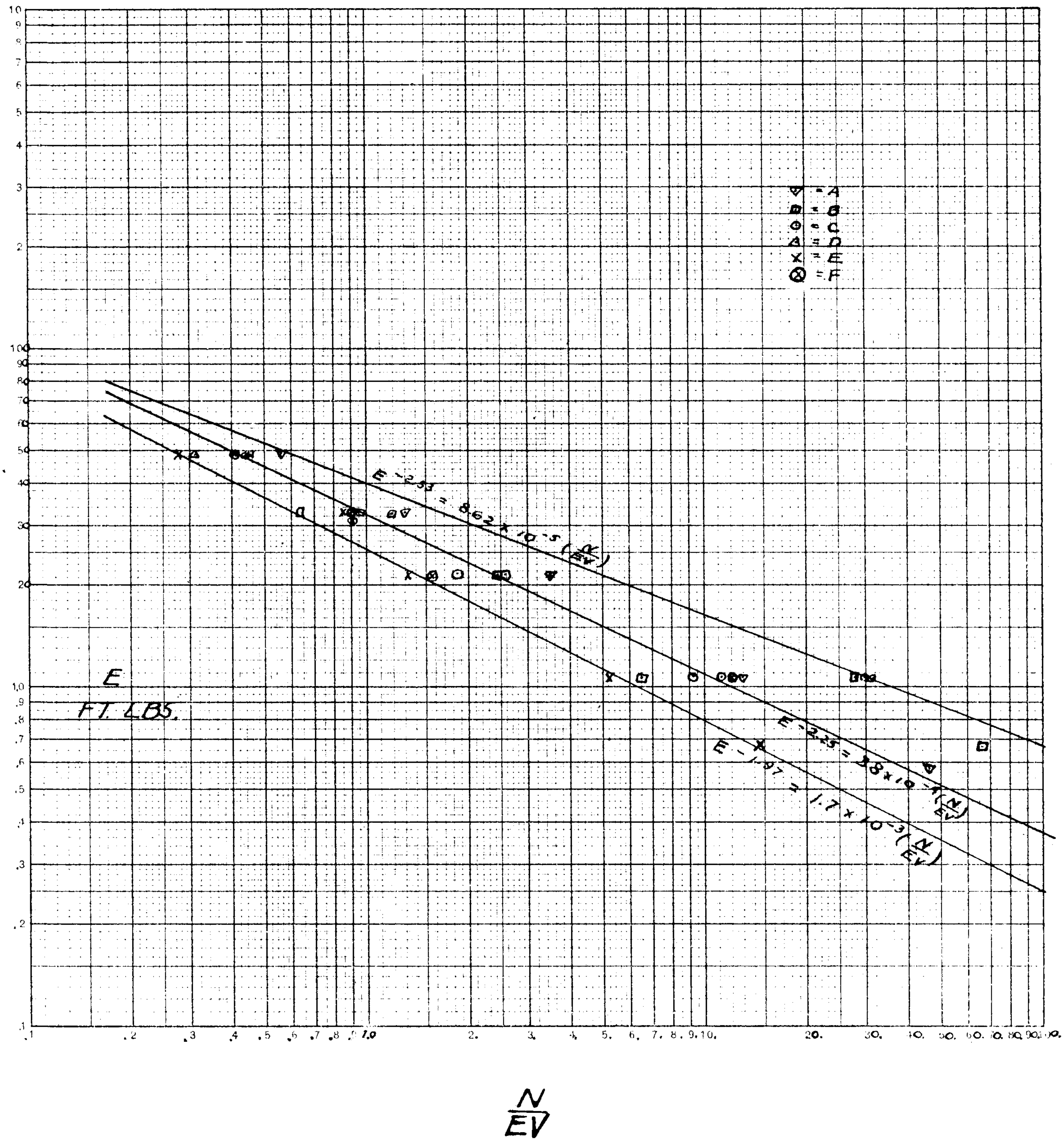
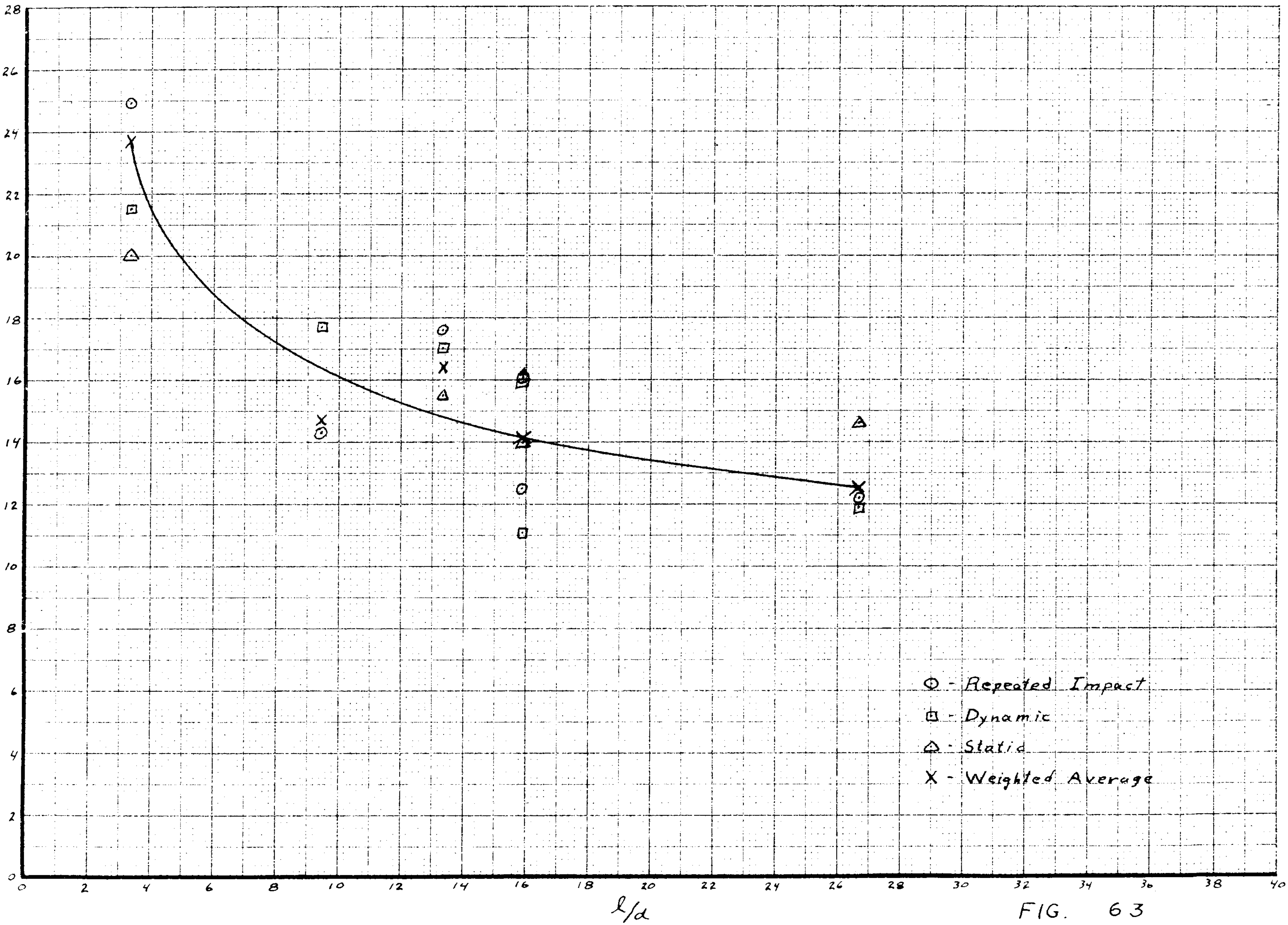

▽ = A
□ = B
○ = C
△ = D
x = E
⊙ = F
E
FT. LBS.
E^-1.03 = 8.62 x 10^-5 (N/V)
E^-1.15 = 3.80 x 10^-4 (N/V)
E^-0.91 = 1.70 x 10^-3 (N/V)
N/V

FIG. 61



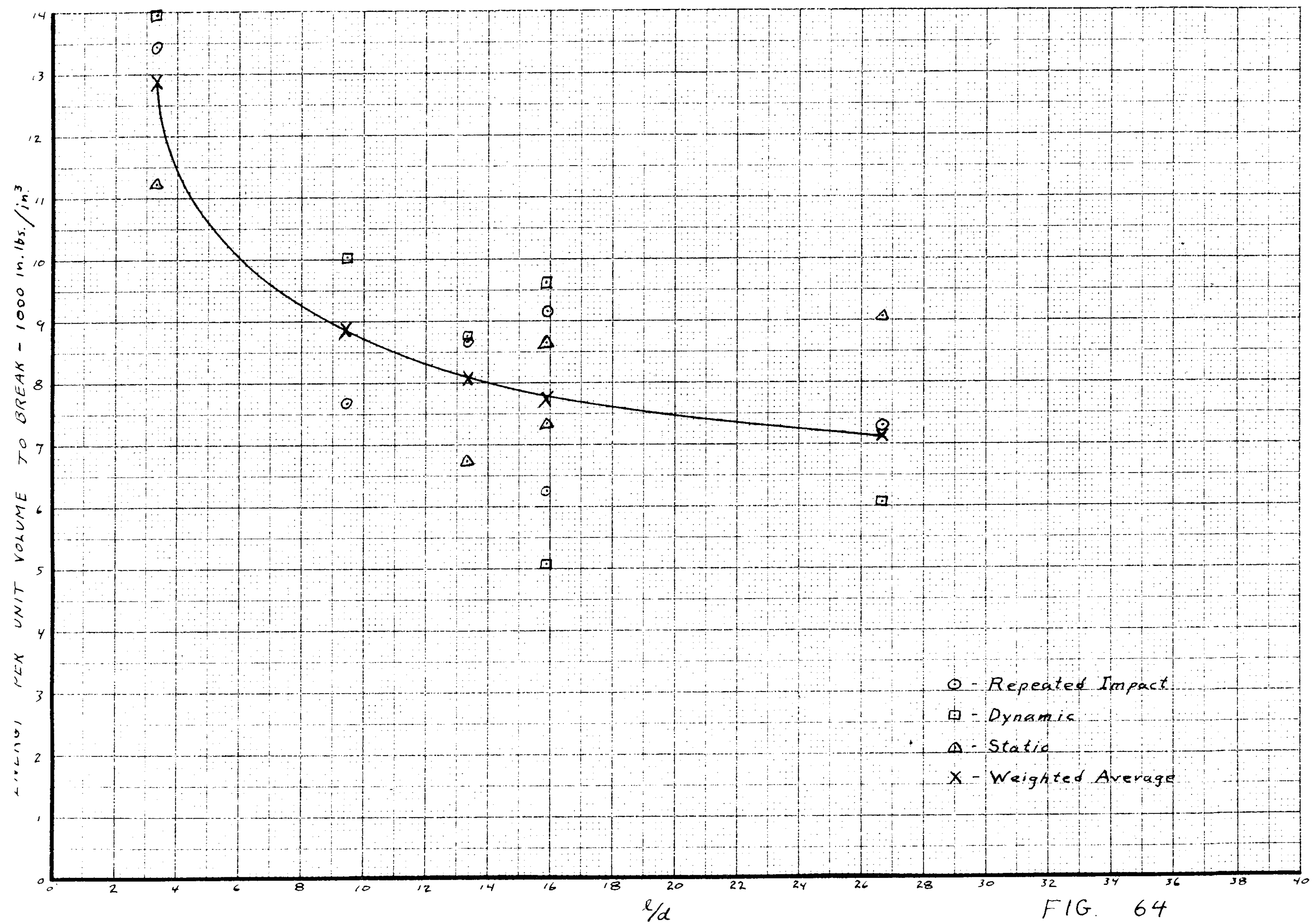
▽ = A
⊡ = B
⊙ = C
Δ = D
X = E
⊗ = F
E
FT. LBS.
$E^{-2.33} = 8.62 \times 10^{-5} \left(\frac{N}{EV}\right)$
$E^{-2.25} = 3.8 \times 10^{-4} \left(\frac{N}{EV}\right)$
$E^{-1.97} = 1.7 \times 10^{-3} \left(\frac{N}{EV}\right)$
$\frac{N}{EV}$

FIG. 62



28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
l/d
⊙ - Repeated Impact
⊡ - Dynamic
△ - Static
X - Weighted Average

FIG. 63



ENERGY PER UNIT VOLUME TO BREAK - 1000 in.lbs./in.3
ℓ/d
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
1
3
5
7
9
11
13
⊙ - Repeated Impact
⊡ - Dynamic
△ - Static
X - Weighted Average

FIG. 64