PROGRESS REPORT

ON

TWELVE INCH FLAT PLATE TESTS

BY

S. T. CARPENTER, W. P. ROOP, N. BARR, E. KASTEN
and A. ZELL

Swarthmore College
Under Bureau of Ships Contract NObs-45521

COMMITTEE ON SHIP CONSTRUCTION

DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH

NATIONAL RESEARCH COUNCIL

ADVISORY TO

SHIP STRUCTURE COMMITTEE

UNDER

Bureau of Ships, Navy Department
Contract NObs-34231

SERIAL NO. SSC-21

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DATE: APRIL 15, 1949

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Washington 25, D. C.

April 15, 1949

Chief, Bureau of Ships
Navy Department
Washington 25, D. C.

Dear Sir:

Attached is Report Serial No. SSC-21 entitled "12 Inch Flat Plate Tests." This report has been submitted by the contractor as a Progress Report of the work done on Research Project SR-98 under Contract NObs-45521 between the Bureau of Ships, Navy Department and Swarthmore College.

The report has been reviewed and acceptance recommended by representatives of the Committee on Ship Construction, Division of Engineering and Industrial Research, NRC, in accordance with the terms of the contract between the Bureau of Ships, Navy Department and the National Academy of Sciences.

Very truly yours,

C. Richard Soderberg, Chairman
Division of Engineering and
Industrial Research

CRS:mh
Enclosure

Preface

The Navy Department through the Bureau of Ships is distributing this report to those agencies and individuals who were actively associated with the research work. This report represents a part of the research work contracted for under the section of the Navy's directive "to investigate the design and construction of welded steel merchant vessels."

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Copy No. 155 -
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Copy No. 159
Copy No. 160 -
Copy No. 161 -
Copy No. 162 -
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PROGRESS REPORT

NAVY BUSHIPS CONTRACT NObs-45521

PROJECT SR-98

12 INCH FLAT PLATE TESTS

FROM: SWARTHMORE COLLEGE, SWARTHMORE, PA.

SCOTT B. LILLY, DIRECTOR OF RESEARCH

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

ABSTRACT

This report contains an account of the testing of the "A", "C", "Bn", "Br", "Dn" and "E" steels, six of the so-called pedigreed steels that were investigated under OSRD and Navy Department contracts. The tests described are tension tests run at various temperatures on specimens 24" long, 12" wide and 3/4" thick, having a central internal notch one-quarter of the width of the plate with ends of the notch 0.010 inch wide made by a jeweler's hacksaw. The load was applied in the direction of the rolling. This program was undertaken because it was believed that tests made under standardized conditions would furnish additional information regarding the behavior of these steels, and would provide a standard that could be used to judge the efficacy of tests of small sized specimens adapted for use as acceptance tests.

The report contains tables giving the load at first visible crack, at maximum load, and at ultimate load, together with the energies computed to those loads. Load-elongation curves for each specimen tested are included, together with diagrams showing maximum load, plotted with temperatures as abscissas, and diagrams showing energy to maximum load plotted with temperatures as abscissas.

The transition temperature zones of these steels based upon the 12" wide plate tests are reported based on energy considerations and on the mode of the fracture.

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

APPENDIX II

PROGRESS REPORT

NAVY BUSHIPS CONTRACT NObs-45521

PROJECT SR-98

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FROM: SWARTHMORE COLLEGE, SWARTHMORE, PA.

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INTRODUCTION

The object of the tests related in this report was to investigate the physical behavior at various temperatures of a large number of 12" wide, full thickness specimens of steel plate. The specimen contains a centrally located internal notch 3" wide terminating with a jeweler's hack saw cut 1/8" long and 0.010" wide (See Figure I-1, Appendix I). All tests were made with tension loading applied in the direction of rolling.

The physical behavior of the steels with respect to maximum loads, strain energy, and mode of fracture was investigated with the principal purpose of establishing transition temperatures based upon 12" wide, 3/4" thick specimens.

The steel tested has been studied by several laboratories and has been designated as "A", "C", "Br", (B as rolled), "Bn" (B normalized), "Dn" (D normalized), "E" and "Q". These were 6' x 10' plates, all 3/4" thick except "Q" steel which was 5/8" thick. All but "Q" have been tested.

The chemical analyses of the steels tested, as previously given on page 35 of the Pennsylvania State College Report[3*], are as follows:

3*. Numerals refer to references in Bibliography

CHEMICAL ANALYSES

Steel	C%	Mn%	P%	S%	Si%	Al%	Ni%	Cu%	Cr%	Mo%	Sn%	N_2%
A	.26	.50	.012	.039	.03	.012	.02	.03	.03	.006	.003	.004
Br	.18	.75	.008	.030	.07	.015	.05	.07	.03	.006	.012	.005
Bn	.18	.73	.011	.030	.04	.013	.06	.08	.03	.006	.015	.006
C	.24	.48	.012	.026	.05	.016	.02	.03	.03	.005	.003	.009
Dr	.22	.55	.013	.024	.21	.020	.16	.22	.12	.022	.023	.006
Dn	.19	.54	.011	.024	.19	.019	.15	.22	.12	.021	.025	.006
E	.20	.33	.013	.020	.01	.009	.15	.18	.09	.018	.024	.005

The fullest use has been made of reports from the University of California[1], the University of Illinois[2], and Pennsylvania State College[3] as an aid to instrumentation and as an aid in the preliminary determination of the transition temperature.

INSTRUMENTATION

Elongation Measurement: To determine strain energy it was necessary to measure the elongation of the test specimens. The gage length was established as three-quarters of the width of the plate, or 9", with the ends of the gage length 4½" above and below the notch. The instrument developed permitted a determination of the elongations of the plate in both the elastic and plastic range. Bakelite SR-4 gages are used in these instruments. The elongations were measured over twelve separate gage lines. Five of the gage lines were on each of the 12" faces of the plate and two of the gage lines were on the edges. The five gage lines on the face of the plate were located as follows: one at the longitudinal centerline of plate, two 1½" either side of the centerline, and two 3 3/4" either side of the centerline. The elongation for each gage line was determined separately. The instruments used and the details of mounting them are fully described in Appendix I.

Preparation of Notch: Careful attention was given to the preparation of the notch. The accepted procedure at all laboratories where wide full-thickness plate tests had been made was to use a jeweler's hack saw to establish the acuity of the notch. To provide uniform acuity, the width of the last 1/8 of an inch of the notch on both sides of the internal notch was specified to be 0.010 inch. See layout of notch in Appendix I. A jig-saw was utilized to make the jeweler's hack saw cut. This machine is described in detail in Appendix I.

Temperature Control Chamber: The temperature control chamber was made of Plexiglas, so that the specimen and instruments would be visible at all stages of the test. Strip heaters were installed to give temperatures above that of the laboratory. Two fans at the top of the box insured the circulation of the heated air. Cooling was obtained by blowing air over dry ice and conducting this cool air to the Plexiglas box by insulated ducts. This installation is described and illustrated in Appendix I.

Measurement of Temperature: The temperature was determined by the use of thermocouples. Three thermocouples are mounted on each specimen, one in the 3/4" drill hole in the center of the plate, one $5\frac{1}{2}$" above the notch in the center of the plate, and the third one located 1/8" from the end of the notch immediately above the junction of the standard and jeweler's hack saw cuts. A fourth thermocouple determined the ambient temperature within the box. A complete description of the instrumentation with photographs of the various pieces of apparatus is contained in Appendix I.

The temperature at the 3/4" drill hole has been used in interpreting all tests.

SPECIMEN IDENTIFICATION

The locations of the specimens in the 6' x 10' plate are shown in the upper left-hand corner of the Figures giving load and energy data for each steel. Upon the arrival of the 6' x 10' plates, they were placed in a rack, each slot of which was numbered. Therefore, the number A-18-8 means that it is the 12" wide, 24" long specimen from the plate of "A" steel racked in slot 18, and its position within the 6' x 10' plate was No. 8. This method of cutting the plate gives eight specimens from the outside edges of the plate, four specimens in the central area of the plate, and eight specimens for the intermediate positions in the plate for a full size 6' x 10' plate.

TESTING PROCEDURE

The general method of testing was to load the specimen to 10,000 lbs. and determine the initial readings of the Elongation Gages. The load was then increased to 190,000 lbs. and the gages read. The load was then reduced to 10,000 lbs. and the initial readings were checked. The test was then started by increasing the load to 190,000 lbs. and proceeding from this load by load increments which produced approximately equal steps of deformation as measured by the edge gages. The total load and the elongation on all gage lines was then determined. During every series of elongation readings the pump of the testing machine was cut off. If the load on the specimen fell off due to plastic deformation, high and low load readings were made. In plotting load-elongation curves the high load has been used.

Load-elongation curves for each specimen are given in Appendix II.

"A" STEEL

Figure 1 shows the fracture of all 27 specimens of the "A" steel. It is noteworthy that fractures of the "A" steel were usually either 100% shear or 100% cleavage failures. Attention should also be called to the symmetry of the fractures. The mode of fracture, cleavage or shear, was very similar on both sides of the notch except for six specimens where a shear failure in a single plane occurred on one side and a double plane shear failure occurred on the other side of notch. Shear failures progressed outward from each end of the notch at the same rate.

Table 1 gives the load and the energy in inch-lbs. to the first visible crack, to maximum load, and to failure. It also gives the temperature and the type of failure in terms of the per cent of shear failure within the 9" net width. Table 2 shows in tabular form the data on energy to maximum load obtained at the University of California[1] on 12" wide plates.

Figure 2 shows the maximum loads plotted as ordinates with temperatures as abscissas. In Figure 3, energies to maximum load are plotted as ordinates with temperatures as abscissas. The data obtained at the University of California[1] on plates 12" wide are superimposed on the Swarthmore data. Figure 4 is a plot of the percentage of shear failure in the various specimens of "A" steel.

The decision to include data on load and energy to the first visible crack deserves some explanation. It was visually observed that the first sign of fracture generally occurred at the mid-thickness of the plate. The load to produce the visible crack varied only slightly with the specimen for a given type of steel and seemed to be independent of the type of fracture which occurred later.

"C" STEEL

Type of Fracture: The behavior of the "C" steel was very erratic. The fractures of many of the "C" steel specimens are shown in Figure 5. There are instances of cleavage fracture followed by shear fracture, cases of shear fracture followed by cleavage fracture, and other cases where cleavage is followed by shear which is followed in turn by cleavage fractures. These mixed types of fracture occur over wide ranges of temperature. The fractures in almost every specimen were symmetrical about the centerline and had the characteristic "thumbnail".

Table 3 gives the load and the energy in inch-lbs. to the first visible crack, to maximum load and to failure. It also gives the temperature and the type of failure in terms of the per cent of shear failure. Table 4 shows the data on energy to maximum load obtained at the University of California[1] on 12" wide plates.

Figure 6 shows the maximum loads as ordinates and Figure 7 shows the energies to maximum load as ordinates, with temperatures as abscissas in each case. Again, the data obtained at the University of California[1] on plates 12" wide are superimposed. Figure 8 represents a plot of the per cent of shear failure observed in each specimen. The abscissas in these curves are temperatures and the ordinates are percentages of shear failure computed on the basis of the net width of 9".

It is of great interest to note that there are often two load maxima in the load elongation curves. Attention is called to Figures 4C, 5C and 9C in Appendix II illustrating this phenomenon. The first maximum is the load at which a cleavage fracture occurs, extending over only a part of the cross-section. When this type of fracture occurs the load drops, and if the load is increased again there is a second maximum. This may be at a load higher or lower than the first. The specimen may then fail by cleavage or continue to yield.

"Bn" STEEL

Nineteen specimens of "Bn" steel were tested, their fracture surfaces being shown in Figure 9. All these fractures started with an initial shear zone, although in the case of specimens 1 and 7 the zone was small. Examples of the initial shear zone may be seen on the right halves of specimens 4 and 11 where the small dark patches at the end of the notch indicate the presence of a shear area.

Table 5 gives the data for the "Bn" steel.

Figure 10 gives the maximum loads as ordinates, Figure 11 the energies to maximum load as ordinates, and Figure 12 the per cent shear, with temperatures as abscissas in each case. Data taken at the University of California[1] are given in Table 6 and the values are plotted in Figure 11.

The "Bn" shear specimens exhibited along their fracture surface striations composed of many small "terraces" mainly to be found around the mid-thickness of the specimen. These "terraces" interrupt the shear surface as flat areas parallel to the specimen surface and are of the order of 1/64" wide. It can be noted at this time that the "Br" steel when fractured exhibited definite striation bands with a middle zone appearing coarser in texture. The "terraces" mentioned for "Bn" steel are undoubtedly associated with these characteristics found in "Br" steel.

"Br" STEEL

The fracture surfaces of the 16 specimens of this steel as shown in Figure 13 are characterized by cleavage fracture of a very coarse appearance, which has not been observed in the other project steels tested at Swarthmore. The shear mode of failure is also unique in that it almost always exhibited a double striation along the fracture, as is shown for example, in Figure 14. The word striation has been used here in an attempt to avoid misleading the reader as to the nature of this effect, which has been variously called lamination, banding, fissuring, etc. by visitors to the Swarthmore laboratory. In Figure 14, three zones of approximately equal thickness may be seen, giving the fracture the appearance of a sandwich. Near the notch localized separation characteristics of laminations may be noted.

Table 7 gives the data for Br steel. The maximum loads are plotted as ordinates in Figure 15, energies to maximum load as ordinates in Figure 16, and per cent shear as ordinates in Figure 17, with temperatures as abscissas in each case. The energy plot also includes the data taken at the University of California[1], and shown in Table 8.

"Dn" STEEL

Figure 18 presents the fracture surfaces of the nineteen "Dn" specimens, six of which are all shear, nine all cleavage (except for an initial shear zone), and four specimens (Nos. 2, 8, 12, 17) have mixed fractures changing from an initial shear to a cleavage failure. In the case of specimen No. 17, one side remained shear while the other altered from shear to cleavage. Specimens No. 2 and No. 8 were very similar in their performance, each starting to fracture with a single shear surface on one side of notch and a double shear surface on the other side of notch. These two specimens fractured in the cleavage mode after the maximum load was reached. Table No. 9 gives the Swarthmore data for "Dn" steel. University of Illinois [2] data for energy to maximum load are shown in Table 10.

Figure 19 shows the maximum loads plotted as ordinates, Figure 20 the energies to maximum load as ordinates, and Figure 20 the per cent shear as ordinates with temperatures as abscissas in each case. University of Illinois[2] data are superimposed on the Swarthmore data in Figure 20

"E" STEEL

The behavior of the 16 specimens of "E" steel is quite erratic, although not to the degree found in "C" steel. It is interesting to note that only these two steels were characterized by "thumbnails" adjacent to the notch. These "thumbnails" are quite evident in Figure 22 which shows the fracture surfaces of "E" steel. The formation of the "thumbnails" was accompanied by a sharp snap clearly audible to the test crew, together with an abrupt drop in load of 20,000 to 50,000 lbs.

Specimen E-36-2, shown in Figure 23, is of interest. To the test crew it seemed that the cleavage fracture occurred "instantaneously" over the entire cross-section. Subsequent examination of the fracture surface showed the familiar "thumbnails" which may indicate that the crack front paused for a very small increment of time and then proceeded to complete failure.

Table No. 11 gives the Swarthmore data for "E" steel. University of Illinois[2] data for energy to maximum load are shown in Table 12. Figure 24 gives the maximum loads plotted as ordinates, Figure 25 the energies to maximum load as ordinates with University of Illinois data superimposed, and Figure 26 the per cent shear as ordinates with temperatures as the abscissas in each figure. By a comparison of the latter two figures with Figures 7 and 8 for "C" steel, it appears that the "C" steel is somewhat more erratic than "E" steel in both its energy-absorbing and per cent shear characteristics.

GENERAL DISCUSSION

A. Types of Failure:

Generally specimen fracture occurred in two extreme modes - cleavage and shear; however, the following sequences of fracture as fracture progressed from the notch were also observed in individual specimens: cleavage to shear, shear to cleavage, cleavage to cleavage, cleavage - shear - cleavage, and shear - cleavage - shear. The shear failures were of two types, one of which had a single surface and the other a double surface. Cleavage fractures exhibited a sparkling granulated surface while the shear fractures appeared dull.

Photographs of the grids of the specimens having the lowest and highest energy absorption tested at Swarthmore are shown in Figures 27 and 28 respectively. Figure 29 depicts a cleavage - shear - cleavage fracture as exemplified by specimen C-24-8.

The appearance of the fracture as based upon the per cent shear was estimated as follows: the sum of the lengths of shear tears on both sides of the notch was divided by the total length of fracture surface. It must be noted that the latter length is not always the 9" of net cross section since some ductile tears do not proceed straight across the specimen but make an angle to the transverse axis such as shown for specimen Dn-33-20 in Figure 28.

B. Specimen Behavior During Testing:

A number of interesting observations were made of specimen behavior during the program. The first to be spoken of is the vibrational response of the steels, which was first noticed in the following manner. The electrical instrumentation for measuring elongation was composed of the conventional setup of SR-4 Bridge Balance Unit and Strain Indicator, and it was the latter which was used in setting points on the load-elongation curve, the load being taken as the dependent variable and the elongation as the independent variable. While loading a ductile specimen the needle of the Strain Indicator would rotate uniformly over the meter face. After a number of experiments had been run, it was definitely established that cleavage fracture of a specimen was almost always preceded by one of two different motions of the needle.

The first type consists of a "stepping" or jerking motion of the indicator needle, always in the same direction. In the second type, the needle progressed with an oscillatory motion of three or four cycles per second superimposed on the steady movement of the needle during increasing load. Such oscillation was intermittent in the early stages preceding cleavage fracture, but became continuous as the break was approached. The amplitude of this vibration is estimated to be of the order of .0005" over the 9-inch gage length.

In some specimens these motions stopped suddenly and such specimens ultimately failed by shear. It is considered very probable that the inertia of the moving parts of the galvanometer was sufficiently large to mask higher frequency components coming from the gage. The SR-4 gages were of the static type and hence the gages could also mask the response.

The characteristic behavior described above was not found in those cleavage failures which occurred after a ductile maximum load had been passed.

The possibility was considered that the vibration might be magnetically induced in the gages by changes in the specimen. To check this, a coil of 1000 turns was mounted around the specimen, its leads being fed into an oscilloscope. No observable effects were indicated by this method even though the input condenser of the oscilloscope for some tests was shorted out to be certain that very low frequency voltage changes were not being blocked. The conclusion of this approach was that the magnetic effects, if any, have such a low time rate of change that the voltage induced by them was too minute to investigate in such a manner.

The second observation of specimen behavior is what might be called delayed fracture. It is convenient to discuss this in terms of testing procedure, as follows. When the elongation readings at one load were completed, an additional load was applied until the next increment of elongation was reached, at which point the pump of the testing machine was cut off and the elongation and thermocouple readings taken. The whole cycle of pumping and reading usually required about two minutes with half a minute needed for reading the 12 elongations. With this in mind, it is interesting to note that 13 specimens (slightly over 10% of the total tested) failed by cleavage after the pump was cut off, at which time the load would be slowly falling. These specimens fractured shortly after the maximum load had been reached and at a load lower than the maximum by five to ten thousand pounds.

The third observation concerning specimen behavior may well be closely related to the above. This concerns those specimens which failed by cleavage while reloading the specimen after completing a set of readings, fracture taking place before the previous maximum load had been reached. The five specimens in this group were C-24-19, Bn-21-8, Bn-21-14, Br-22-9, and Dn-33-16. (See Figures 5,9,13, 18, and load-elongation curves, Appendix II.)

The last consideration of specimen behavior is the "double maxima" observed for certain specimens of "C" and "E" steels. This effect can produce considerable discrepancies in the energy to maximum load. For example, specimen E-36-10, Figure 6E, Appendix II, has a difference of only 300 lbs. in the two peak loads; yet the energy to the second maximum load was almost 2½ times the energy to the first maximum load. Although it is possible to make the energy **versus** temperature plots take on a more desirable appearance by using one or the other value, the points in the energy-temperature plots have been plotted strictly in accordance with the numerically greater load.

C. Transition Temperatures:

Criteria for transition temperature are varied and depend largely upon the person making the interpretation. Many experimentors believe in drawing the best curve through the energy (to maximum load) temperature data and using certain points on this curve to define the transition temperature. In this report we have avoided drawing energy-temperature curves, since the scatter and weighting of data will rule the type of curve.

At this time it appears that decisions relative to transition temperature can be realistically discussed only by considering the data for each steel separately. The transition temperatures are stated as a zone of temperature.

"A" Steel - Fractures with a low energy absorption occurred at a temperature as high as 58°F. High energy levels were observed for temperatures down to 42°F. The transition temperature for "A" steel on the basis of these data has been judged to be in a zone between 42°F and 58°F. (See Figure 3).

The transition temperature zone based on appearance of the fracture as evaluated in terms of the per cent of shear also lies between 42°F and 58°F. (See Figure 4).

"C" Steel - Fractures with a low energy absorption occurred at a temperature as high as 90°F and a high level of energy absorption prevailed for temperatures down to 98°F if test No. 8 is omitted. Hence these data would place the transition temperature of "C" steel in a zone from 90°F to 98°F. (See Figure 7).

The transition temperature zone based on appearance of the fracture as evaluated in terms of the per cent of shear lies between 90°F and 116°F. (See Figure 8).

"Bn" Steel - Neglecting specimens No. 3 and 6 because No. 3 is overweighted by specimens 4, 10, 11 and 15 and No. 6 is overweighted by specimens 2, 9, 14, and 18, the transition temperature appears to be in a zone between 25° to 30°F. (See Figure 11).

The transition temperature zone based on appearance of the fracture as evaluated in terms of the per cent of shear also lies between 25° and 30°F. (See Figure 12).

"Br" Steel - Omitting specimen No. 11, the transition temperature for this steel based on the energy to maximum load appears to be at about 12°F; however, it is thought that a zone ranging from 10°F to 15°F is more likely. (See Figure 16).

The transition temperature zone based on appearance of the fracture as evaluated in terms of the per cent of shear also lies between 10°F and 15°F. (See Figure 17).

"Dn" Steel - From the energy data, high energy absorption occurs for a temperature as low as 10°F, and low energy absorption occurs for a temperature as high as 16°F. Hence the transition temperature zone has been interpreted as being between 10° and 16°F. (See Figure 20).

The transition temperature zone based on appearance of the fracture as evaluated in terms of the per cent of shear lies between 15° and 25°F. (See Figure 21).

"E" Steel - On the basis of energy data, the high level of energy is judged to have a lower temperature limit at 92°F. 92°F also marks the upper temperature limit at which low energy absorption occurred. The lower limit of the transition zone has been deemed to be at about 70°F. Hence the transition temperature has been estimated to lie in a zone between 70°F and 92°F. (See Figure 25).

The transition temperature zone based on appearance of the fracture as evaluated in terms of the per cent of shear appears to lie between 70° and 100°F. (See Figure 26).

The above findings with reference to transition temperature are summarized in the following table.

TABLE 13

Summary of Transition Temperature Zones

Steel	Based on Energy Absorption to maximum load	Based on Percentage of Shear
A	42° to 58°F	42° to 58°F
C	90° to 98°F	90° to 116°F
Bn	25° to 30°F	25° to 30°F
Br	10° to 15°F	10° to 15°F
Dn	10° to 16°F	15° to 25°F
E	70° to 92°F	70° to 100°F

The mechanism by which steel either fails in the cleavage or shear mode is not clearly understood. If identical homogeneous steel specimens were subjected to carefully controlled tests it might be expected that the transition from shear to cleavage fracture would occur at a single temperature rather than in a temperature zone. Physical discontinuities are usually accompanied by sharp breaks in performance characteristics. The "Br" steel illustrates the point in question, test specimens 5, 10, and 12 exhibiting shear failure, while specimens 2 and 7 indicate cleavage failure, when all of these specimens were tested at approximately the same temperature.

D. Effect of Temperature on Maximum Load:

In making a comparison of maximum loads it must be realized that for a cleavage failure the fracture load is usually the maximum load, while the maximum load for a ductile specimen is not the fracture load. In general the average maximum load is approximately 50,000 pounds lower in the cleavage mode than in the shear mode.

A summary of average maximum loads for those specimens failing in the completely shear or completely cleavage modes for the various steels is shown in the following table.

TABLE 14

Steel	Column 1 Average Max. Load in lbs. Specimens failing in 100% Shear	Column 2 Average Max. Load in lbs., Specimens failing in 0% Shear	Ratio of Column 1 to Column 2
A	317,000	268,000	1.18
C	348,000	294,000	1.18
Bn	319,000	286,000	1.11
Br	333,000	288,000	1.16
Dn	346,000	311,000	1.11
E	318,000	264,000	1.20

E. Comparison of Energy to Maximum Load:

The average energies to maximum load for the various steels for specimens which broke by shear and by cleavage are:

TABLE 15

Steel	Column 1 Average Energy to Max. Load for Specimens failing in 100% Shear. In. lbs.	Column 2 Average Energy to Max. Load for Specimens failing in 0% Shear. In. lbs.	Ratio of Column 1 to Column 2
A	95,700	25,500	3.75
C	105,000	38,400	2.74
Bn	122,000	47,800	2.56
Br	131,000	34,300	3.80
Dn	128,000	49,200	2.60
E	99,800	32,000	3.12

It can be noted by comparing the ratios of "shear" to "cleavage" energy in Table 15 with the ratio of "shear" to "cleavage" loads in Table 14, that the ratios of load are more consistent.

The high ratio of energy in the shear mode to energy in the cleavage mode for steels "A" and "Br" may possibly be explained by the presence of laminations in the "A" steel and the striations in the "Br" steel.

An additional complication in comparing energy arises from the occurrence of two peak loads while straining the specimen, of which the first or the second load may be the greater. This is common for steels "C" and "E" and is shown for example in Figures 10C, 11C, 6E and 8E.

F. <u>Variations Due to Location of Specimen in a 6' x 10' Plate:</u>

The tests were planned so that differences due to location of specimens within a 6' x 10' plate could be studied. It was desired to compare the specimens taken from the outer longitudinal zones of a rolled plate with specimens from the center zones of the plate, as well as comparing specimens taken from the same longitudinal zone in the direction of rolling.

The results do not enable any general statements to be made relative to the effect of longitudinal or transverse position of the specimen within the plate. It appears, however, that local variations or inhomogeneities in a plate are likely to have more effect than normal metallurgical and rolling variations within the plate.

As an example of differences in energy absorption, see Figure 16 and note that specimens 9, 11 and 17 of the "Br" steel were all tested at approximately 2°F. A comparison of specimen 9 from the center zone and Specimen 17 from the outside zone shows less energy variation between these specimens than shown by Specimens 9 and 11 taken from the center zone.

On the same figure also note the great differences between specimens 5 and 7 which were taken from the same longitudinal strip. When a small number of specimens exist, a comparison of outside and center specimens is meaningless unless specimens lying in the same longitudinal zone behave consistently alike at a given temperature. Cases of agreement may be noted by comparing specimens 19 and 20, and 10 and 12 on Figure 16. A careful study of all steels shows no consistent performance.

G. <u>Tensile Tests:</u>

The yield point and tensile strength of the various steels were determined by using one 6" wide, 48" long, and 3/4" thick unnotched specimen of each steel. The results are tabulated below.

Steel	Yield Point p.s.i.	Tensile Strength p.s.i.
A	31400	59500
C	37400	67800
Bn	32100	59300
Br	32200	57700
Dn	34300	61300
E	33200	59200

The above values, when compared with transition temperatures, show no relationship between strength and transition temperatures. The average maximum loads tabulated in Table 14 bear a closer relationship to the tensile strength but even here a strict correlation is not achieved.

The comparison of average energy for ductile behavior with tensile strength shows that "Br" steel, having the highest average energy absorption, has the lowest tensile strength.

H. Future Analysis of the Data:

The recorded data may be analyzed and interpreted in various ways. Since the same facts may be seen from different points of view, consequences stemming from a given point of view are left for consideration separately from the facts themselves, and will be the subject of further analysis.

As an index of ductility use has been made of the energy absorbed by the specimen, taken up to the point of the maximum load on the load-elongation curve. In ductile specimens this point is not well-defined, since the curve there is quite flat. Such a curve is given in the report for each specimen and the limit to which the energy value is taken may be chosen by a reader in any way desired. The limits used in the analysis of this report are indicated on the curves.

This choice for the index of ductility was made partly because it has been used in earlier work, but also partly because it is less subject to doubt as to its exact value than the other index which might be used, namely, the energy to fracture. It is recognized that in some design problems energy to fracture may be the significant quantity.

As an index, a value of energy may be preferred to deformation, or to an estimate based on appearance of fracture, because energy is itself pertinent in design and not simply an indicator whose validity must be established by some process of correlation.[4]

The threshold of brittleness also may be chosen in different ways. At a sufficiently high temperature no risk of brittleness exists, but as temperature is reduced, a temperature is reached at which this is no longer true. At lower and lower temperatures the chance of brittle action becomes greater and greater. No need is felt to follow this development to the point where the chance approaches certainty of brittleness, since material certain to act in a brittle mode is useless for structural applications.

However a limit must be set for what is acceptable. For convenience in the work of several laboratories the threshold has been put at the temperature at which the index of ductility has fallen to half its value at the upper level. This does not at all mean that a 50-50 chance of brittle fracture is acceptable in service structures; it leaves the whole question of the prediction of the threshold in service from laboratory tests on a relative basis. The ground for this choice is that the half-level threshold is easier to determine than the more indefinite limit at which the sloping line of transition levels off at the fully ductile value of the index.

Wherever possible, it is preferred to place the threshold at the beginning of transition, the temperature below which ductile behavior is no longer assured.

The reason for this choice is as follows: placing the threshold at half-value of the index overestimates the security in the case of a material whose transition zone covers a wide range of temperatures, or whose transition line slopes moderately and not steeply.

In addition, however, another margin of security must also be provided even if the criterion places the threshold at the point of departure from the upper level, since this point is in itself uncertain. The question is how far above the threshold must we stay to be <u>sure</u> of not going below it.

An analysis by which a line may be fitted to transitional data, and at the same time the tolerance of the threshold measured, has been described in Reference[5]. An analysis of the data in the present report will be made according to the scheme there described and will be separately reported.

CONCLUSIONS

1. The tentative transition temperature zones as found for the various steels is reported as follows, as based on two criteria:

Summary of Transition Temperature Zones

Steel	Based on Energy Absorption	Based on Percentage of Shear
A	42° to 58°F	42° to 58°F
C	90° to 98°F	90° to 116°F
Bn	25° to 30°F	25° to 30°F
Br	10° to 15°F	10° to 15°F
Dn	10° to 16°F	15° to 25°F
E	70° to 92°F	70° to 100°F

2. The ratio of the average maximum loads for specimens failing in 100% shear to the maximum loads for specimens failing in 0% shear was found to be practically constant for all steels tested.
3. The ratio of the average energy for specimens failing in 100% shear to the average energy for specimens failing in 0% shear is variable for the separate steels. A comparison between "Bn" and "Br" indicates a higher ratio for "Bn". This may be due to normalizing.

4. The tensile tests of unnotched specimens indicate no correlation between tensile strength and the transition temperature, energy absorbed, or maximum loads for the notched specimens.

5. The vibrational phenomenon observed in measuring strains for specimens that were later to prove brittle is worthy of further experimental investigation. This may lead to a clue regarding the physical changes prior to cleavage failure.

ORGANIZATION

The investigations were conducted at Swarthmore College in the Structural Engineering Laboratory. The late Scott B. Lilly, Chairman of the Division of Engineering, was the Technical Representative for the Project, and the work was performed under his general direction.

Samuel T. Carpenter, Professor of Civil Engineering, and Norris Barr, Research Associate in Engineering, have been in charge of the technical phases of the investigation. Captain W. P. Roop, USN (ret.), has acted as a technical consultant and has given invaluable assistance.

To a large degree, the success of the instrumentation of this project has been due to the efforts of Ewald Kasten, Mechanician. In addition, Mr. Kasten has directed the shop work, which has been done by the following staff: Theodore Bartholomew, Lawrence Robbins, Arnold Bleiman, Walter Cosinuke, Richard M. Turner, and Robert Vernon.

Adolph Zell has served as a general technician on this project and has assisted in taking all data. John O. Briggs has made the drawings. Frances Shero and Ruth Sommer have assisted greatly in the preparation of the manuscript. Clifford Renshaw, Jr. and Steve Mucha have acted as photographers.

Dr. Finn Jonassen, of the National Research Council, has been a constant adviser.

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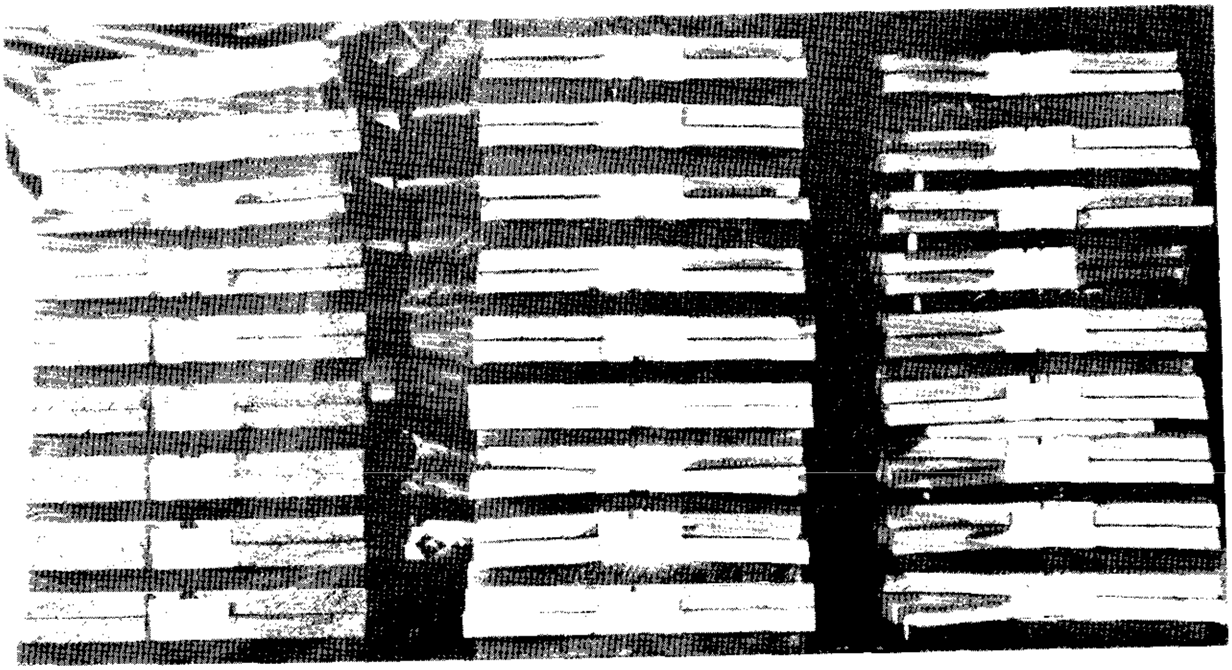


Fig. 1 "A" STEEL

PHOTOGRAPH OF FRACTURE SURFACES

TABLE 1

"A" Steel

TESTS OF SPECIMENS 12" WIDE, 3/4" THICK WITH STANDARD NOTCH

(The notch is 3" wide and has at its extremities a cut 1/8" long and 0.010" wide made with a jeweler's hack saw)

Spec. No.	Temperature °F	Visible Crack Energy in-lbs.	Visible Crack Load lbs.	Max. Load Energy in-lbs.	Max. Load Load lbs.	Failure Energy in-lbs.	Failure Load lbs.	Type of Failure % Shear
A-18-13	31	6,500	247,500	13,800	248,500	13,800	248,500	0
A-19-11	38	1,100	230,000	29,300	283,000	29,300	283,000	0
A-19-2	38	5,800	240,500	22,800	265,400	22,800	265,400	0
A-19-3	38	6,400	245,000	61,600	312,500	61,600	312,500	10
A-18-5	40	4,200	241,000	21,900	270,300	21,900	270,300	0
A-19-9	42	4,000	230,000	95,900	321,600	234,500	60,000	100
A-19-1	42	2,800	230,000	22,400	265,500	22,400	265,500	0
A-19-4	46	1,100	230,000	24,400	256,000	24,400	256,000	0
A-19-12	46	1,200	230,000	117,300	328,000	249,200	131,000	100
A-18-17	48	10,300	235,500	43,100	283,000	43,100	283,000	0
A-18-15	50	11,200	248,000	100,900	319,500	240,900	80,000	100
A-18-6	51	7,800	241,500	91,500	322,000	236,300	67,000	100
A-18-14	52	4,000	234,500	20,700	265,000	20,700	265,000	0
A-18-20	58	8,500	240,000	31,000	274,000	31,200	274,000	0
A-18-7	58	14,100	250,000	92,400	319,500	233,900	68,000*	100
A-18-16	58	8,300	235,000	100,500	319,000	250,600	72,000*	100
A-18-8	59	11,700	243,700	91,100	318,000	232,100	52,000*	100
A-18-11	66	18,700	253,000	104,600	315,000	229,400	58,000	100
A-18-3	66	12,800	243,000	92,800	314,300	234,000	50,000	100
A-18-12	71	17,100	250,000	86,400	314,400	247,100	95,000	100
A-18-18	71	16,600	250,000	104,300	317,000	263,700	15,000	100
A-18-4	71	10,100	243,000	84,700	312,500	232,700	76.500	100
A-18-19	82	10,900	237,600	99,700	314,000	274,000	90,000	100
A-18-1	88	12,600	238,000	82,400	312,200	237,900	50,000	100
A-18-9	88	11,300	240,000	98,100	314,500	255,600	50,000	100
A-18-10	97	15,300	248,500	93,000	314,000	230,200	50,000	100
A-18-2	97	12,400	238,000	92,600	311,500	263,700	50,000	100

* Indicates that this was not the load at fracture, but is given as the last load immediately preceding fracture.

TABLE 2

"A" Steel

TESTS OF SPECIMENS 12" WIDE MADE AT
UNIVERSITY OF CALIFORNIA

NObs - 31222

Spec. No.*	Temp. °F	Energy to Max. Load In-lbs.	Type of Failure % Shear
A-5	(-9)-(-8)	14,400	0
A-41x	7-8	19,000	0
A-4	11	16,300	0
A-42x	19	15,000	0
A-2	31-33	104,000	26
A-3	50	96,000	100
A-1	86	98,000	77

* These are the designations of plates assigned by the University of California as described in their final report.[1]

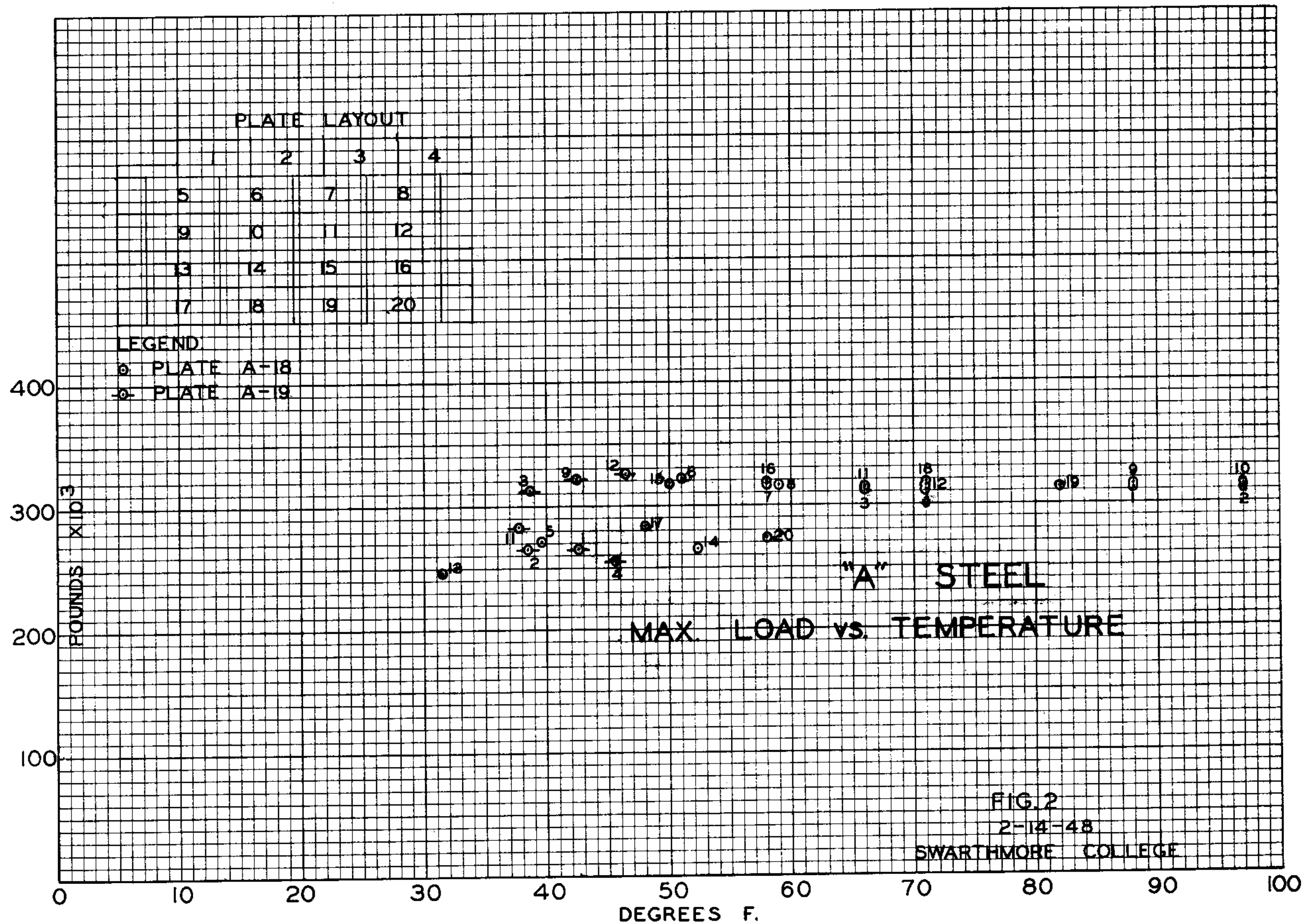
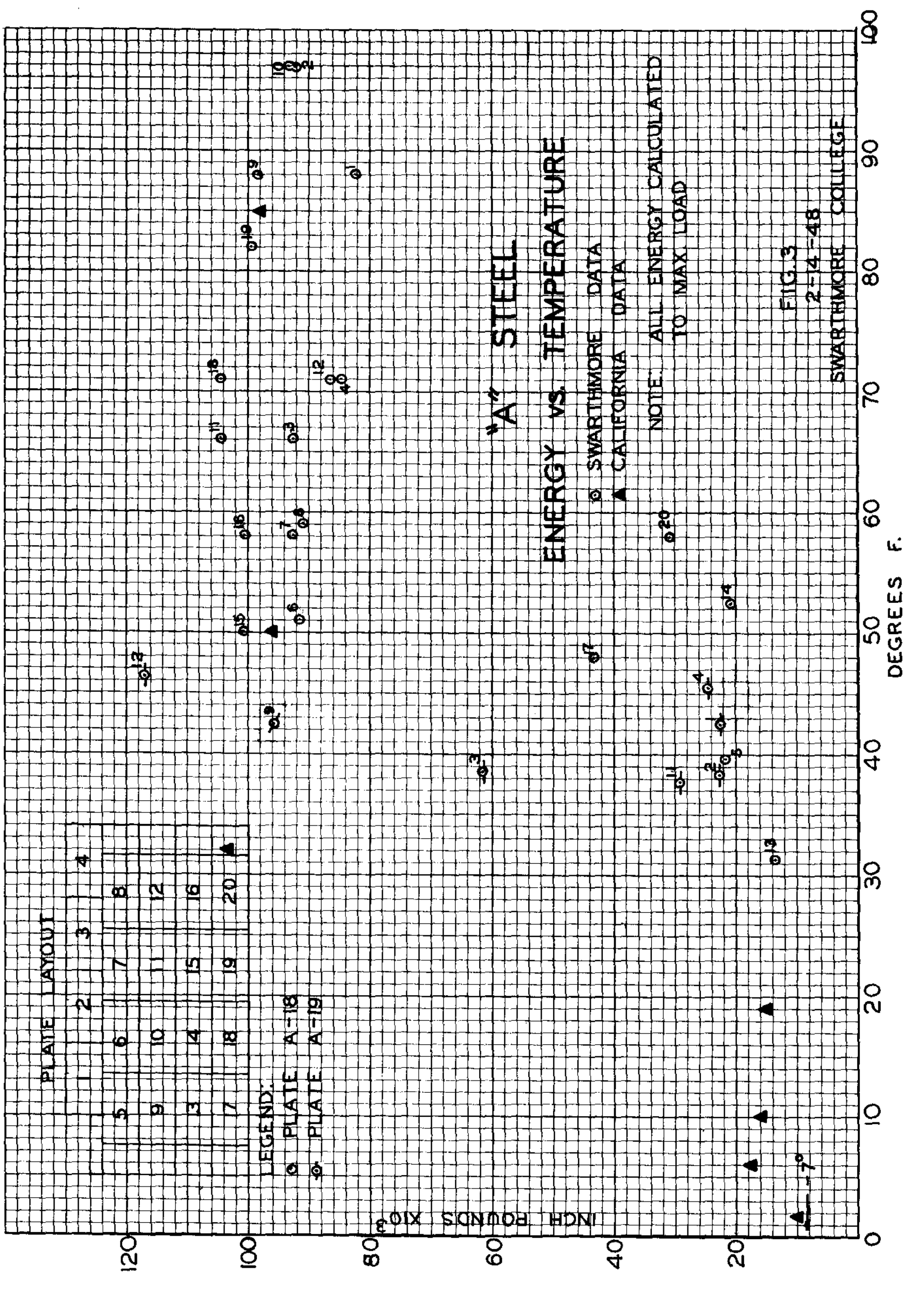
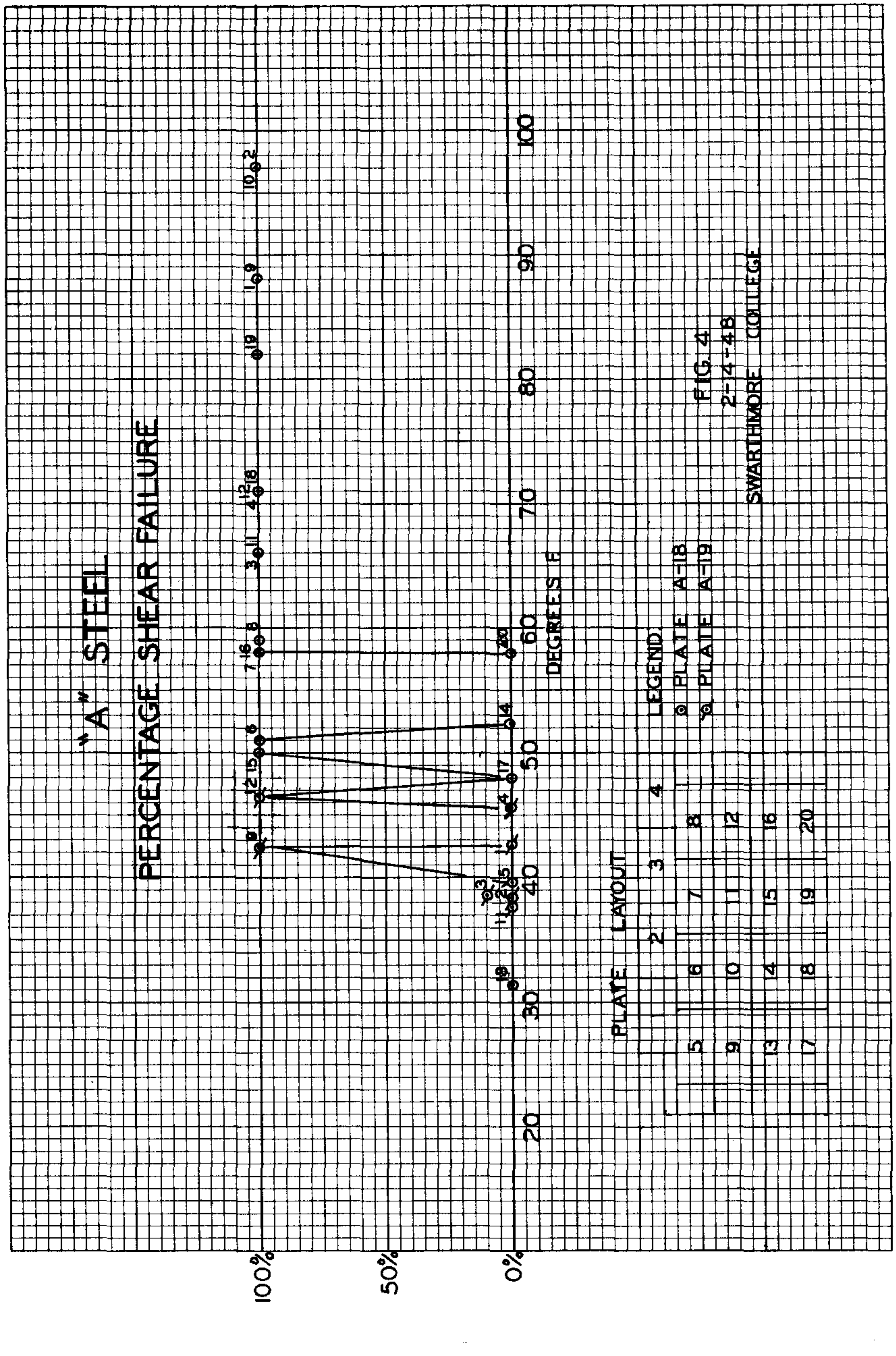


FIG. 2
2-14-48
SWARTHMORE COLLEGE


"A" STEEL
ENERGY VS. TEMPERATURE
SWARTHMORE DATA
CALIFORNIA DATA
NOTE: ALL ENERGY CALCULATED
TO MAX LOAD
FIG. 3
2-14-48
SWARTHMORE COLLEGE
PLATE LAYOUT
1 2 3 4
5 6 7 8
9 10 11 12
13 14 15 16
17 18 19 20
LEGEND:
PLATE A-18
PLATE A-19
INCH POUNDS X10³
DEGREES F.
0 10 20 30 40 50 60 70 80 90 100
20 40 60 80 100 120


"A" STEEL
PERCENTAGE SHEAR FAILURE
DEGREES F
20
30
40
50
60
70
80
90
100
100%
50%
0%
PLATE LAYOUT
1 2 3 4
5 6 7 8
9 10 11 12
13 14 15 16
17 18 19 20
LEGEND
PLATE A-18
PLATE A-19
FIG. 4
2-4-48
SWARTHMORE COLLEGE

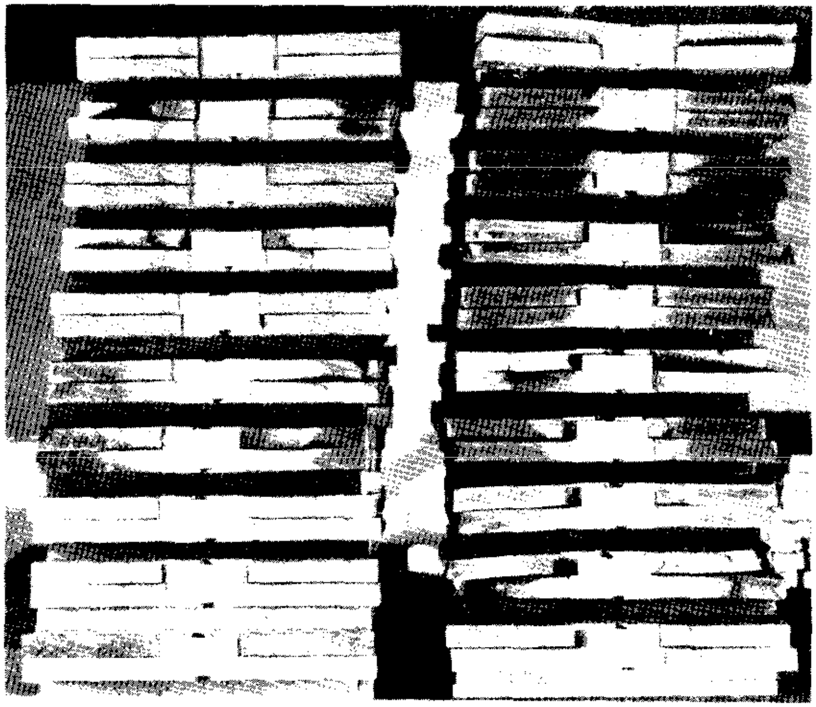


Fig. 5 "C" STEEL

PHOTOGRAPH OF FRACTURE SURFACES

TABLE 3

"C" Steel

TESTS OF SPECIMENS 12" WIDE, 3/4" THICK WITH STANDARD NOTCH

(The notch is 3" wide and has at its extremities a cut 1/8" long and 0.010" wide made with a jeweler's hack saw)

		Visible Crack		Max. Load		Failure		
Spec. No.	Temperature °F	Energy in-lbs.	Load lbs.	Energy in-lbs.	Load lbs.	Energy in-lbs.	Load lbs.	Type of Failure % Shear
C-24-7	63	1,700	256,300	18,600	287,500	18,600	287,500	0
C-24-19	63	15,100	273,000	32,600	281,000	32,600	252,000	0
C-24-14	73	15,100	275,000	29,200	316,000	29,200	316,000	0
C-24-17	73	40,400	286,000	40,400	286,000	140,100	72,500	65
C-24-5	74	2,000	227,700	42,000	291,700	151,400	60,000	59
C-24-13	78	12,100	267,500	40,500	295,000	40,500	295,000	0
C-24-8	81	4,300	261,500	97,600	308,300	114,600	298,000	15
C-24-20	82	15,700	276,000	42,800	291,200	57,100	236,800	0
C-24-6	88	4,500	255,500	55,200	310,700	137,100	147,000	40
C-24-15	88	15,900	275,500	49,700	293,000	49,700	293,000	0
C-24-18	89	33,400	292,000	33,400	292,000	45,200	278,700	0
C-24-10	96	22,500	287,500	69,700	311,500	147,300	54,000	58
C-24-2	97	1,900	248,500	87,300	308,500	205,300	17,000	71
C-24-9	107	15,500	271,000	91,200	321,500	278,800	75,000	89
C-24-1	108	3,900	249,000	128,900	370,000	268,900	216,400	63
C-24-3	116	5,800	254,500	130,600	360,000	238,300	50,000	100
C-24-11	116	30,100	300,000	117,000	371,500	329,200	60,000	100
C-24-4	124	10,100	262,500	104,200	369,000	299,400	80,000	100
C-24-12	124	8,500	250,000	95,300	344,100	236,700	59,000	92
C-24-16	130	14,200	275,000	91,300	374,000	291,200	100,000	100

TABLE 4

"C" Steel

TESTS OF SPECIMENS 12" WIDE MADE AT
UNIVERSITY OF CALIFORNIA

NObs - 31222

Spec. No.*	Temp. °F	Energy to Max. Load in-lbs.	Type of Failure % Shear
C-1	32-33	13,400	0
C-2	84	20,300	3
C-52x	90	72,000	10
C-3	101	85,000	51
C-51x	120-123	93,000	100
C-11x	132-136	83,000	93
C-5	141-145	78,000	91

* These are the designations of plates assigned by the University of California as described in their final report.[1]

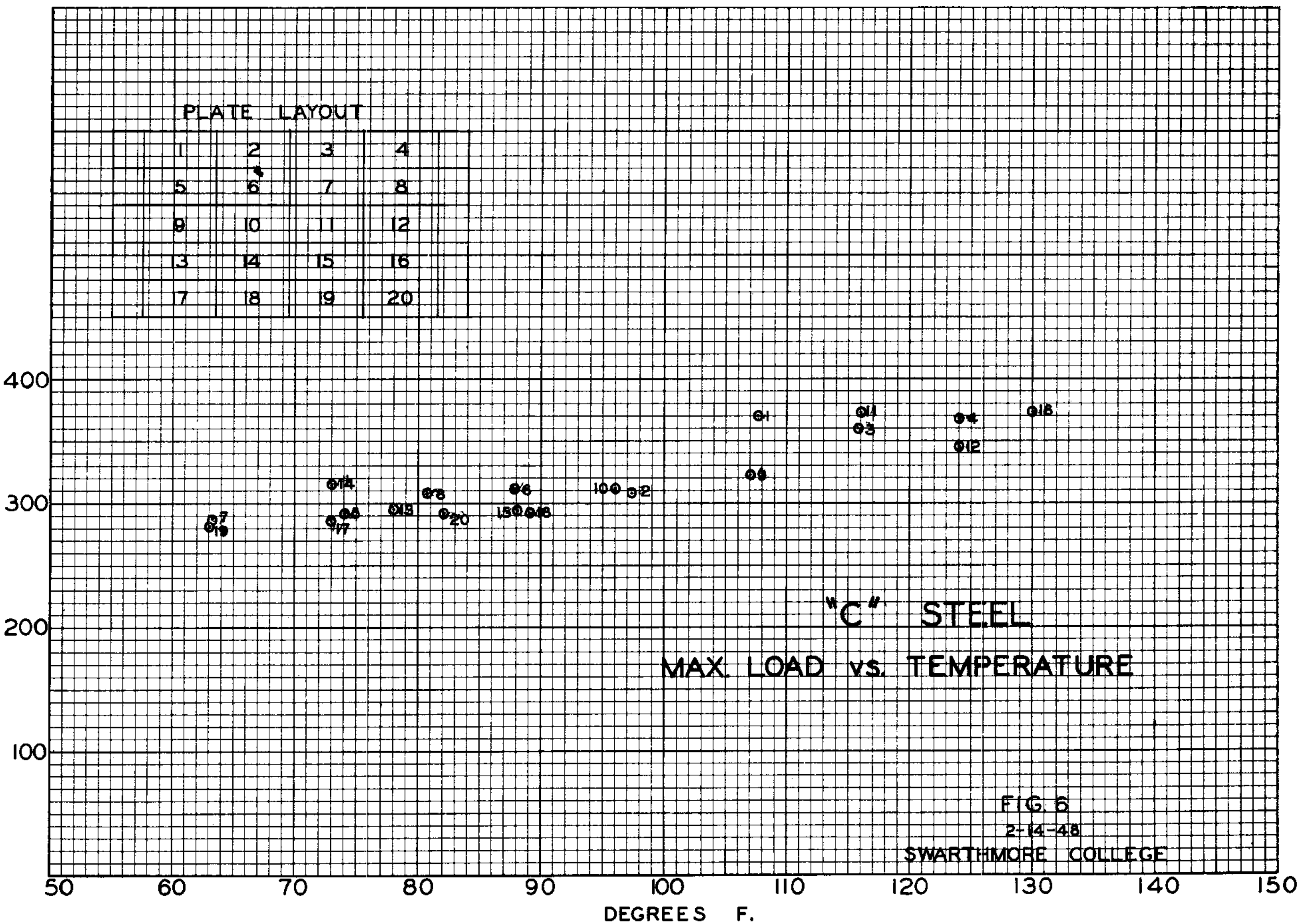
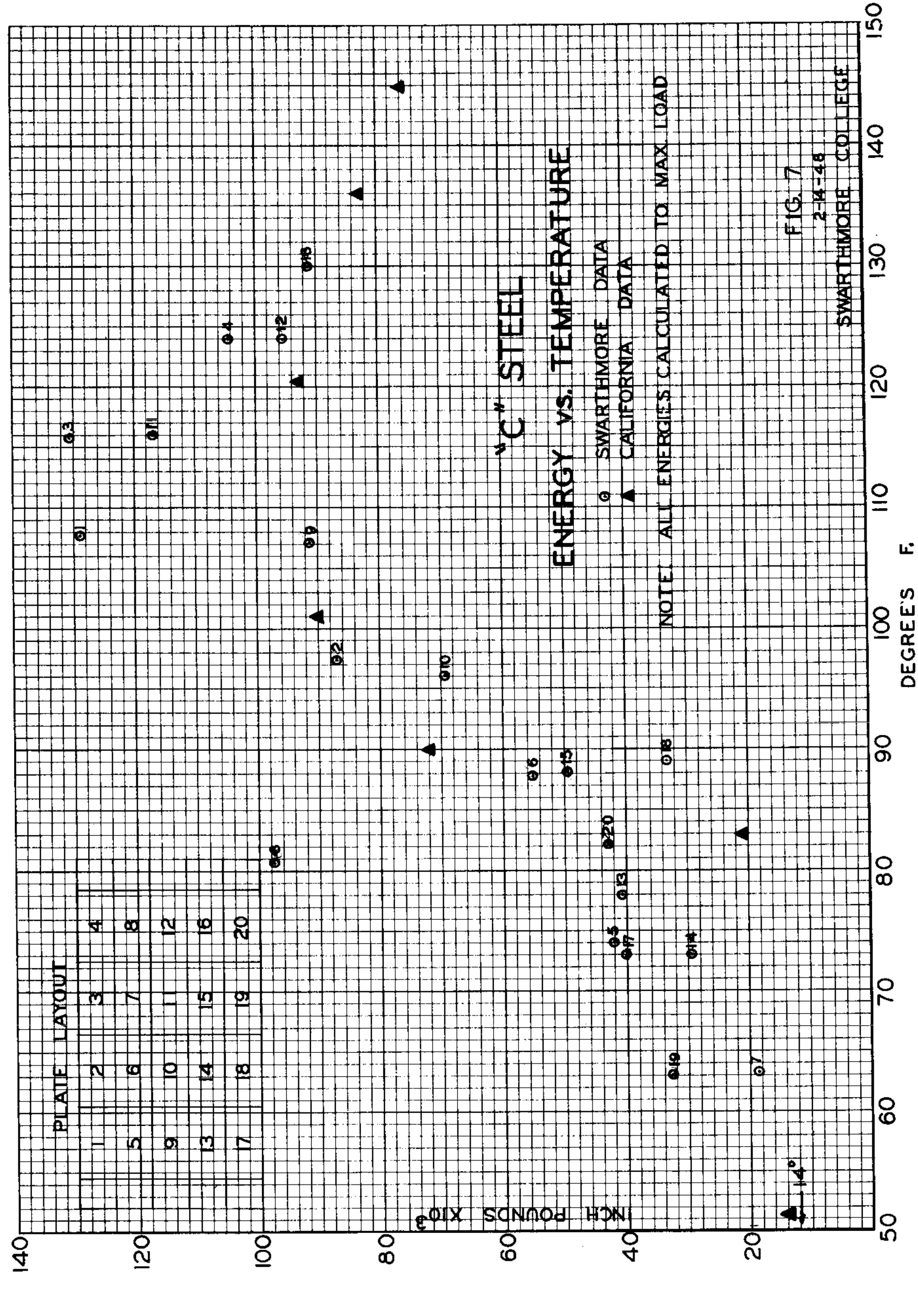


PLATE LAYOUT
1 2 3 4
5 6 7 8
9 10 11 12
13 14 15 16
7 18 19 20
"C" STEEL
MAX. LOAD vs. TEMPERATURE
FIG. 6
2-14-48
SWARTHMORE COLLEGE
400
300
200
100
50 60 70 80 90 100 110 120 130 140 150
DEGREES F.


"C" STEEL
ENERGY VS. TEMPERATURE
⊙ SWARTHMORE DATA
▲ CALIFORNIA DATA
NOTE: ALL ENERGIES CALCULATED TO MAX LOAD
FIG. 7
2-14-48
SWARTHMORE COLLEGE
PLATE LAYOUT
1 2 3 4
5 6 7 8
9 10 11 12
13 14 15 16
17 18 19 20
INCH POUNDS X10³
DEGREE'S F.
14°
50 60 70 80 90 100 110 120 130 140 150
20 40 60 80 100 120 140

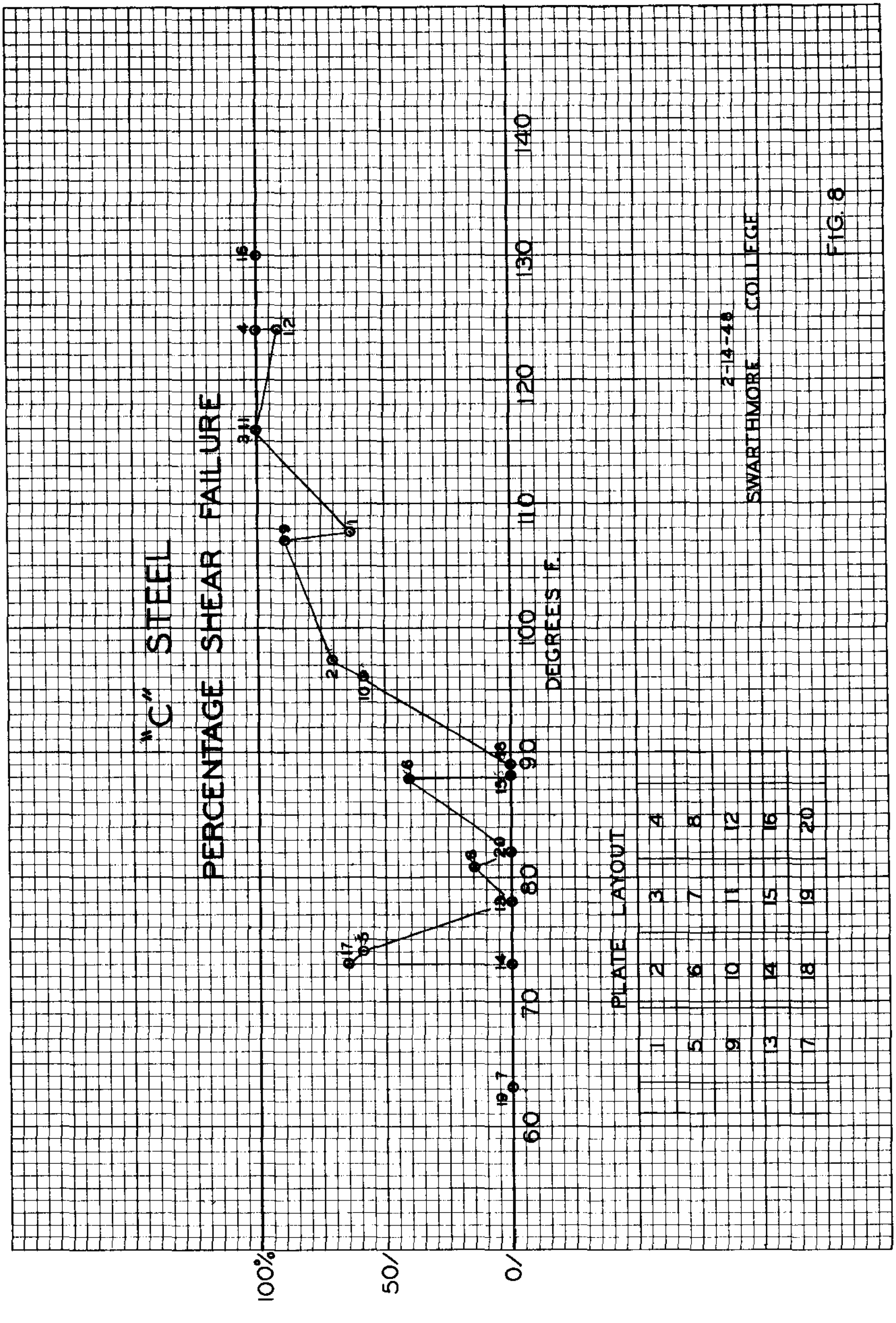

"C" STEEL
PERCENTAGE SHEAR FAILURE
DEGREES F.
60
70
80
90
100
110
120
130
140
100%
50/
0/
PLATE LAYOUT
1 2 3 4
5 6 7 8
9 10 11 12
13 14 15 16
17 18 19 20
2-14-48
SWARTHMORE COLLEGE

FIG. 8

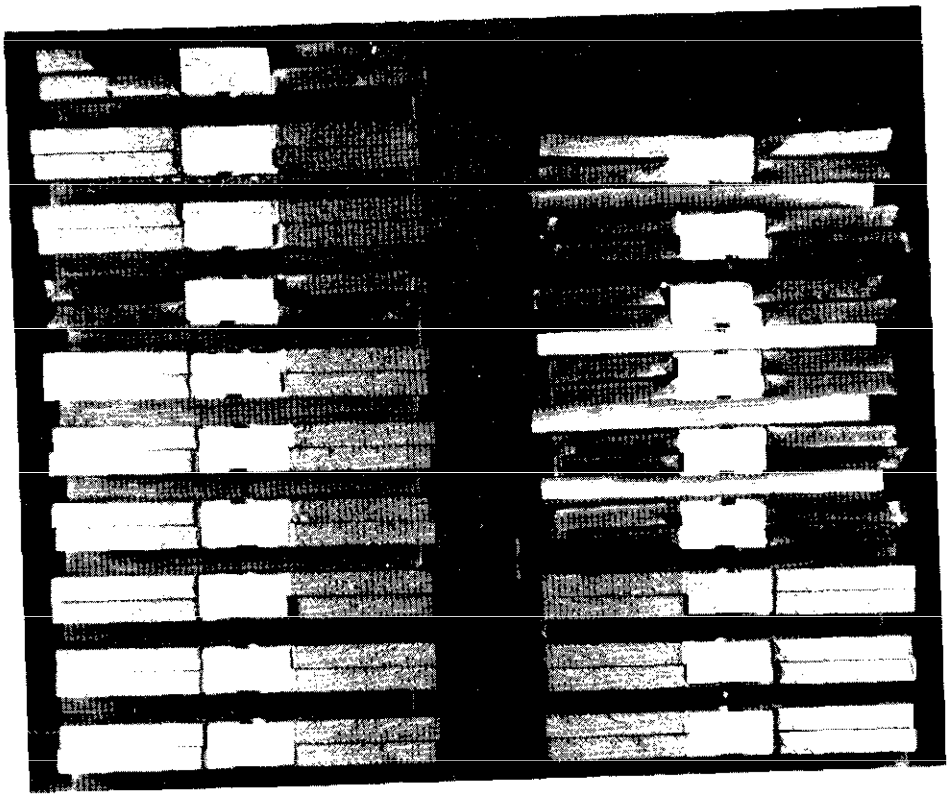


Fig. 9 "Bn" STEEL

PHOTOGRAPH OF FRACTURE SURFACES

TABLE 5

"B_N" Steel

TESTS OF SPECIMENS 12" WIDE, 3/4" THICK WITH STANDARD NOTCH

(The notch is 3" wide and has at its extremities a cut 1/8" long and 0.010" wide made with a jeweler's hack sa

Spec. No.	Temp. °F	Visible Crack Energy in-lbs.	Visible Crack Load lbs.	First Maximum Energy in-lbs.	First Maximum Load lbs.	Second Max. Energy in-lbs.	Second Max. Load lbs.	Failure Energy in-lbs.	Failure Load lbs.	Type of Failure % Shear
B_N-21-7	-8.9	4,700	238,000	41,500	272,000	-	-	41,500	272,000	0
B_N-21-1	-1.2	7,700	240,000	32,900	270,800	-	-	32,900	270,800	0
B_N-21-8	1.2	6,300	242,000	41,300	283,400	44,500	279,400	44,500	279,400	1
B_N-21-2	9.1	6,400	238,700	59,700	295,700	-	-	59,700	290,000	3
B_N-21-9	9.2	7,700	240,500	53,900	289,300	-	-	53,900	289,300	3
B_N-21-18	9.9	4,900	243,400	30,000	274,000	-	-	30,000	274,000	0
B_N-21-6	10.0	4,000	240,000	137,000	326,300	-	-	309,100	50,000	100
B_N-21-14	10.0	4,600	245,400	49,200	292,500	51,000	288,000	57,000	288,000	2
B_N-21-10	18.9	5,200	236,300	70,200	309,000	-	-	70,200	309,000	3
B_N-21-3	19.8	6,500	234,800	125,600	321,800	-	-	266,700	199,000	66
B_N-21-4	23.8	3,300	227,500	56,100	299,400	-	-	56,100	299,400	3
B_N-21-11	24.5	6,400	234,800	60,600	294.700	-	-	60,600	294,700	3
B_N-21-15	25.3	5,900	233,800	29,800	263,500	-	-	29,800	263,500	1
B_N-21-12	29.4	6,400	234,500	121,500	318,900	-	-	293,500	25,000	100
B_N-21-17	29.8	5,700	234,900	120,000	317,700	-	-	290,400	50,000	100
B_N-21-16	29.9	4,700	237,600	118,200	320,400	-	-	295,600	22,000	100
B_N-21-20	30.2	4,900	235,500	119,000	324,800	-	-	294,000	40,000	100
B_N-21-19	41.3	3,400	229,800	123,500	316,000	-	-	287,200	30,000	100
B_N-21-5	73.8	3,800	222,500	115,000	310,000	-	-	292,500	41,000	100

TABLE 6

"B_N" Steel

TESTS OF SPECIMENS 12" WIDE MADE AT
UNIVERSITY OF CALIFORNIA

NObs - 31222

Spec. No.*	Temp. °F	Energy to Max. Load in-lbs.	Type of Failure % Shear
B-8	(-12)-(-10)	22,000	0
B-21x	10	53,000	0
B-10	10-15	116,000	87
B-2	32-36	134,000	78
B-5	50-51	121,000	100
B-4	89	133,000	94

* These are the designations of plates assigned by the University of California as described in their final report.[1]

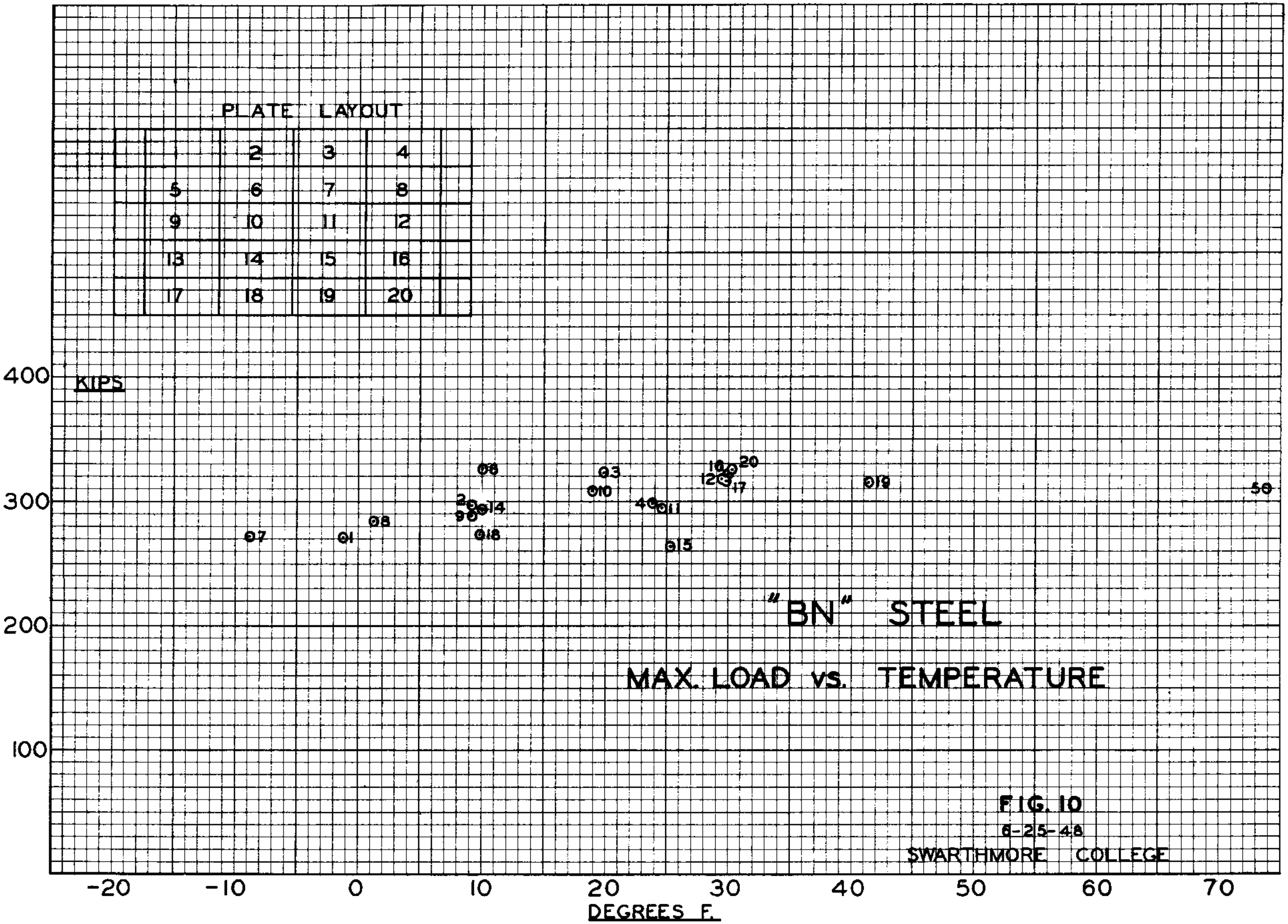
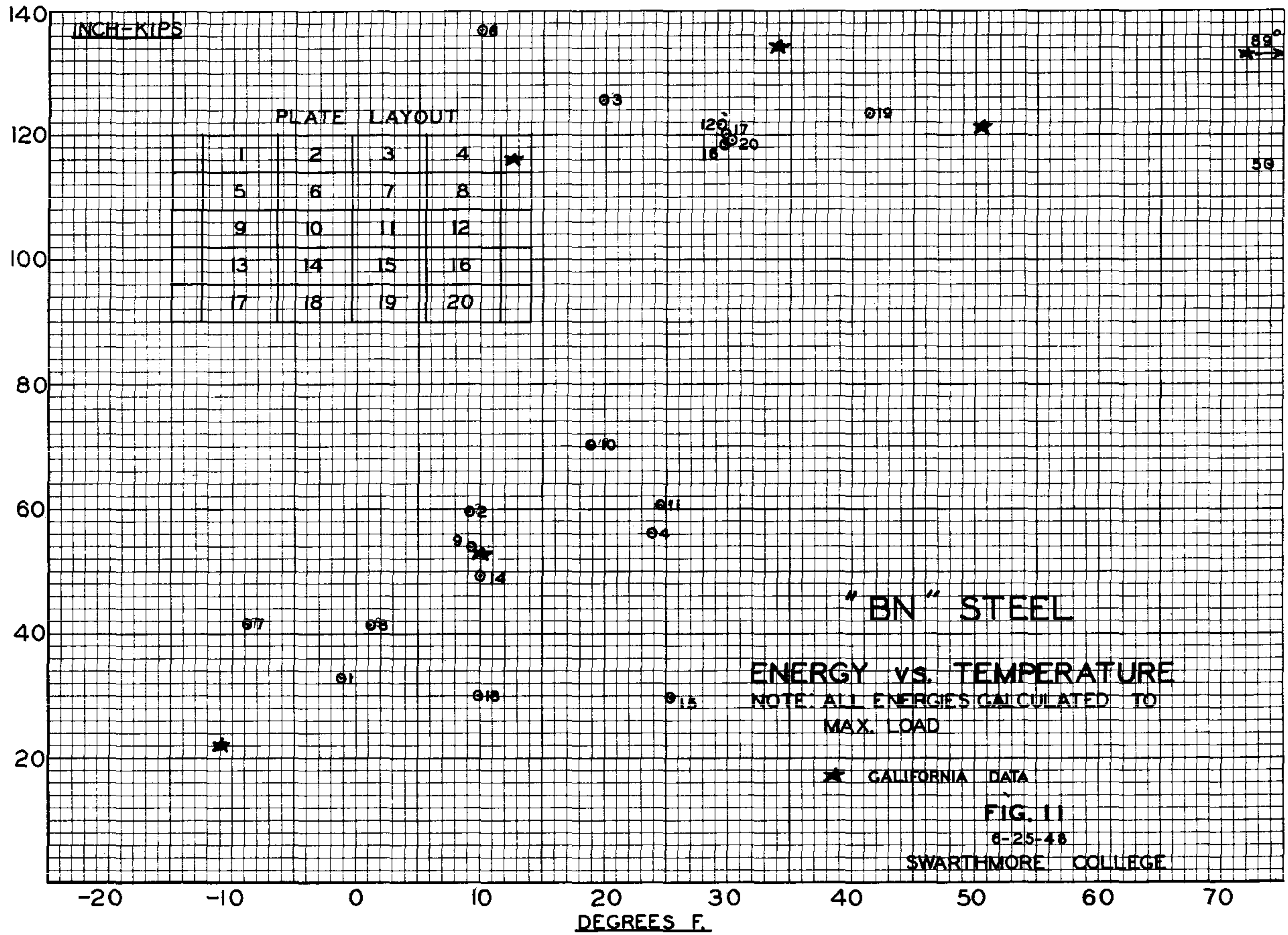


PLATE LAYOUT
2 3 4
5 6 7 8
9 10 11 12
13 14 15 16
17 18 19 20
KIPS
400
300
200
100
-20 -10 0 10 20 30 40 50 60 70
DEGREES F.
7
1
8
2
9
6
14
18
3
10
4
11
15
16
12
20
17
19
5
"BN" STEEL
MAX. LOAD vs. TEMPERATURE
FIG. 10
6-25-48
SWARTHMORE COLLEGE


INCH-KIPS
PLATE LAYOUT
1 2 3 4
5 6 7 8
9 10 11 12
13 14 15 16
17 18 19 20
"BN" STEEL
ENERGY vs. TEMPERATURE
NOTE: ALL ENERGIES CALCULATED TO MAX. LOAD
CALIFORNIA DATA
DEGREES F.
FIG. 11
6-25-48
SWARTHMORE COLLEGE

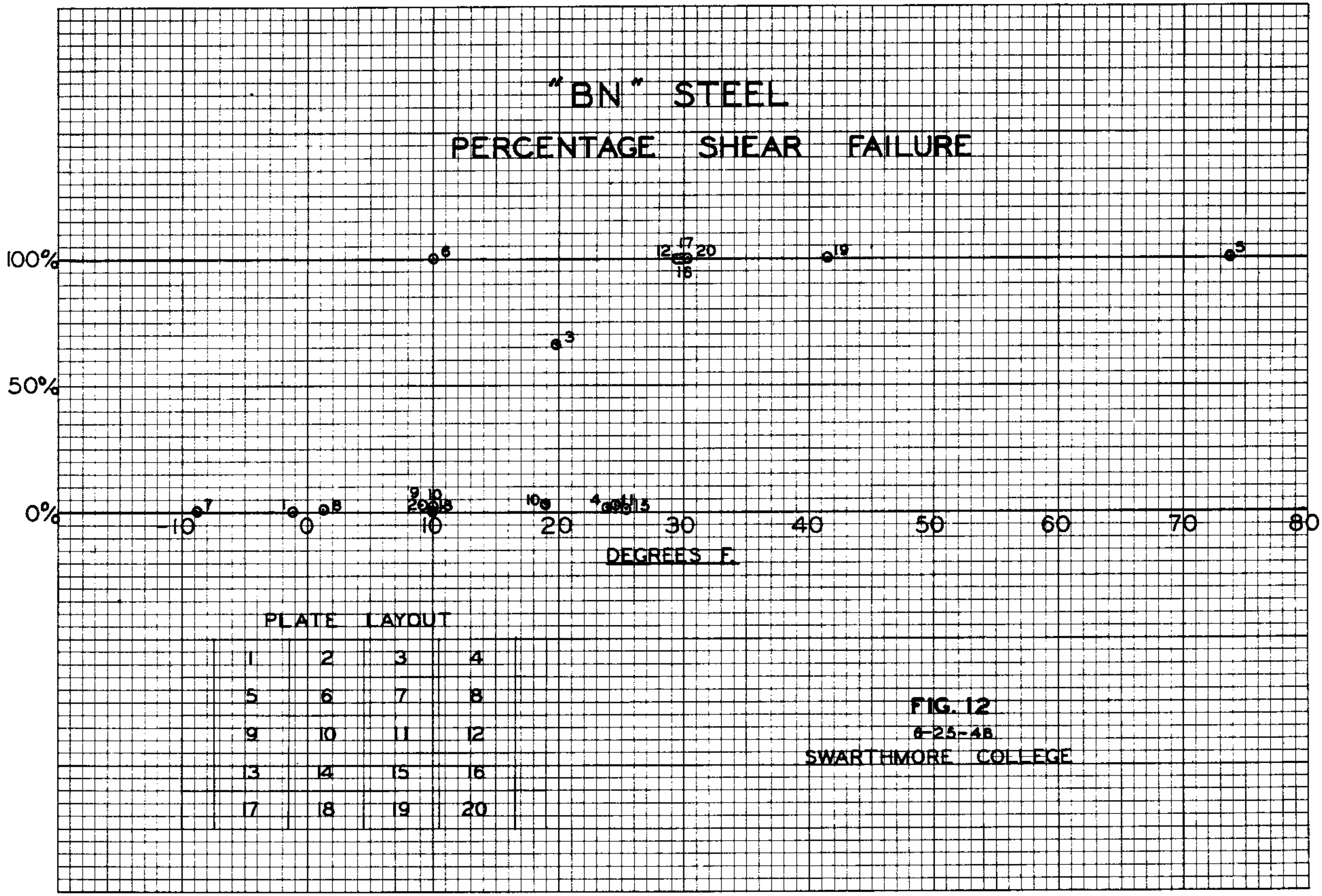


FIG. 12
6-25-48
SWARTHMORE COLLEGE

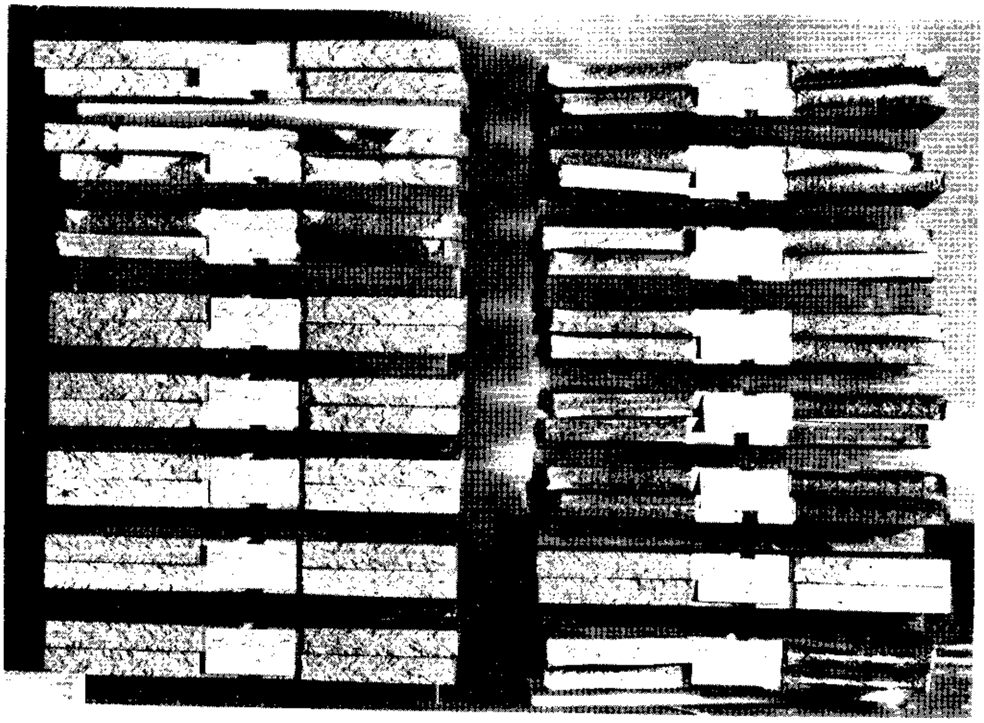


Fig. 13 "Br" STEEL

PHOTOGRAPH OF FRACTURE SURFACES

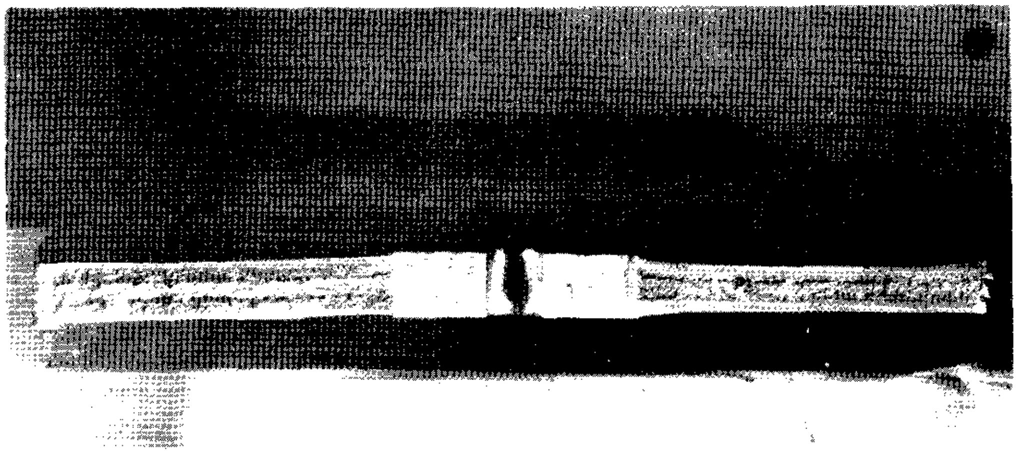


Fig. 14 - Specimen BR-22-12

Showing Striations Along Fracture Surfaces

TABLE 7

"B_R" Steel

TESTS OF SPECIMENS 12" WIDE, 3/4" THICK WITH STANDARD NOTCH

(The notch is 3" wide and has at its extremities a cut 1/8" long and 0.010" wide made with a jeweler's hack saw)

Spec. No.	Temperature °F	Visible Crack Energy in-lbs.	Visible Crack Load lbs.	Max. Load Energy in-lbs.	Max. Load Load lbs.	Failure Energy in-lbs.	Failure Load lbs.	Type of Failure % Shear
B_R-22-18	-12.7	3,900	234,200	36,700	293,000	36,700	293,000	1
B_R-22-8	-10.3	6,700	249,300	31,500	283,500	31,500	280,000	0
B_R-22-9	1.9	9,900	245,000	46,700	296,300	46,800	295,000	2
B_R-22-11	2.0	4,800	240,800	92,600	332,500	92,600	328,000	6
B_R-22-17	2.8	1,600	224,800	36,000	290,000	36,000	290,000	1
B_R-22-10	11.6	10,100	240,500	140,300	340,100	335,100	74,500	100
B_R-22-5	11.9	7,800	243,300	138,600	346,500	286,800	210,000	59
B_R-22-2	12.1	10,500	239,500	34,300	279,500	34,300	279,500	0
B_R-22-12	13.0	5,200	232,200	134,000	329,700	310,900	32,000	100
B_R-22-7	13.6	6,300	237,300	30,000	280,500	30,000	280,500	1
B_R-22-20	19.3	3,400	230,000	120,000	325,600	295,100	78,000	100
B_R-22-19	19.6	3,500	230,000	120,000	329,300	306,500	40,000	100
B_R-22-4	20.3	2,700	230,000	120,700	329,500	315,500	45,000	100
B_R-22-3	30.0	1,000	224,500	129,200	329,500	316,300	35,000	100
B_R-22-1	41.5	7,400	230,700	132,900	337,300	330,400	25,000	100
B_R-22-6	68.8	6,500	228,500	140,200	327,000	350,800	30,000	100

TABLE 8

"B_R" Steel

TESTS OF SPECIMENS 12" WIDE MADE AT
UNIVERSITY OF CALIFORNIA

NObs - 31222

Spec. No.*	Temp. °F	Energy to Max. Load in-lbs.	Type of Failure % Shear
B-7	(-35)-(-34)	21,000	0
B-9	(-7)-(-6)	36,000	0
B-1	32	112,000	83
B-6	50-51	114,000	100
B-3	70-73	115,000	94

* These are the designations of plates assigned by the University of California as described in their final report.[1]

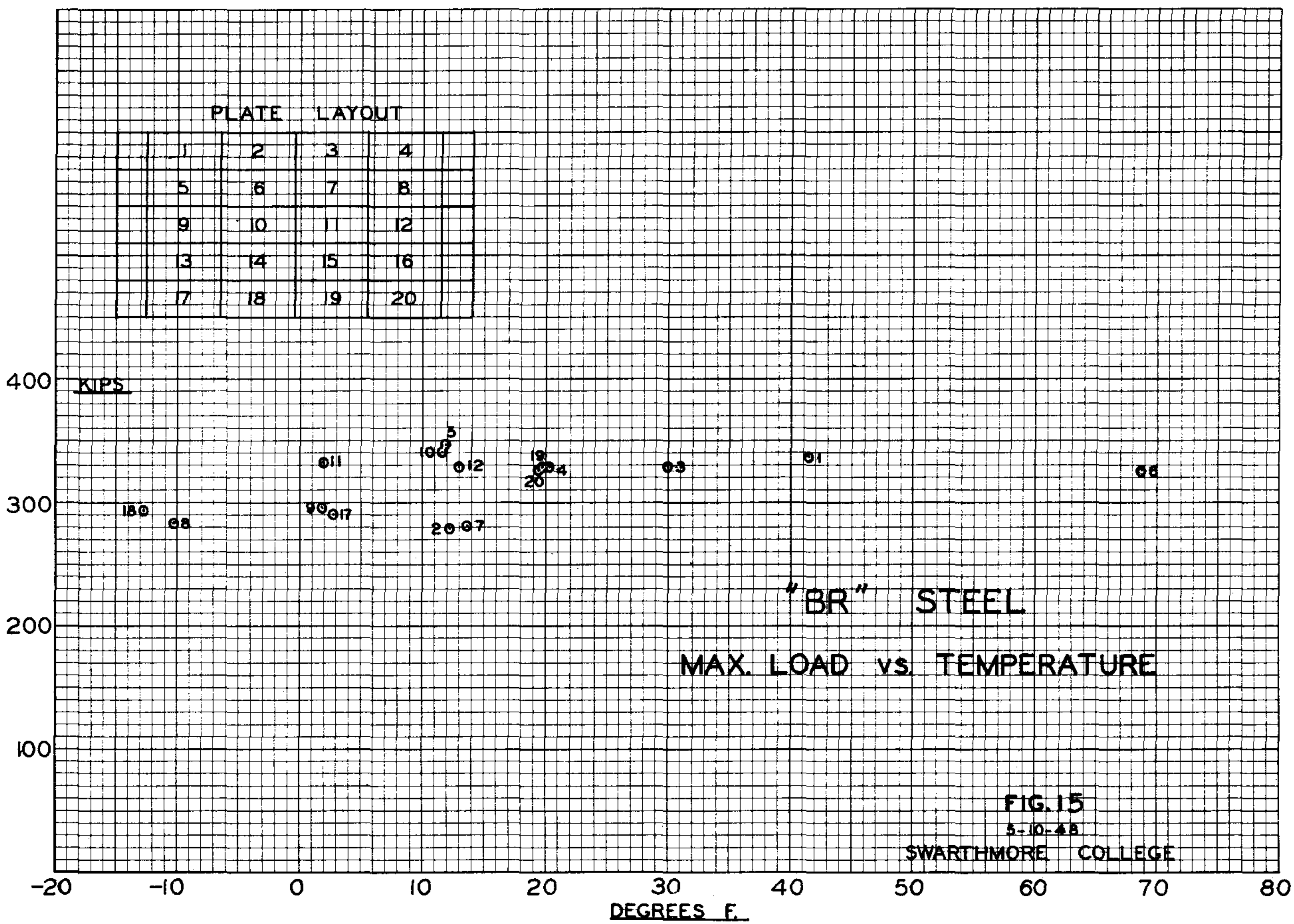
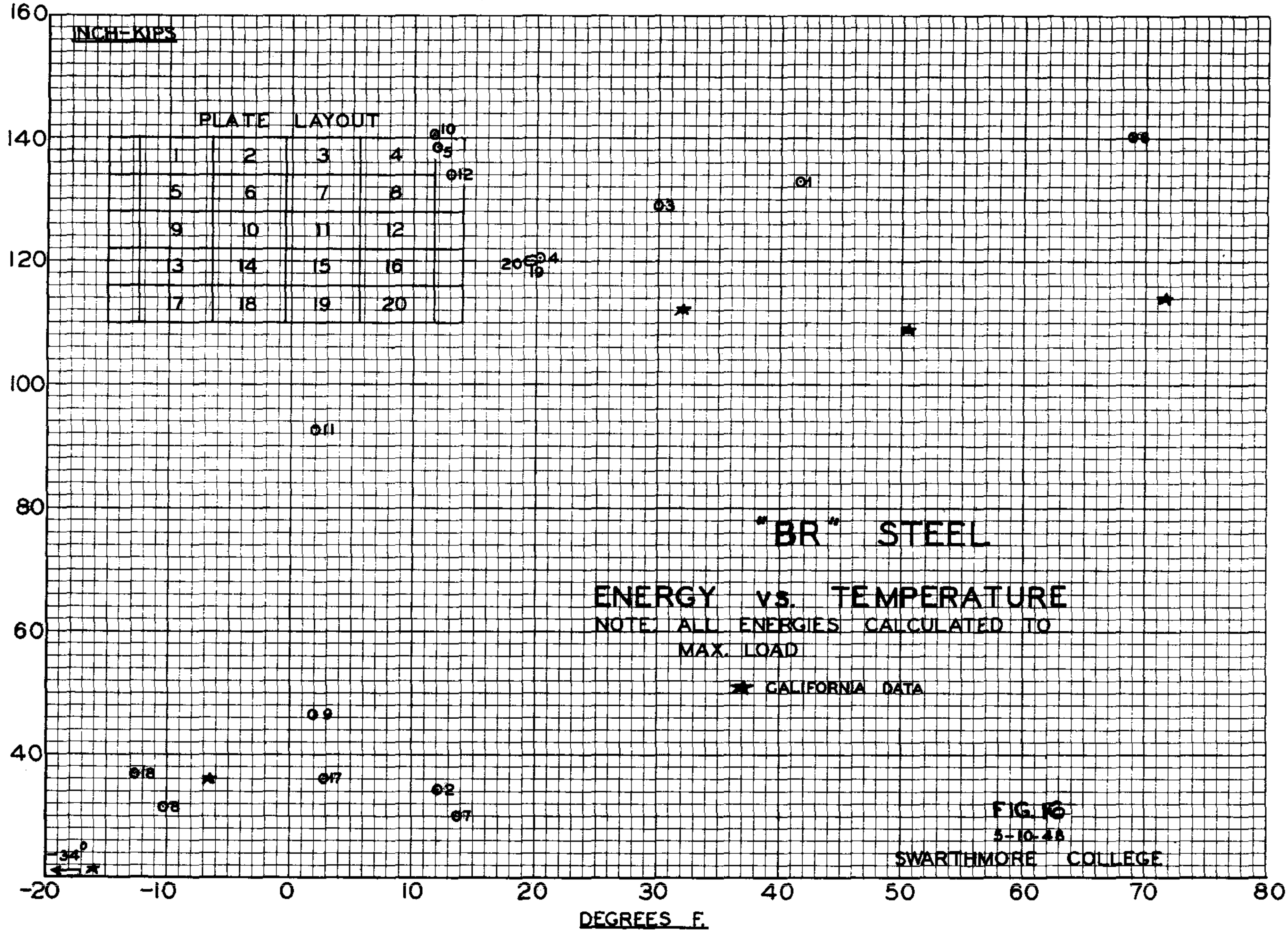


PLATE LAYOUT
1 2 3 4
5 6 7 8
9 10 11 12
13 14 15 16
17 18 19 20
KIPS
400
300
200
100
-20 -10 0 10 20 30 40 50 60 70 80
DEGREES F.
"BR" STEEL
MAX. LOAD vs. TEMPERATURE
SWARTHMORE COLLEGE

FIG. 15
5-10-48



INCH-KIPS
PLATE LAYOUT
1 2 3 4
5 6 7 8
9 10 11 12
13 14 15 16
17 18 19 20
"BR" STEEL
ENERGY vs. TEMPERATURE
NOTE: ALL ENERGIES CALCULATED TO MAX. LOAD
★ CALIFORNIA DATA
FIG. 16
5-10-48
SWARTHMORE COLLEGE
-34°
DEGREES F.

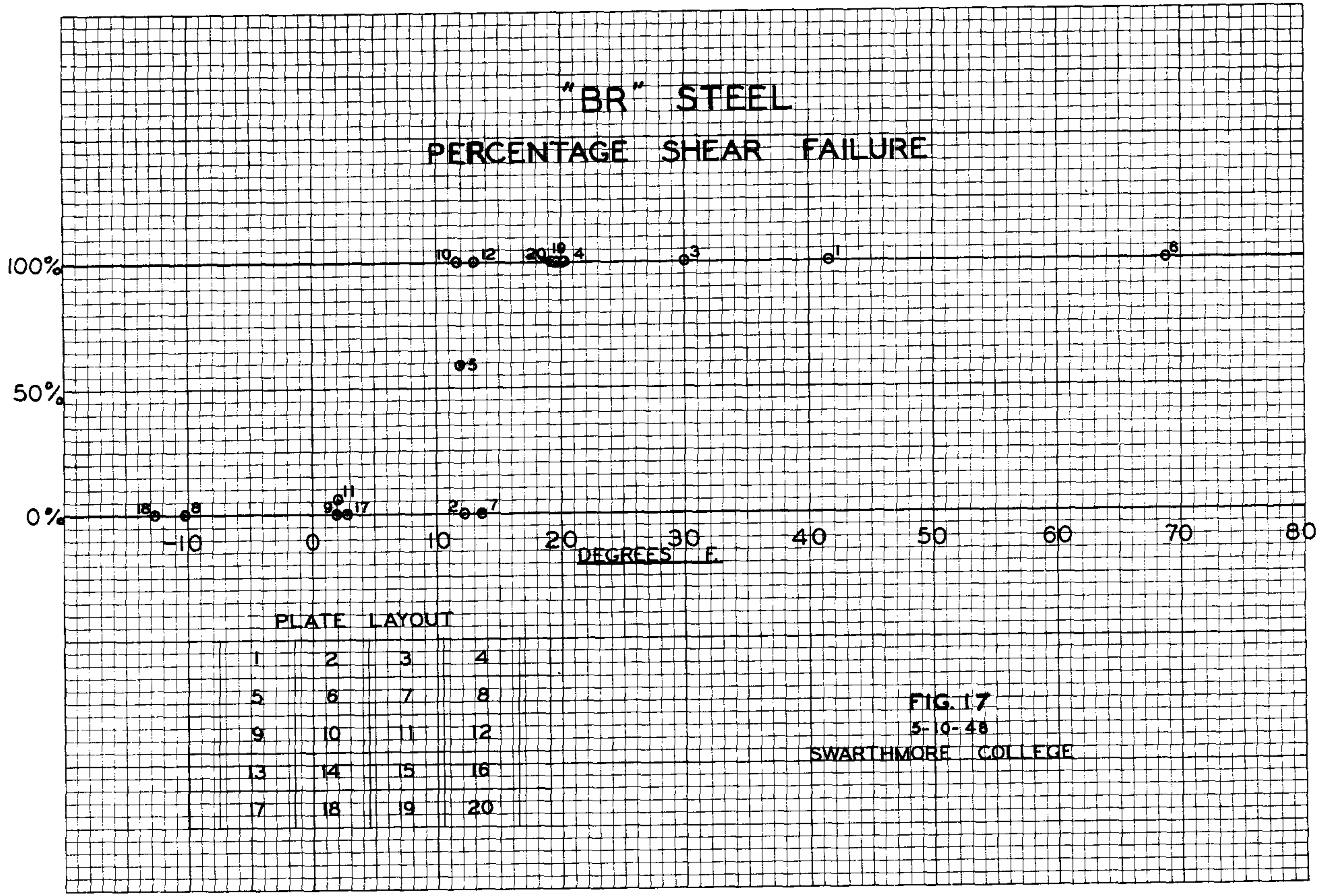


FIG. 17
5-10-48
SWARTHMORE COLLEGE

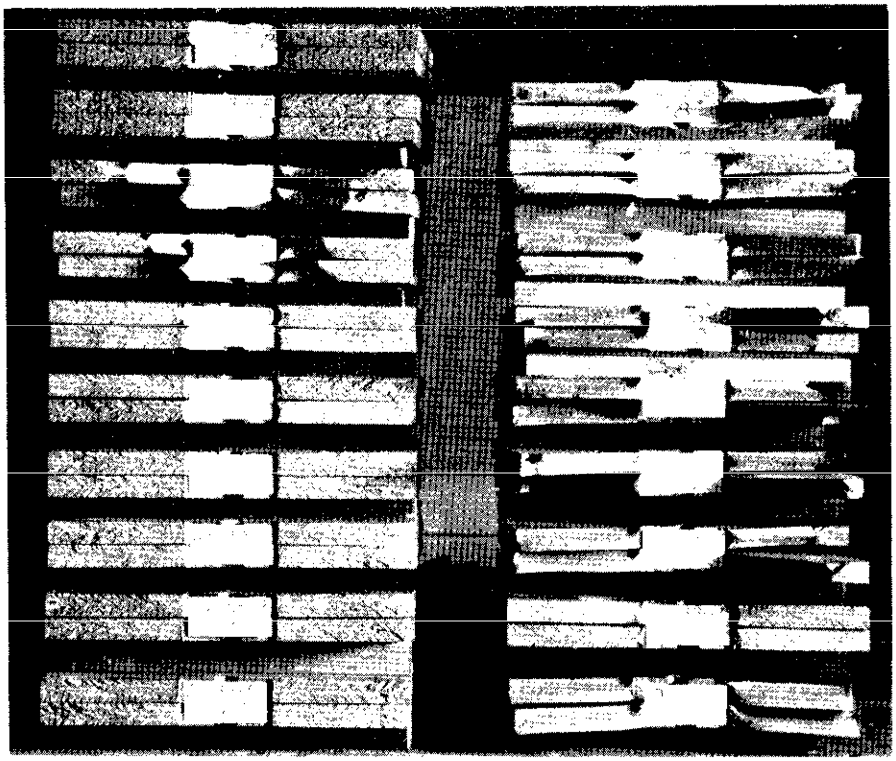


Fig. 18 "Dn" STEEL

PHOTOGRAPH OF FRACTURE SURFACES

TABLE 9

"D_N" Steel

TESTS OF SPECIMENS 12" WIDE, 3/4" THICK WITH STANDARD NOTCH

(The notch is 3" wide and has at its extremities a cut 1/8" long and 0.010" wide made with a jeweler's hack saw*)

Spec. No.	Temperature °F	Visible Crack Energy in-lbs.	Visible Crack Load lbs.	Max. Load Energy in-lbs.	Max. Load Load lbs.	Failure Energy in-lbs.	Failure Load lbs.	Type of Failure % Shear
D_N-33-5	-16.5	4,900	255,500	27,700	285,400	27,700	285,400	0
D_N-33-9	-2.9	4,800	248,200	31,500	291,000	31,500	291,000	0
D_N-33-1	-2.0	6,400	260,400	36,900	306,000	36,900	306,000	0
D_N-33-19	4.8	4,500	249,000	35,700	294,000	35,700	294,000	0
D_N-33-4	4.9	3,400	238,000	54,700	324,000	54,700	324,000	1
D_N-33-10	9.6	6,100	250,300	66,400	323,000	66,400	323,000	3
D_N-33-8	9.9	3,600	245,000	130,700	349,200	214,100	313,000	34
D_N-33-2	10.1	4,700	245,200	125,300	358,900	280,700	242,000	52
D_N-33-18	15.0	4,500	245,700	44,200	321,000	44,200	321,000	1
D_N-33-16	16.0	3,700	243,600	59,500	316,200	59,500	316,200	2
D_N-33-3	19.6	4,500	245,700	127,400	348,800	310,800	30,000	100
D_N-33-11	19.8	4,700	242,600	86,000	338,000	86,000	338,000	4
D_N-33-17	24.8	6,500	259,500	135,400	345,700	311,800	78,000	87
D_N-33-20	24.9	2,600	244,100	140,400	355,000	346,700	60,000	100
D_N-33-13	29.8	3,900	249,000	129,700	344,400	324,600	90,000	100
D_N-33-12	29.9	6,000	247,300	125,000	343,200	300,600	125,000	77
D_N-33-7	41.0	4,400	241,500	117,500	340,500	314,900	40,000	100
D_N-33-14	55.4	7,500	243,500	127,900	336,900	314,900	48,000	100
D_N-33-6	78.4	2,900	230,000	119,900	332,500	316,400	60,000	100

TABLE 10

"Dn" Steel

TESTS OF SPECIMENS 12" WIDE MADE AT
UNIVERSITY OF ILLINOIS*

NObs - 31224

Spec. No.*	Temp. °F	Energy to Max. Load in-lbs.	Type of Failure % Shear
15-5A	41	100,000	87
9-2	30	109,000	80
15-6B	16	99,000	46
10A-4	1	36,300	0

* See page 12 of reference No. 2

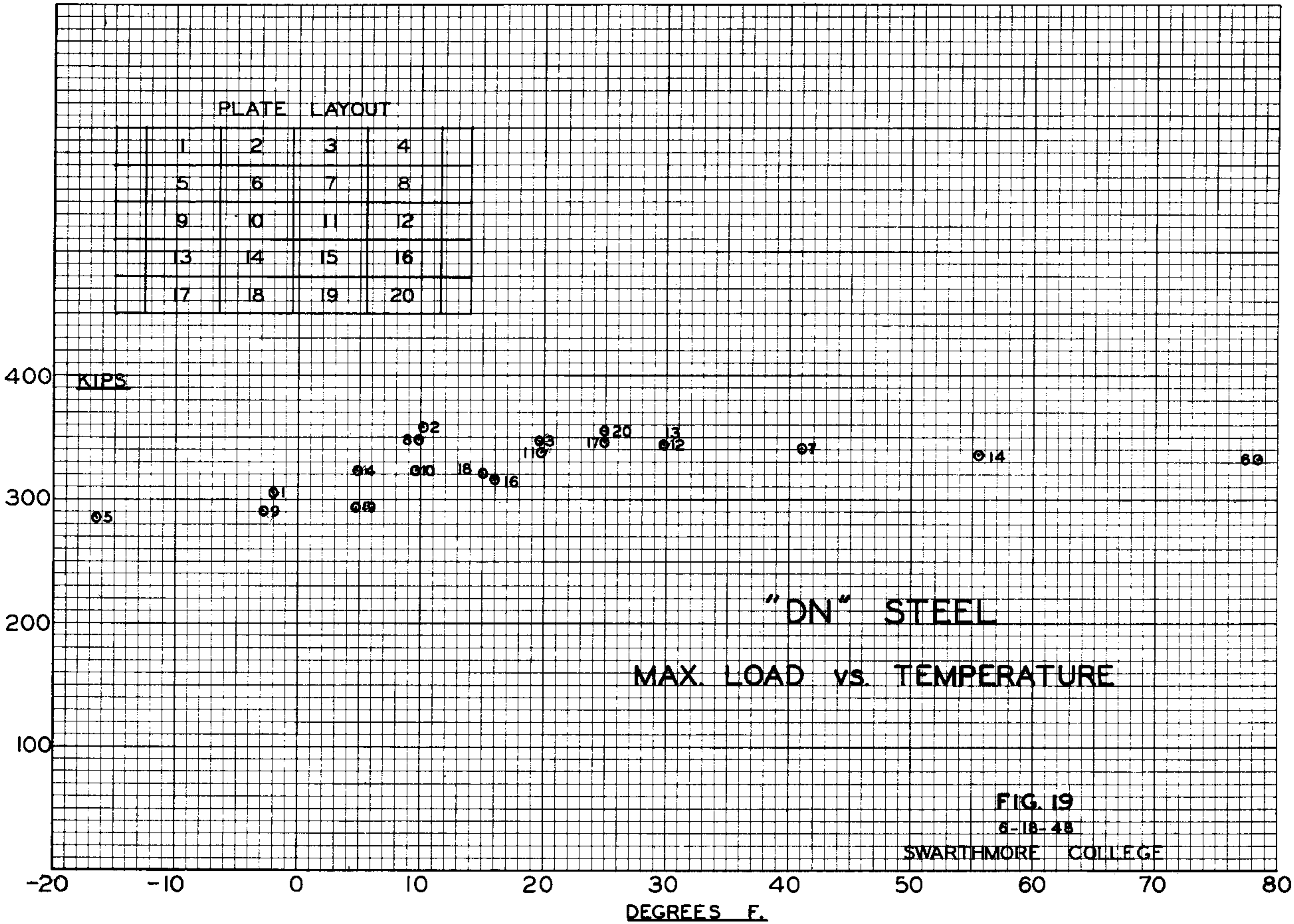


PLATE LAYOUT
1 2 3 4
5 6 7 8
9 10 11 12
13 14 15 16
17 18 19 20
KIPS
400
300
200
100
-20 -10 0 10 20 30 40 50 60 70 80
DEGREES F.
"DN" STEEL
MAX. LOAD vs. TEMPERATURE
FIG. 19
6-18-48
SWARTHMORE COLLEGE

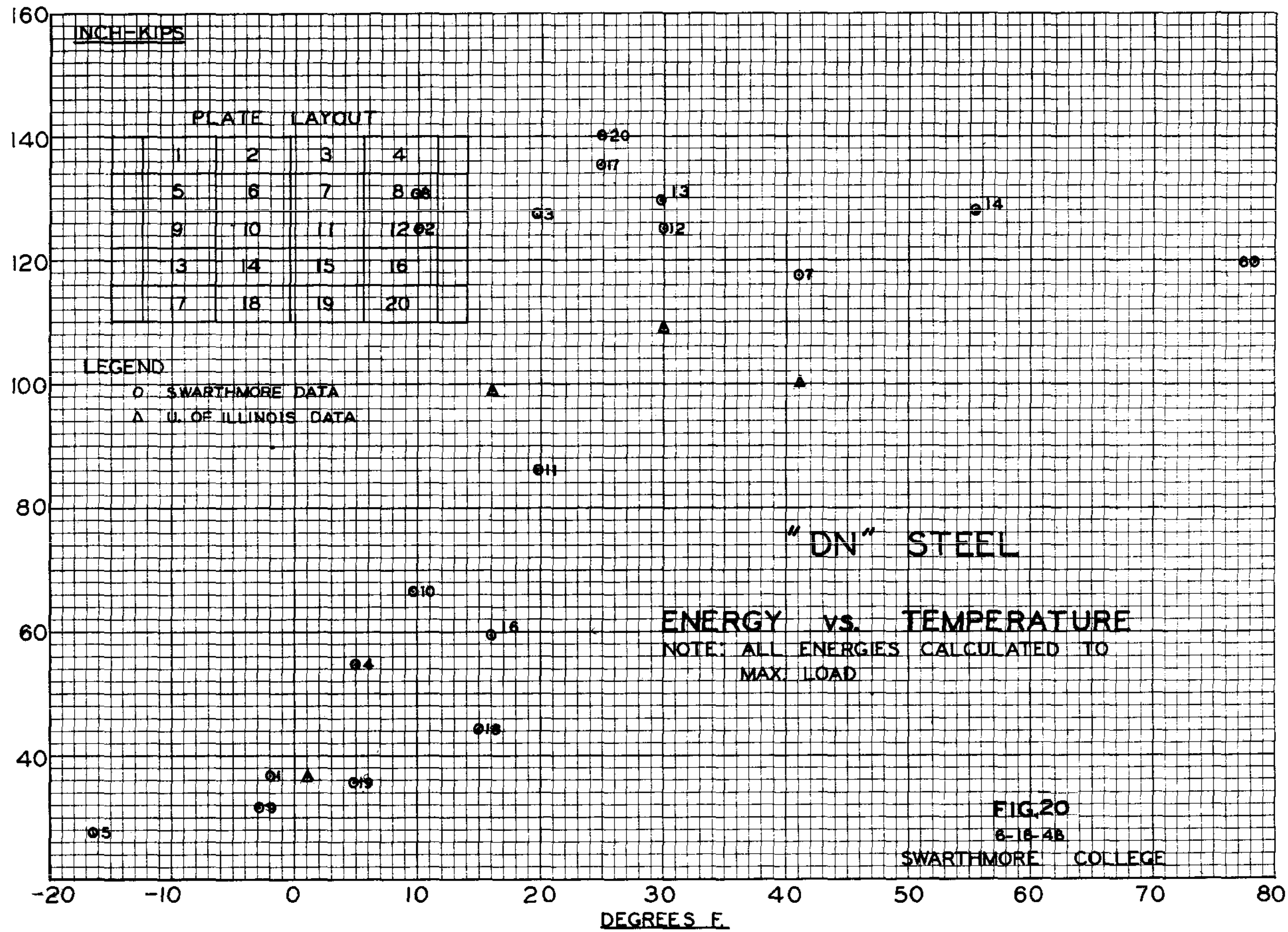


FIG. 20
6-18-48
SWARTHMORE COLLEGE

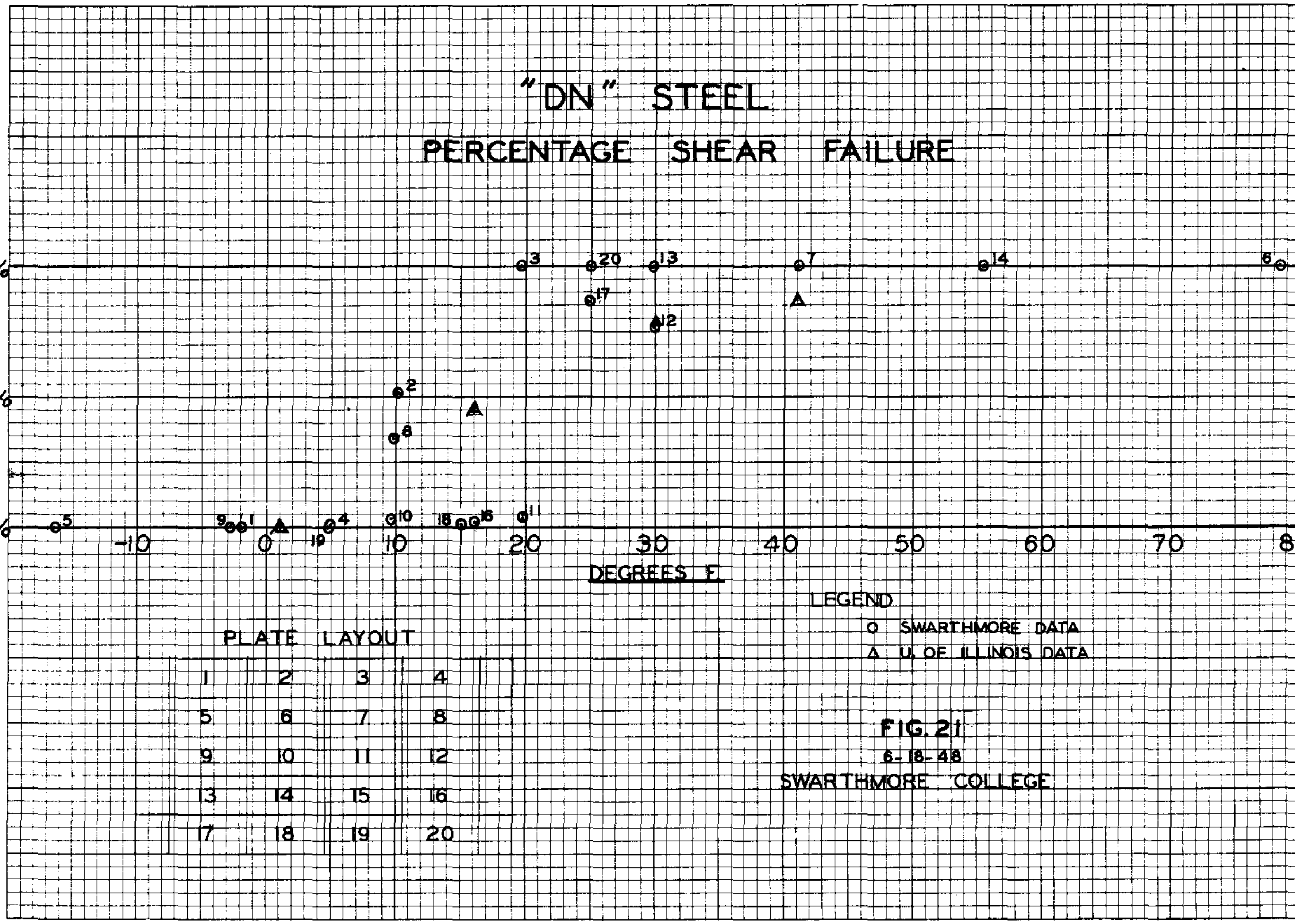

"DN" STEEL
PERCENTAGE SHEAR FAILURE
100%
50%
0%
-10
0
10
20
30
40
50
60
70
80
DEGREES F.
LEGEND
O SWARTHMORE DATA
Δ U. OF ILLINOIS DATA
PLATE LAYOUT
1 2 3 4
5 6 7 8
9 10 11 12
13 14 15 16
17 18 19 20
FIG. 21
6-18-48
SWARTHMORE COLLEGE

Fig. 22 "E" STEEL"

PHOTOGRAPH OF FRACTURE SURFACES

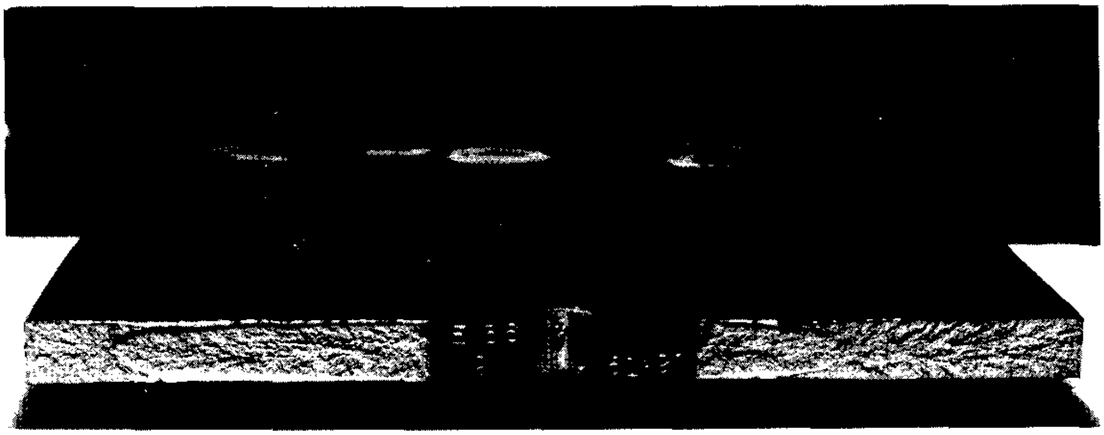


Fig. 23 Specimen E-36-2 showing THUMBNAILS WHICH DEVELOPED DURING COMPLETE FRACTURE

TABLE 11

"E" Steel

TESTS OF SPECIMENS 12" WIDE, 3/4" THICK WITH STANDARD NOTCH

(The notch is 3" wide and has at its extremities a cut 1/8" long and 0.010" wide made with a jeweler's hack saw)

		Visible Crack		First Maximum		Second Max.		Failure		Type of Failure
Spec. No.	Temp. °F	Energy in-lbs.	Load lbs.	Energy in-lbs.	Load lbs.	Energy in-lbs.	Load lbs.	Energy in-lbs.	Load lbs.	% Shear
E-36-7	61.3	3,900	229,800	21,400	262,500	-	-	21,400	262,500	1
E-36-2	61.9	2,300	226,500	27,600	256,700			27,600	256,700	0
E-36-19	70.2	4,000	225,300	27,000	254,400	39,700	242,000	39,700	242,000	2
E-36-8	70.5	6,100	229,000	60,600	261,000	-	-	84,900	102,000	38
E-36-1	82.2	6,200	229,000	39,000	271,500	78,800	257,000	181,800	45,000	73
E-36-10	83.3	5,000	227,500	34,500	265,700	84,000	266,000	182,400	15,000	76
E-36-11	91.6	11,800	233,600	38,900	271,000	83,500	264,300	176,200	58,000	77
E-36-9	91.6	5,700	230,000	104,900	320,500	-	-	246,900	45,000	100
E-36-20	99.8	3,500	220,500	34,400	264,500	83,400	284,800	196,200	60,000	90
E-36-3	99.8	4,900	224,500	32,800	264,500	86,800	283,000	195,300	30,000	85
E-36-17	106.6	4,500	219,000	101,500	319,900	-	-	248,400	60,000	100
E-36-12	111.6	6,900	225,500	87,100	314,000	-	-	239,200	25,000	100
E-36-6	115.0	9,000	224,000	103,800	316,500	-	-	242,200	30,000	100
E-36-18	115.6	2,700	221,500	100,800	320,000	-	-	251,000	50,000	100
E-36-4	126.0	4,500	220,600	106,300	313,700	-	-	238,200	60,000	100
E-36-5	149.1	5,000	222,500	93,400	322,800	-	-	237,500	25,000	100

TABLE 12

"E" Steel

TESTS OF SPECIMENS 12" WIDE MADE AT
UNIVERSITY OF ILLINOIS*

NObs - 31224

Spec. No.*	Temp. °F	Energy to Max. Load in-lbs.	Type of Failure % Shear
18-9A	128	66,000	94
23-3B	109	60,000	87
13A-5B	74	40,000	0
13A-5A	40	17,000	0
20-2A	-73	10,000	0

* See page 12 of reference No. 2

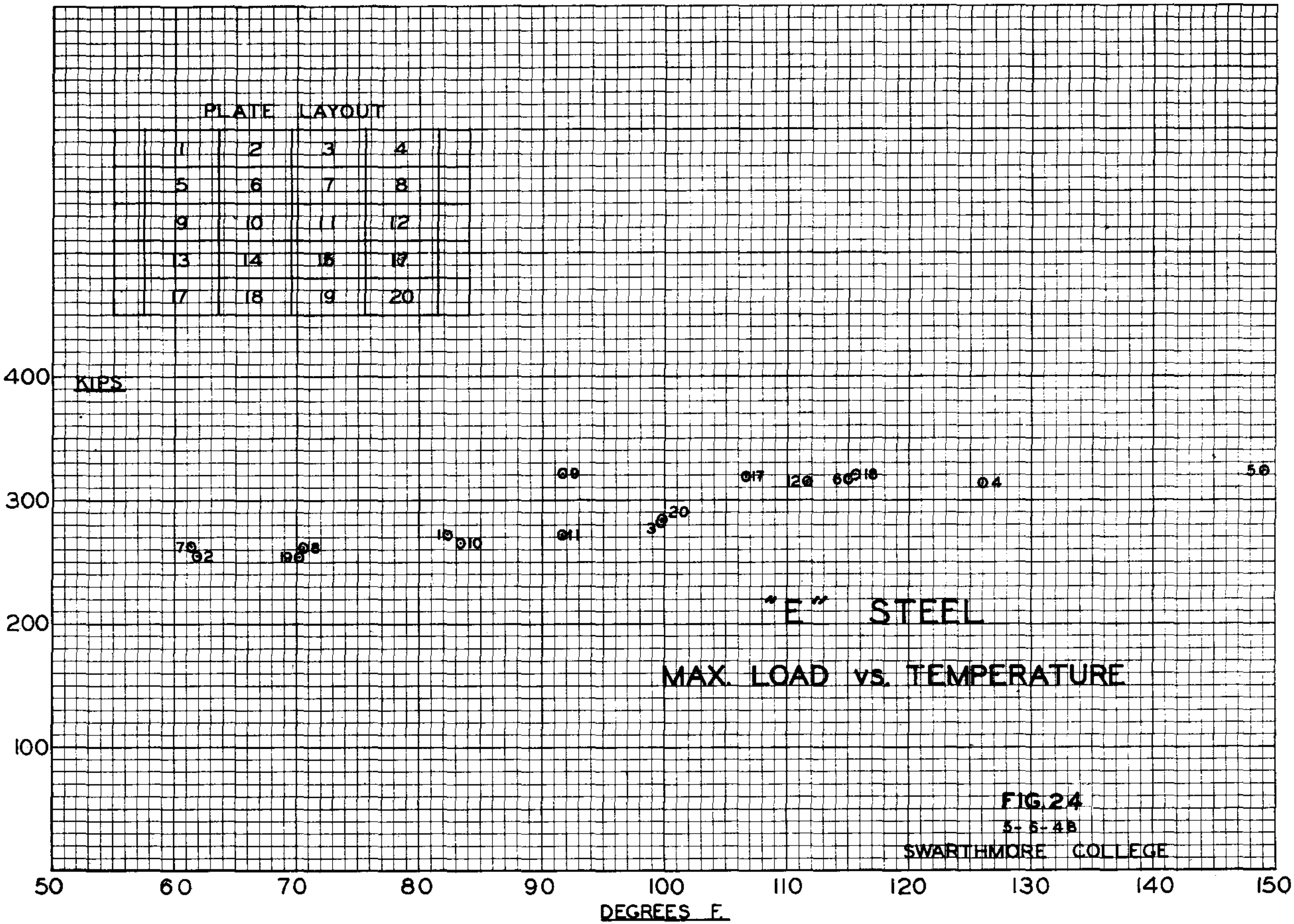
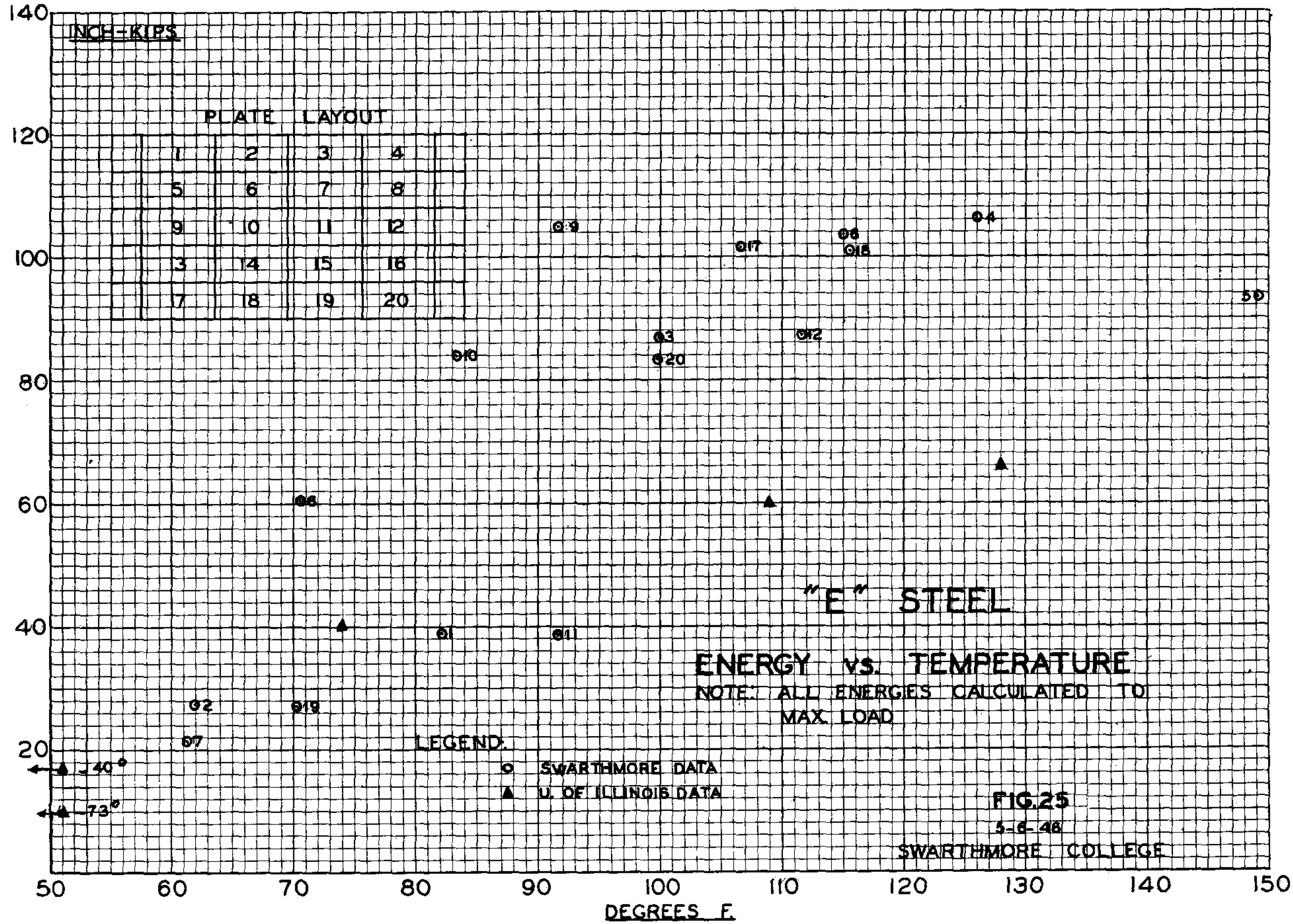
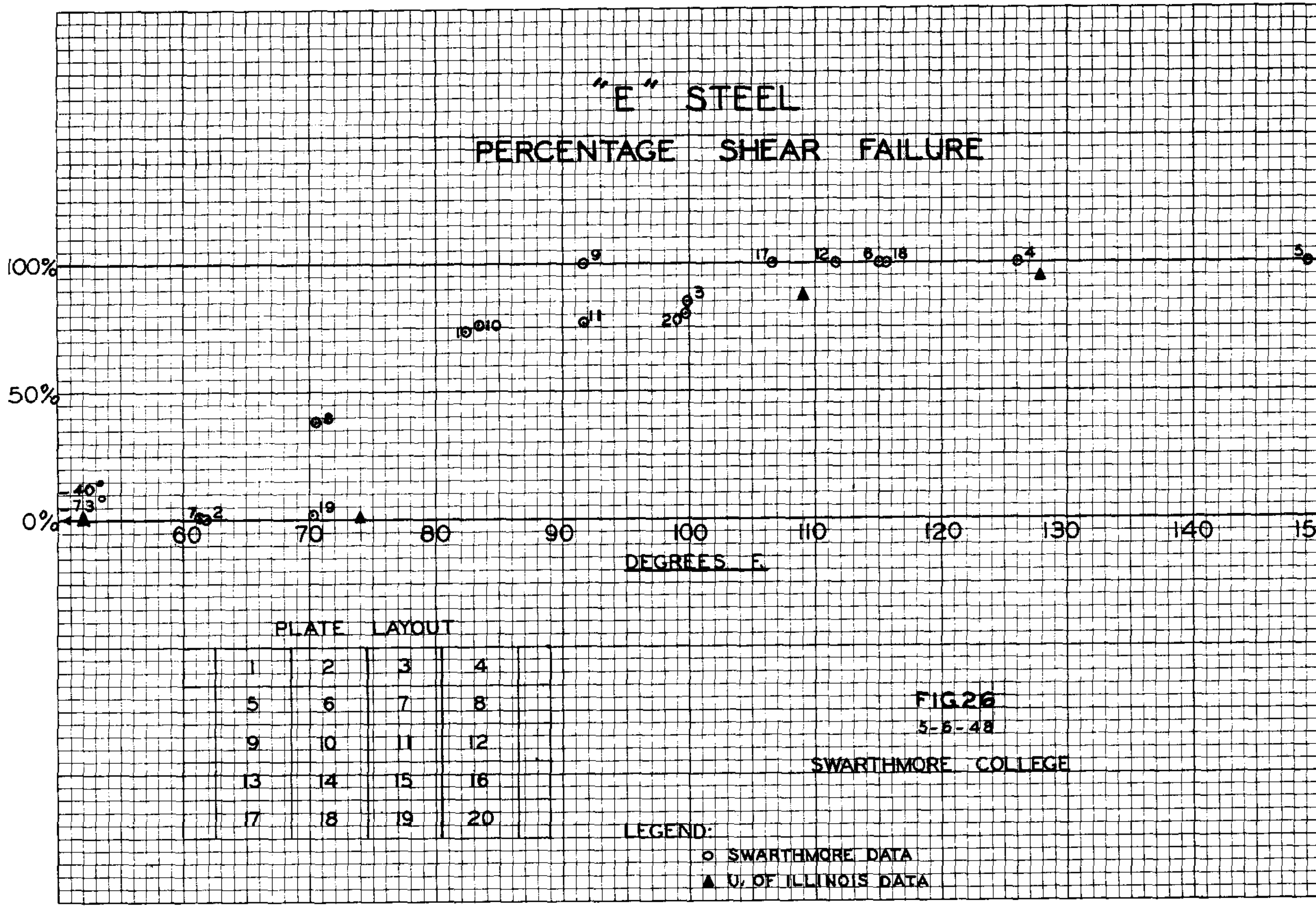


PLATE LAYOUT
1 2 3 4
5 6 7 8
9 10 11 12
13 14 15 16
17 18 19 20
KIPS
400
300
200
100
50 60 70 80 90 100 110 120 130 140 150
DEGREES F.
"E" STEEL
MAX. LOAD vs. TEMPERATURE
FIG. 24
3-6-48
SWARTHMORE COLLEGE


INCH-KIPS
PLATE LAYOUT
1 2 3 4
5 6 7 8
9 10 11 12
13 14 15 16
17 18 19 20
"E" STEEL
ENERGY vs. TEMPERATURE
NOTE: ALL ENERGIES CALCULATED TO MAX. LOAD
LEGEND:
SWARTHMORE DATA
U. OF ILLINOIS DATA
-40°
-73°
DEGREES F.
SWARTHMORE COLLEGE
FIG. 25
5-6-48


"E" STEEL
PERCENTAGE SHEAR FAILURE
100%
50%
0%
-40°
-73°
60
70
80
90
100
110
120
130
140
150
DEGREES F.
PLATE LAYOUT
1 2 3 4
5 6 7 8
9 10 11 12
13 14 15 16
17 18 19 20
FIG 26
5-6-48
SWARTHMORE COLLEGE
LEGEND:
o SWARTHMORE DATA
▲ U. OF ILLINOIS DATA

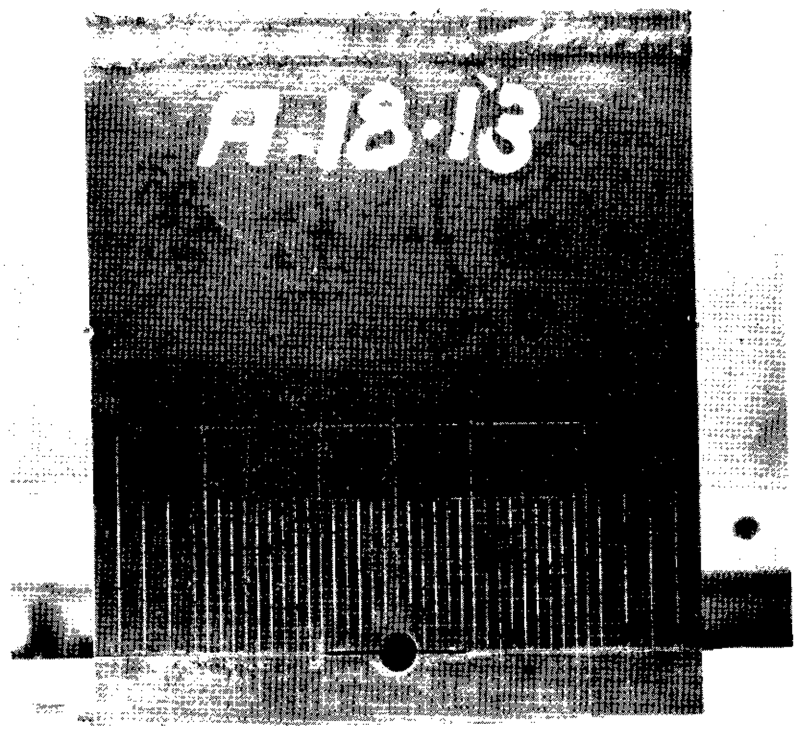


Fig. 27 - Specimen A-18-13

Lowest Energy Absorption

to Maximum Load

of all Specimens Tested

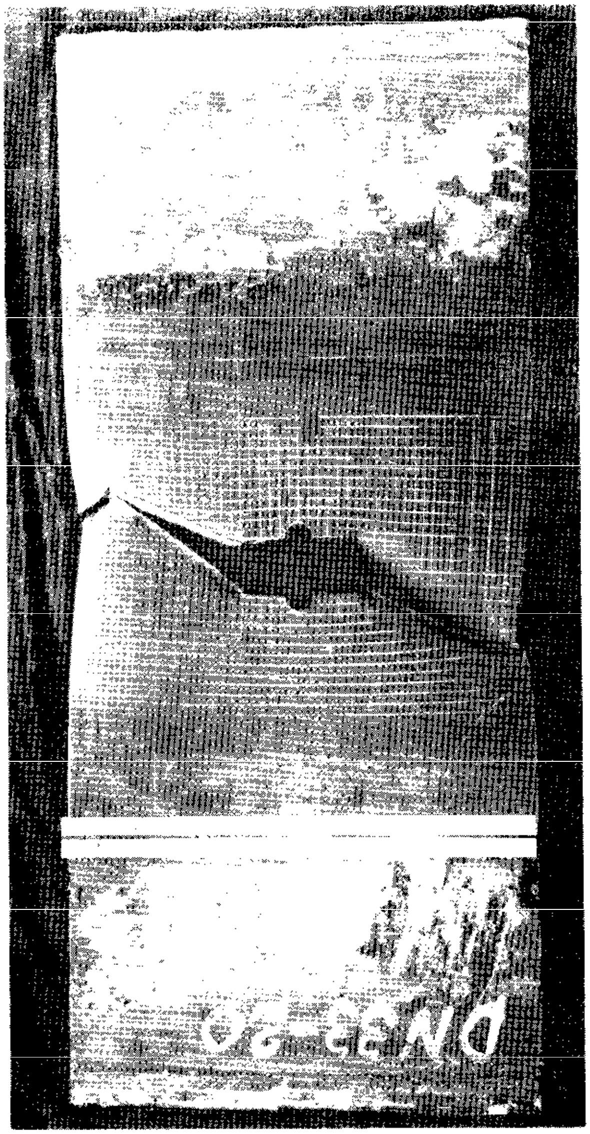


Fig. 28 - Specimen Dn-33-20

Highest Energy Absorption

to Maximum Load

of all Specimens Tested

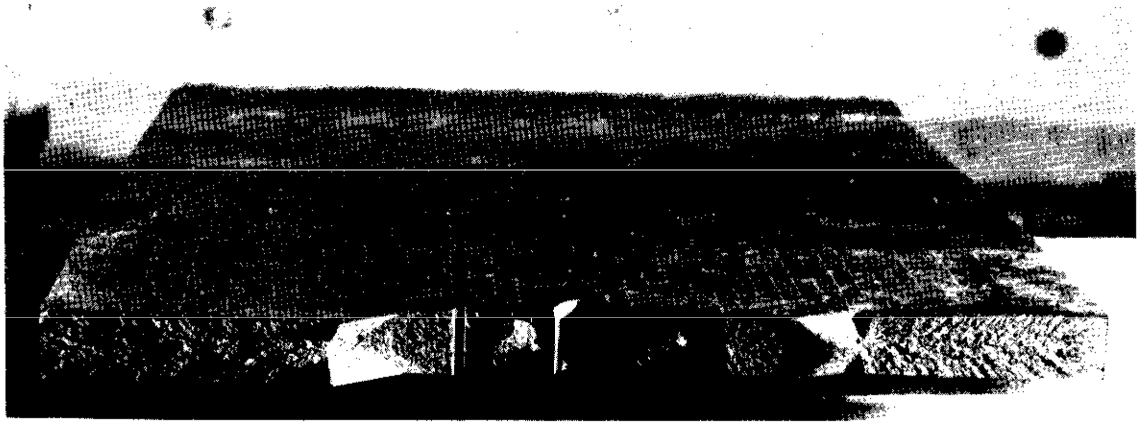


Fig. 29 - Specimen C-24-8

Example of Cleavage - Shear - Cleavage

Mode of Fracture

APPENDIX I

APPENDIX I

INSTRUMENTATION AND PREPARATION OF SPECIMENS

(1) Notching of Plates: The notch was located in the middle of the plate, and a jeweler's hack saw, 0.010" thick, was used for the last 1/8" of the notch so that the acuity obtained would be comparable with that used by other laboratories that had tested these steels. Figure I-1 shows the detail of the notch and layout of the specimen. The edges of the plates were machined. A jig saw was mounted on a base as shown in Figures I-2 and I-3 so that the saw could be moved at right angles to the axis of the piece. The depth of the saw cut could be easily controlled. Either a standard hack saw or a jeweler's hack saw can be used in the jig saw. Using this machine, notches were obtained that are similar and at right angles to the axis of the piece.

(2) Measuring Elongations Through the Elastic and Plastic Range: The problem was to design a gage which would permit the accurate measurement of elongations through the elastic and plastic range up to the point of failure. The requirement for the mounting was that the gage should not in any way be damaged by a cleavage failure. These conditions were met by mounting SR-4 gages on both sides of a flat spring, $10\frac{1}{2}$" long, mounted in ball bearing supports at the 9" gage lines. See Figs. I-4, I-5. The first SR-4 gages were affected by moisture; therefore, bakelite SR-4 gages are now used. These instruments are made up of four main parts:

(a) Gage mountings: The mountings are centered by drilling holes 1/16" in diameter and 1/16" deep on the 9" gage line at the proper distances from the edge of the plate. The hardened steel pins which are inserted in these holes are a part of the base piece which is 5/8" in diameter. This wide support insures stability. Since the width of the test specimens narrows and a given transverse plane of plate may rotate, a ball bearing is provided to permit the rotation of the mounting about the 1/16" center. The slot in which the end pivots of the gage are inserted will then remain perpendicular to the axis of the piece throughout the test. The pins on each end of the flat spring permit the flat spring to rotate freely at the ends.

(b) The second part is the flat spring with the bakelite SR-4 gages baked on.

(c) The third part is a frame for retaining the end gage mountings in position. The frame surrounds the test piece and is held in position by firm but unrestrained attachments to the specimen outside of the gage length.

(d) The fourth part consists of a coil spring which is sprung between the retention frame and the gage mounting. These springs hold the mountings in close contact with the member but are flexible so that any differential change in length bdtween the points where the gages are mounted and the points on the specimen to which the retention frame is attached will be accommodated by the movement of the spring.

These gages have proved entirely satisfactory in service and even with cleavage fracture the gages often remain in position after the break.

(3) Temperature Control Chamber: The tests necessitated raising the temperature above room temperature and lowering it to points well below room temperature. A double walled temperature control chamber of Plexiglas was built to permit visual observation. The half-tones, Figs. I-6, and I-7, show clearly the method of supporting the chamber on the test specimen. The chamber is composed of two separate boxes held against the test piece by adjustable clips. The edges of the boxes are equipped with sponge rubber which rests against a wooden member the thickness of the test plate, so that the chamber so formed can be adapted to the testing of specimens of any thickness.

In the photograph, the heating elements are shown together with fans for circulating the air.

(4) <u>Description of Cooling System:</u> The cooling system may be considered under three subheadings:

(a) Source of low temperature

(b) Measurement of temperature

(c) Control of temperature

The source of low temperature was dry ice placed in a double-walled box insulated with fibre glass and marked "A" in Figure I-8. It is supported on cantilever brackets projecting from the movable platform and has a capacity of 250 pounds of dry ice. The air passes from Box A into a mixing chamber from which two separate flexible insulated ducts marked "B" carry the cooled air, one to each half of the temperature control chamber made of Plexiglas and marked "C".

In the bottom of either half of the control chamber is a diffuser "D", having many small holes. After passing through the control chamber, the air is conducted through insulated ducts marked "E", similar to the ducts marked "B", to an insulated box containing a centrifugal blower marked "F", driven by the motor shown in Figure <u>I-8.</u> Between the fan chamber and the dry ice box the slide valve "G" is inserted. This valve is operated manually by raising or lowering the slide.

To determine the temperature of the specimen, thermocouples are located at three points on the specimen: (1) in the 3/4" drill hole; (2) at a point just above the 0.010" notch in the specimen; (3) $5\frac{1}{2}$" above the center of the notch. The fourth thermocouple measures the temperature of the air. The potentiometer for these measurements is shown at "J" and the galvanometer at "K" in Figure <u>I-8.</u>

The ends of the test specimen are covered with sheets of cellular rubber as at "H", and insulating shims are placed between the grips and the spacers of the upper and lower crossheads. The ducts carrying the cold air to the Plexiglas chamber are insulated by wrapping fibre glass around the tubes and covering them with muslin. This muslin has been coated with asphalt paint to prevent the moisture from entering the insulation.

This method has proved satisfactory; the temperature differential between the gage at the 0.010" notch and that 5½" above the center of the notch was 1.5° for specimen tested at 17°. For specimen tested at 62°F the differential between these points was 0.1°F.

(5) Accessories are Mounted on Elevator: The elevator attached to the columns supplies sufficient area so that all of the electrical apparatus used in connection with the gage assembly and also the cooling box with the necessary blowers, can be mounted near the specimen.

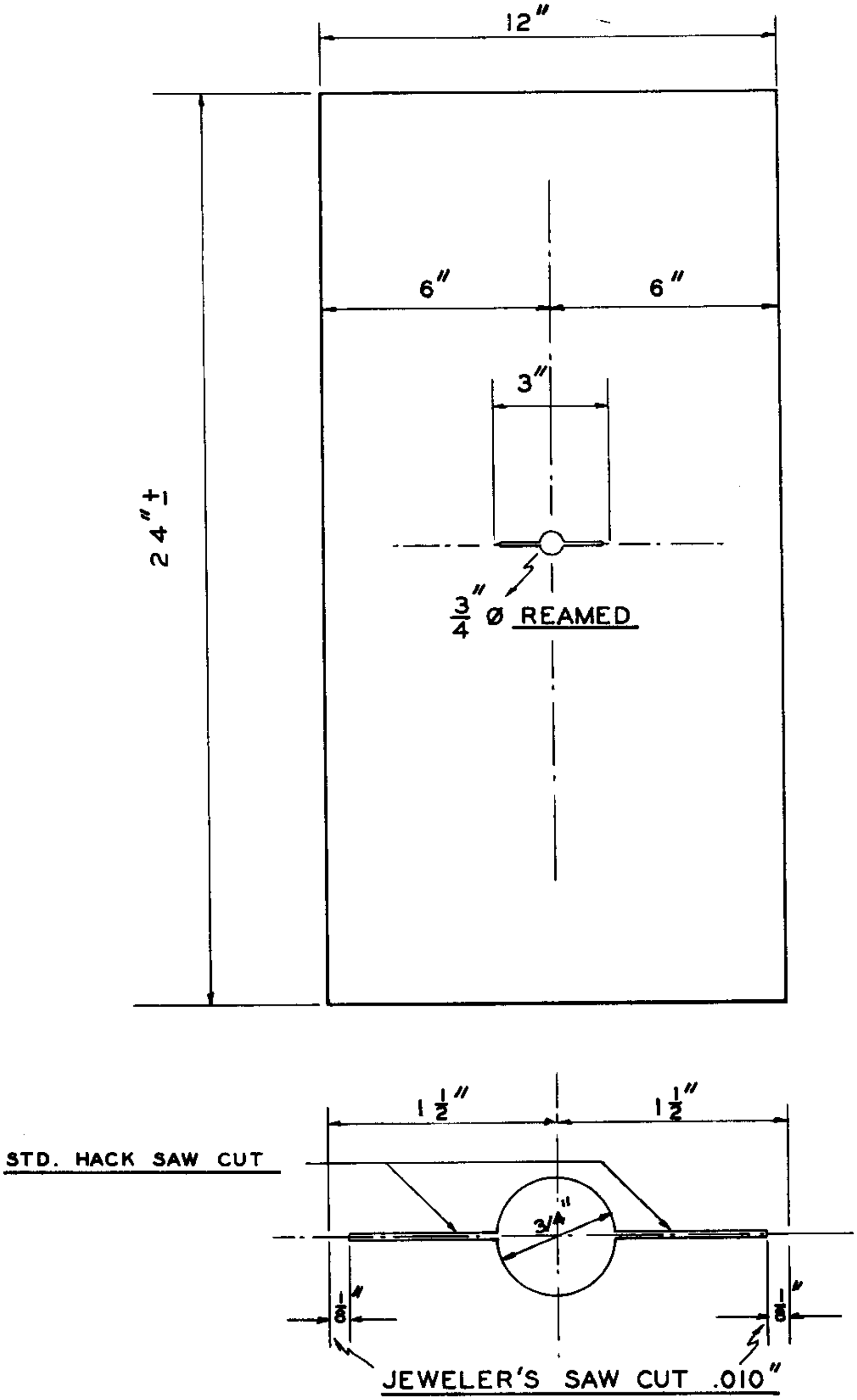


FIG. I-1

NOTCH LAYOUT

SWARTHMORE COLLEGE

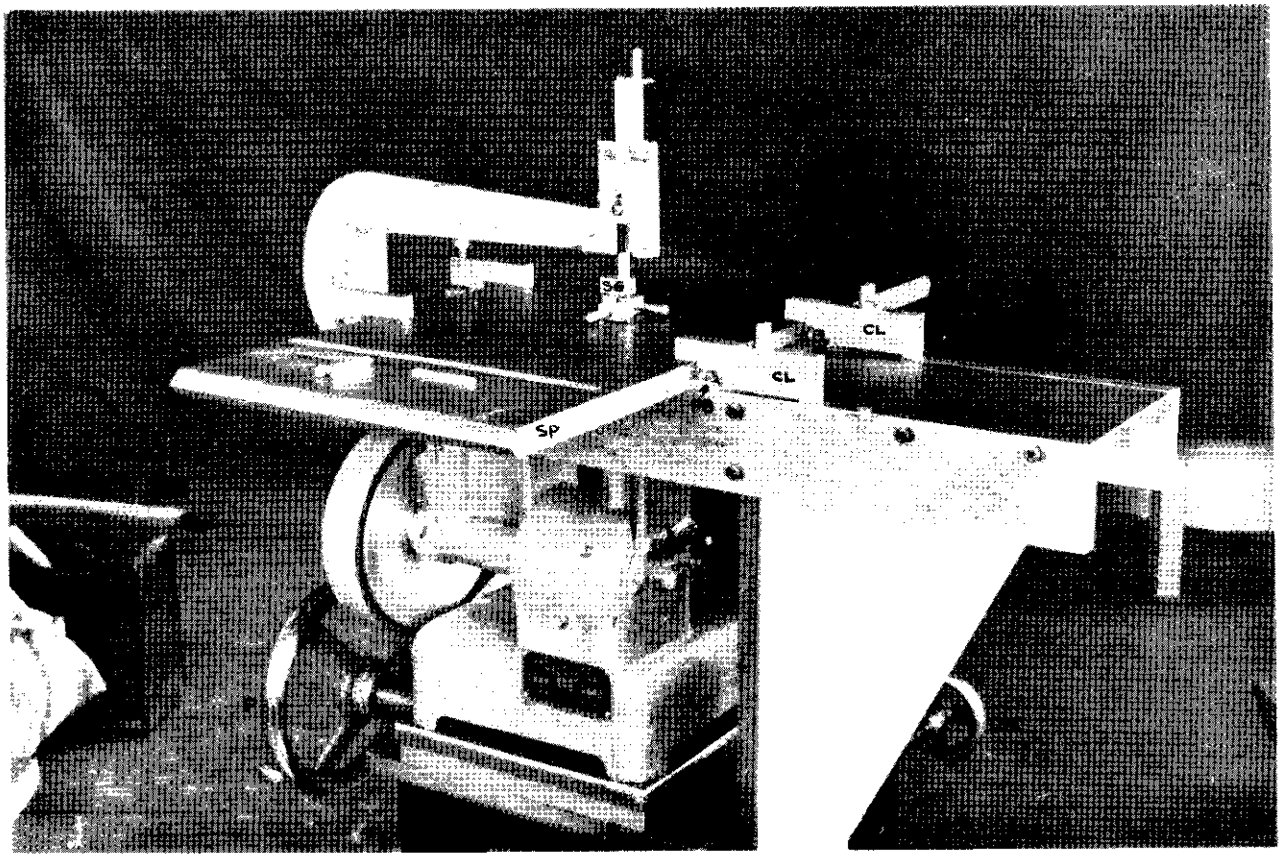


Fig. I-3 JIG SAW ASSEMBLY

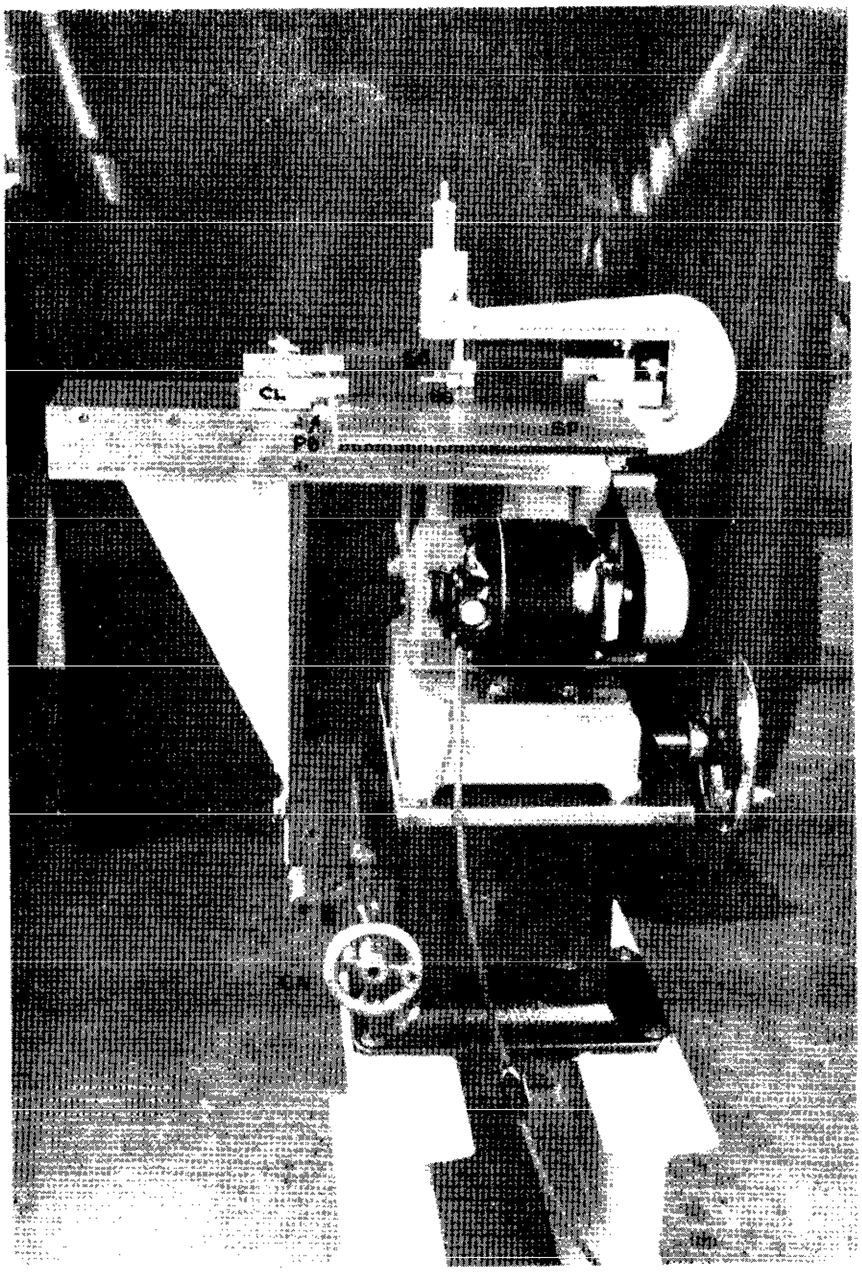


Fig. I-3 JIG SAW ASSEMBLY

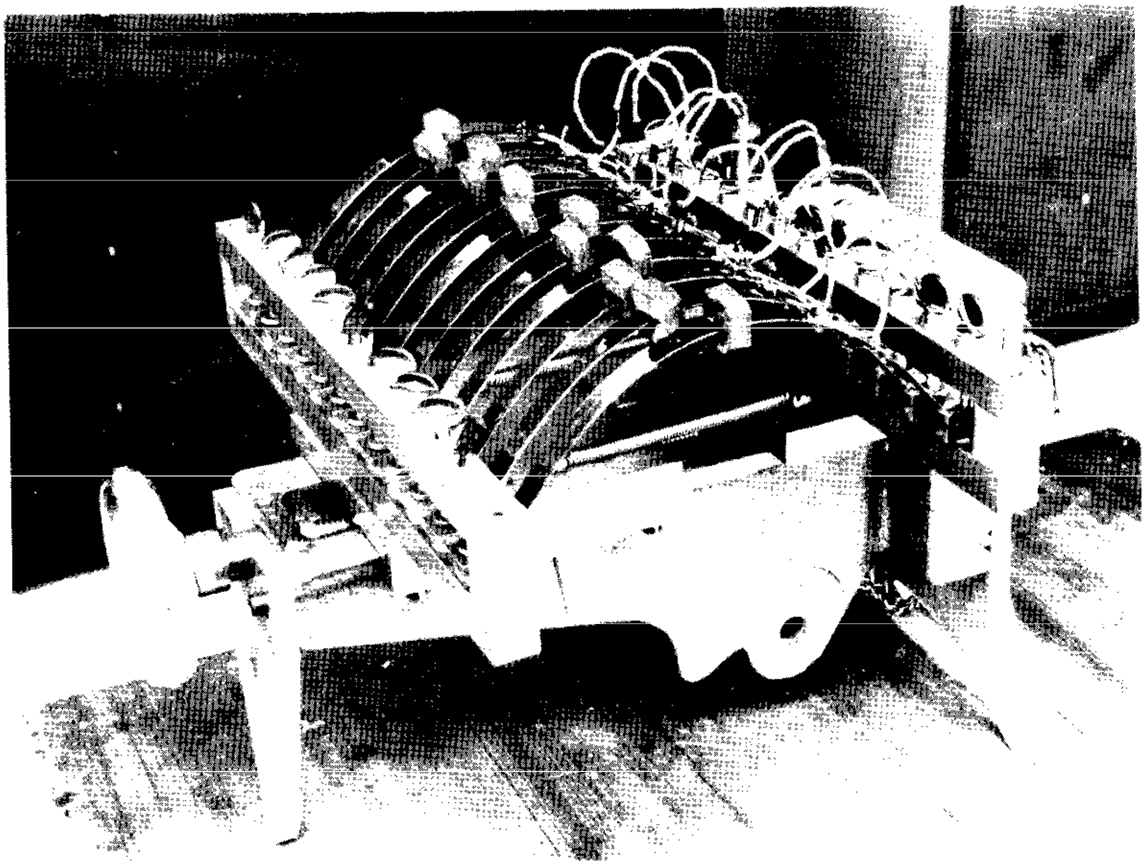


Fig. I-4 GAGES IN CALIBRATOR

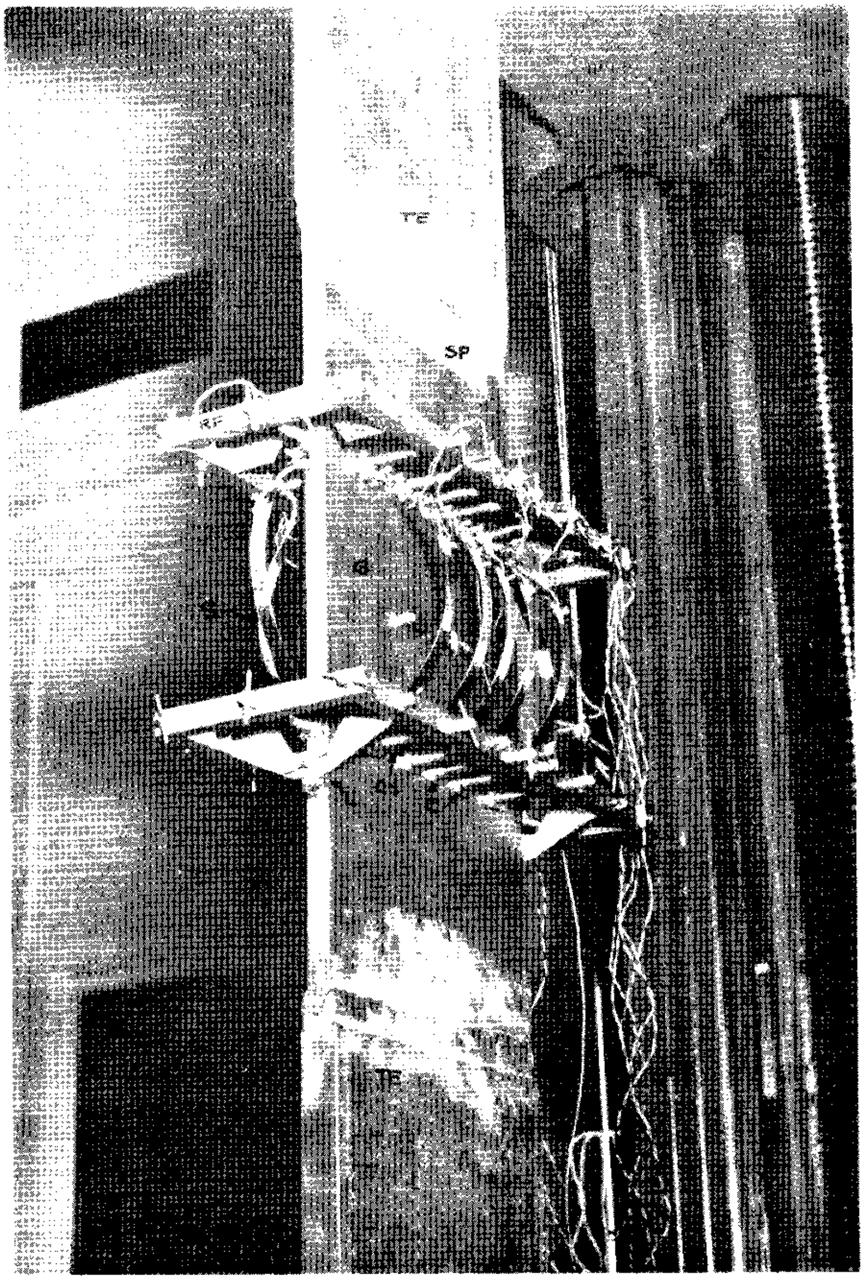


Fig. I-5 GAGE ASSEMBLY

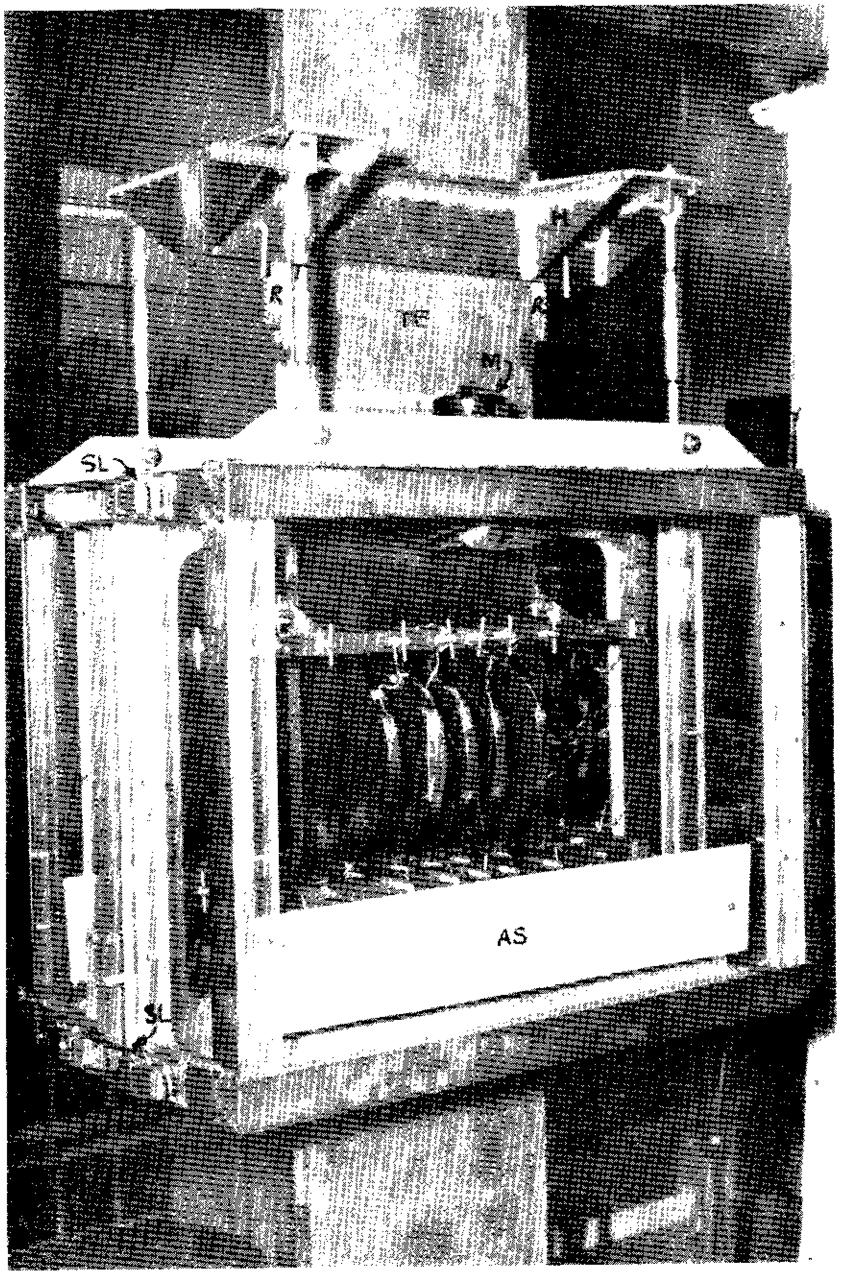


Fig. I-6

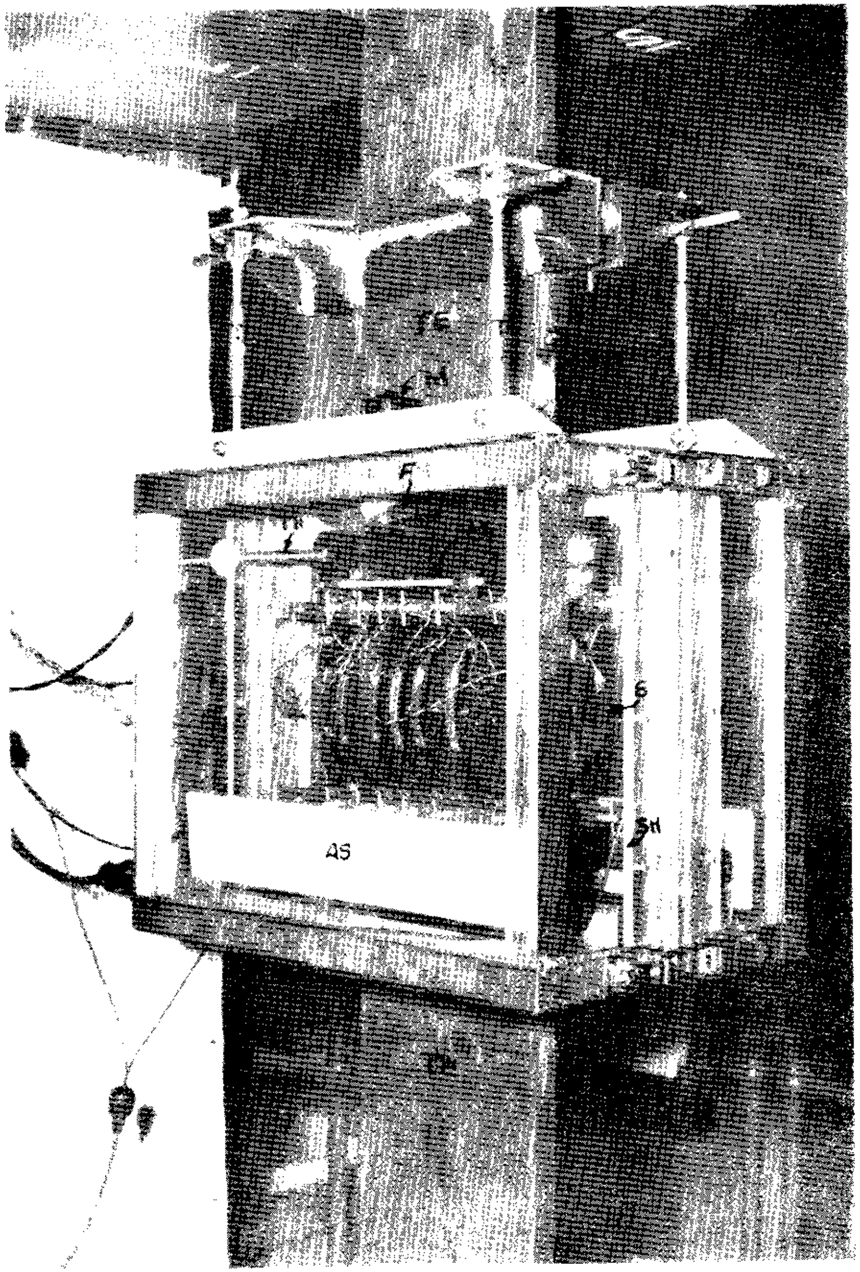


Fig. I-7

PLEXIGLAS CHAMBER

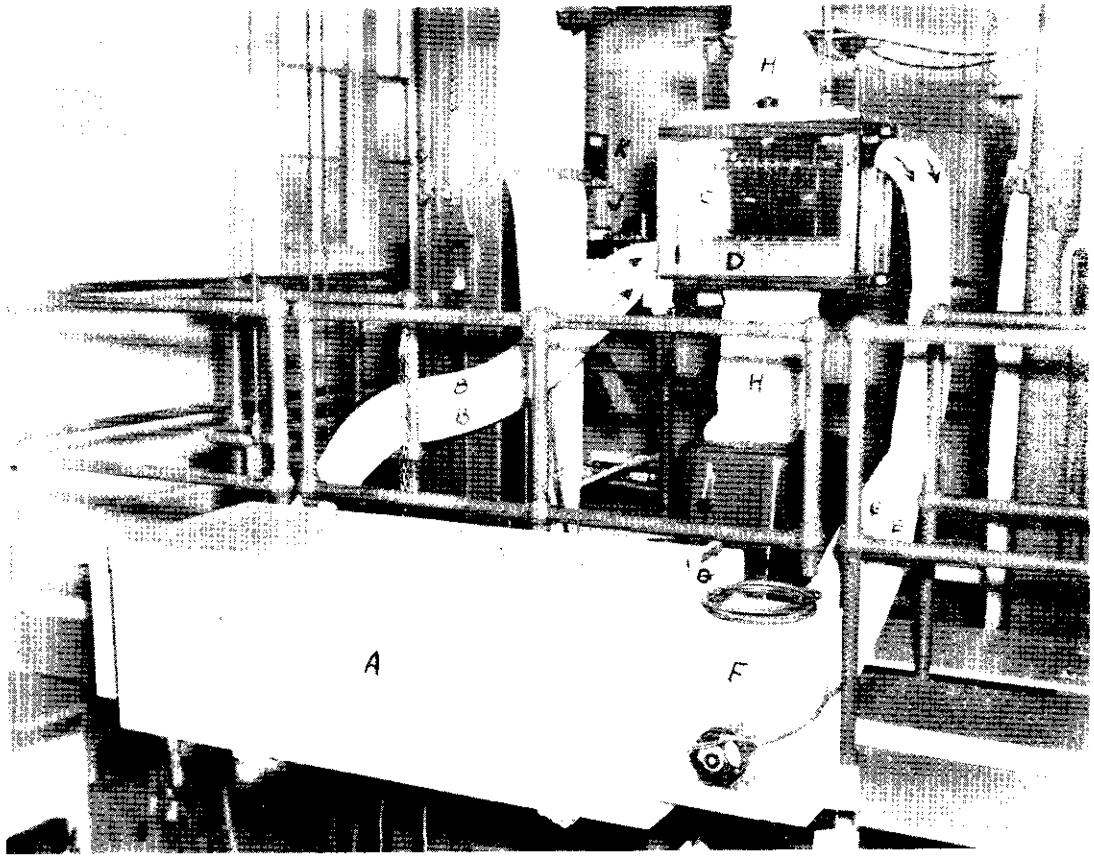


Fig. I-8 COOLING MECHANISM

APPENDIX II

APPENDIX II

Notes on Load-Elongation Curves

It may be noted that some temperatures shown on the load-elongation curves are indicated to one degree F and others to one-tenth of a degree F. This is due to the fact that more precise temperature-measuring equipment was available for the latter tests. For tests run with this instrumentation the average temperature at the 3/4" drill-hole is given together with its variation during the test.

An observation concerning the shape of the load-elongation curve may also be made. In the first tests run it was considered sufficient to take readings and plot values of elongation of the order of .05 inch over a gage length of nine inches. While this does not alter the energy values significantly, it does tend to obscure some of the finer details of specimen behavior. In view of this, the testing procedure was altered to record and plot more points along the load-elongation curve. As a result a rather characteristic shape of the curve preceding cleavage fracture has been noticed; i.e., a rapidly increasing slope as the material begins to behave in a brittle fashion. Examples of this are to be seen for the following tests:

Figure 2A - A-19-11
Figure 7A - A-19-1
Figure 13A- A-18-14
Figure 10C- C-24-15

However, this type of response is not exclusively associated with cleavage fracture since it also is evident in ductile specimens such as

Figure 9A - A-19-12
Figure 16C - C-24-3

It is also brought to the reader's attention that a dashed portion near the end of the load-elongation curve indicates either an estimated fracture load or estimated fracture elongation, or both. In a few tests one-half of the specimen failed before the other. When this occurred the load-elongation curve was terminated at the last load at which both sides were still intact.

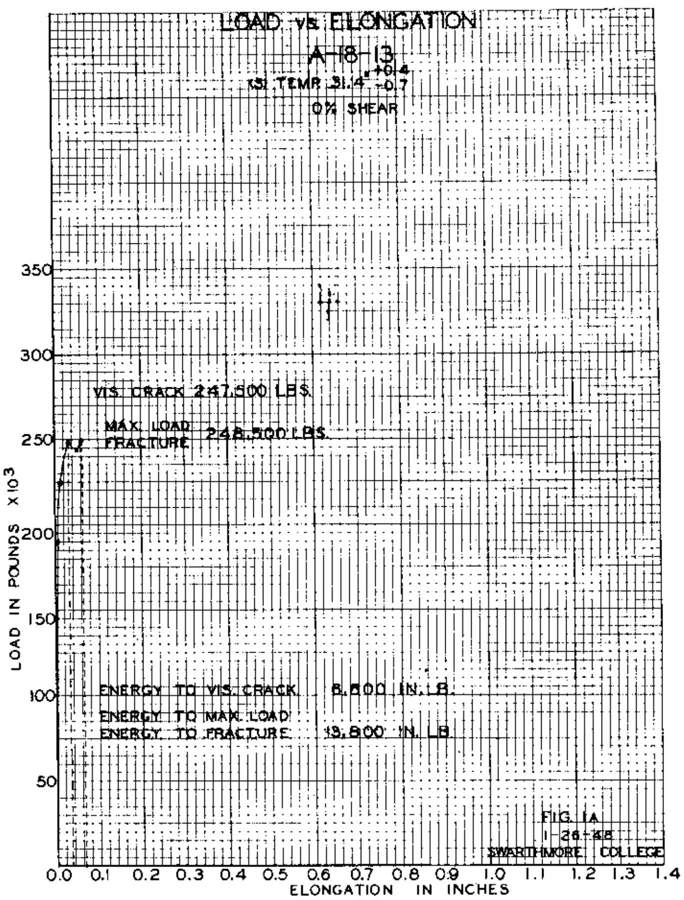


FIG. 1A
1-26-48

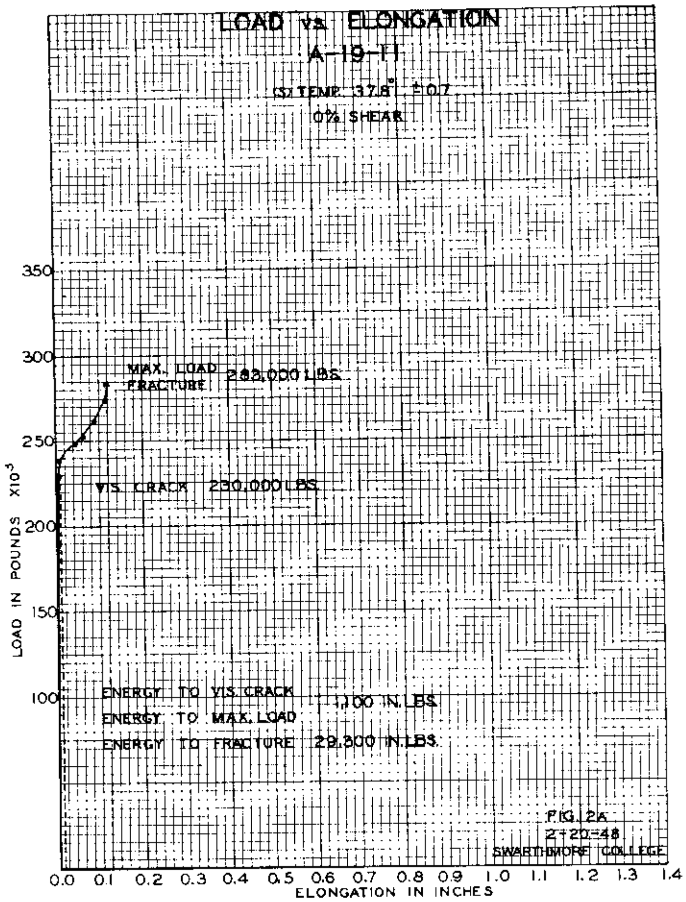


FIG. 2A
2-20-48

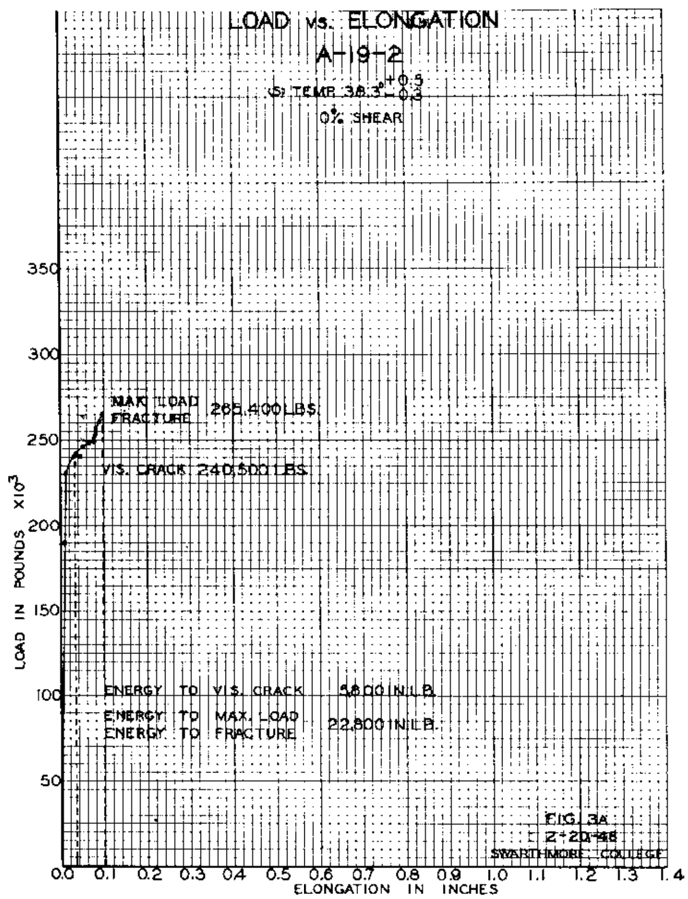


FIG. 3A
2-20-48

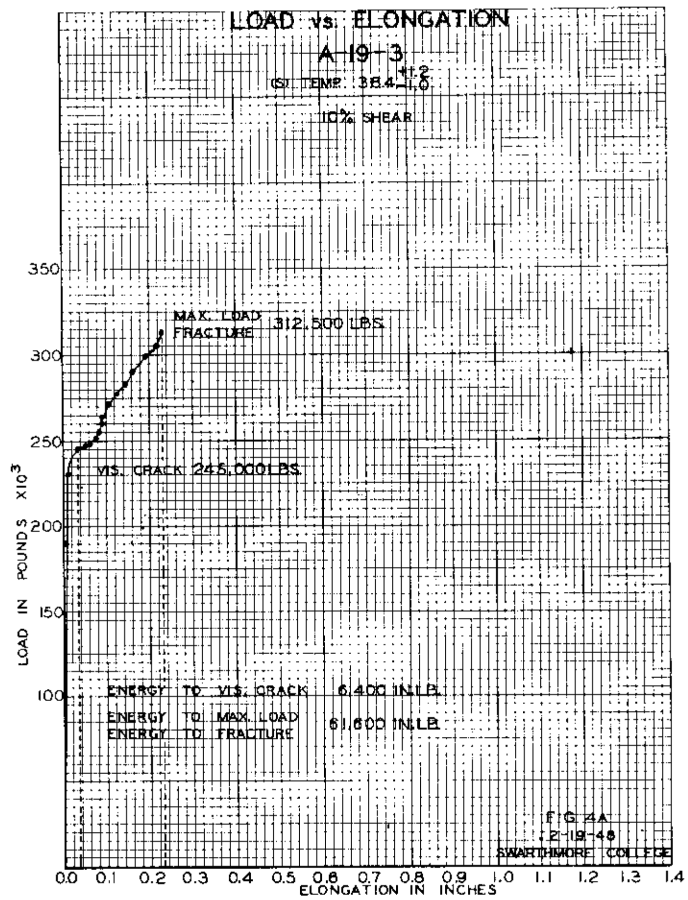
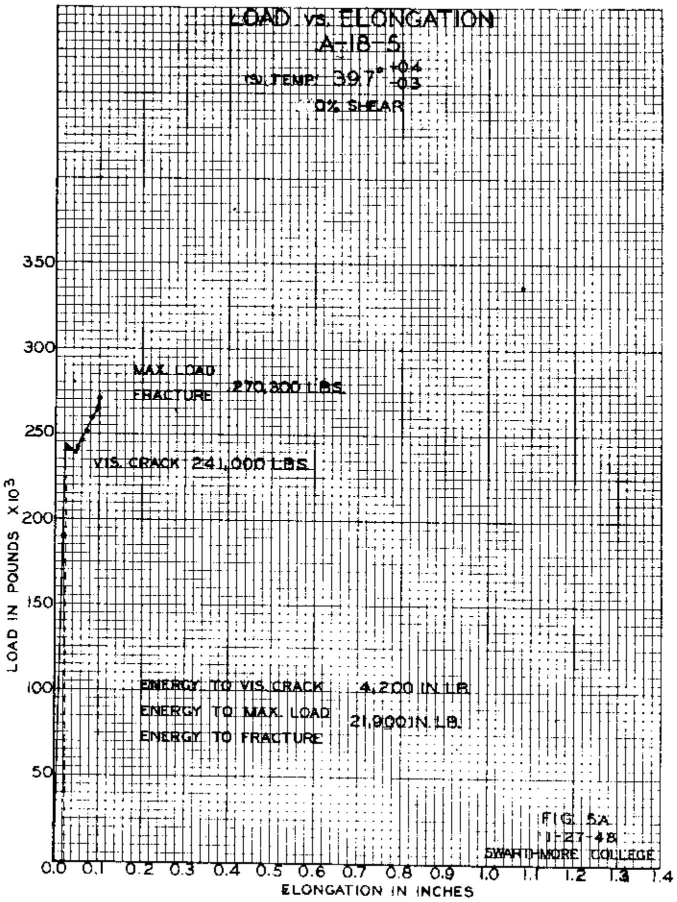
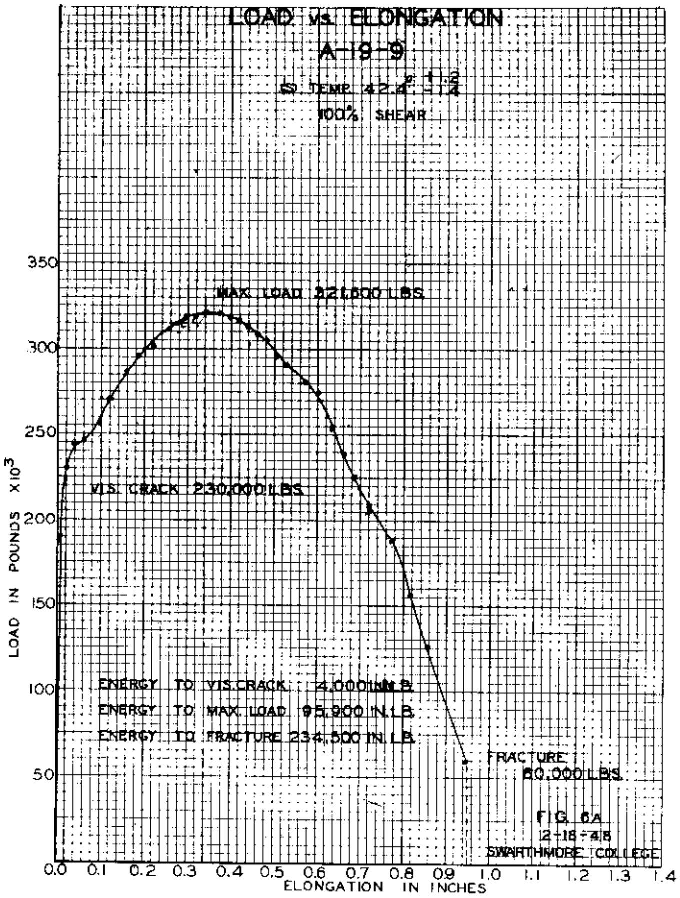
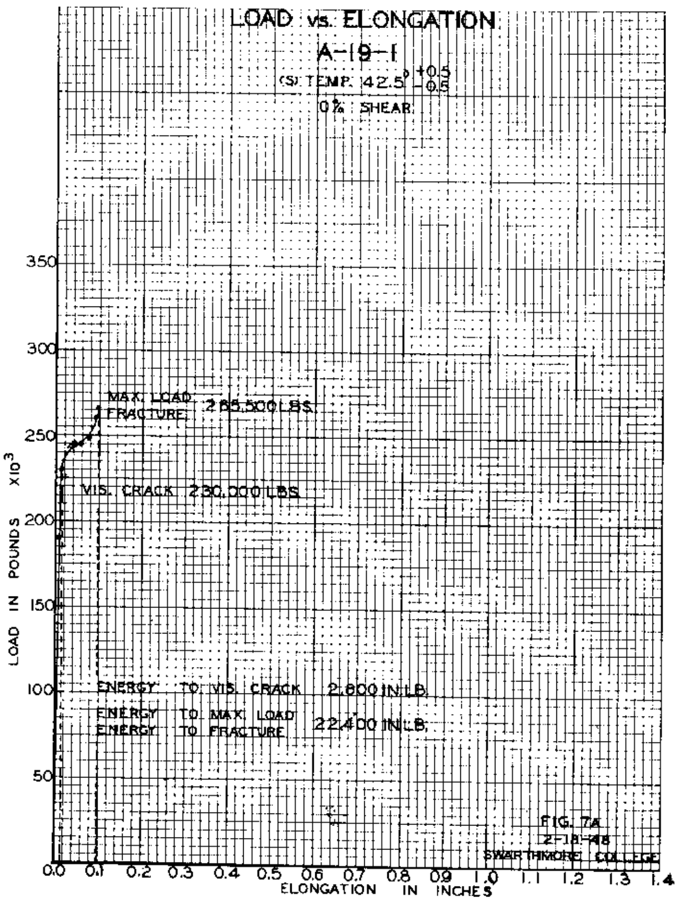
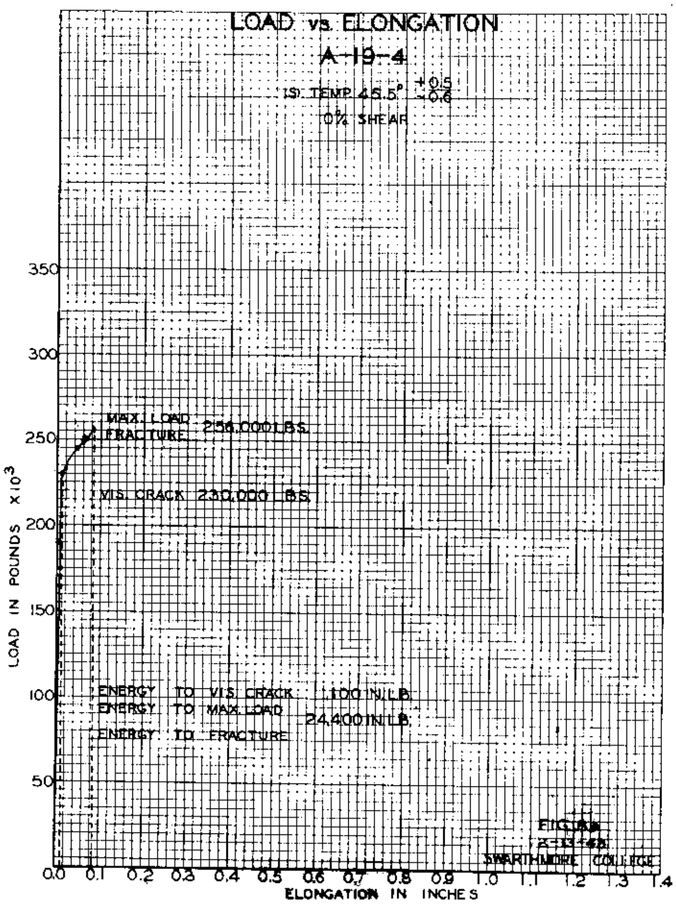


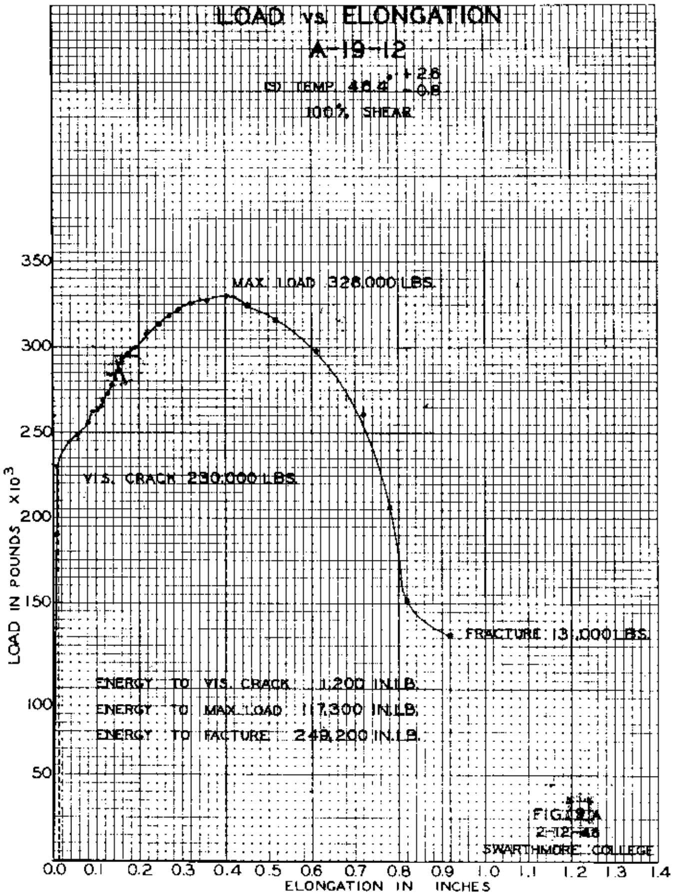
FIG. 4A
2-19-48

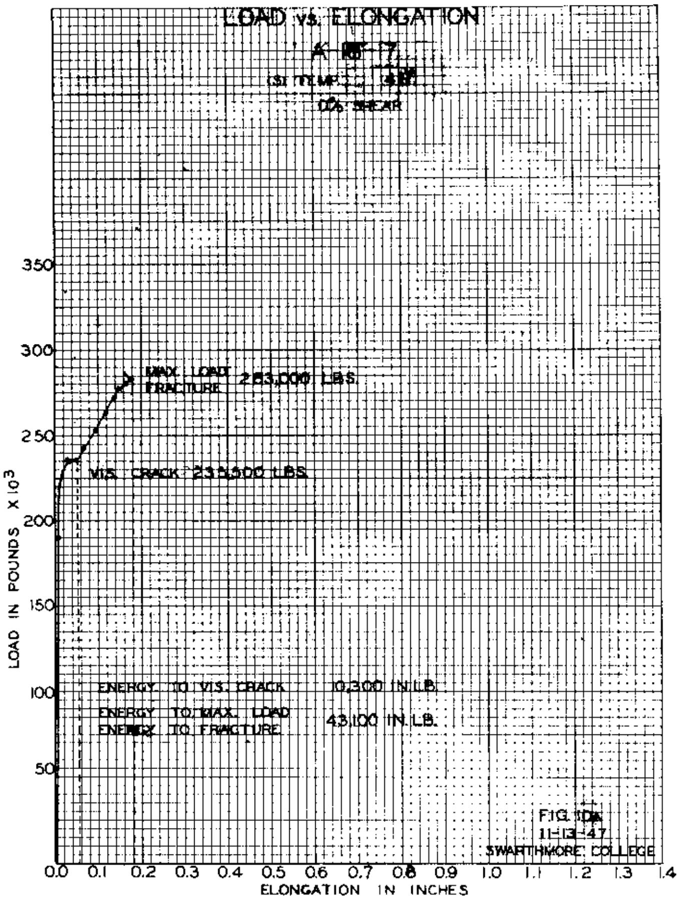

LOAD vs. ELONGATION
A-18-5
(S) TEMP. 39.7° +0.4 -0.3
0% SHEAR
MAX. LOAD
FRACTURE 270,300 LBS.
VIS. CRACK 241,000 LBS.
ENERGY TO VIS. CRACK 4,200 IN. LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 21,900 IN. LB.
FIG. 5A
1-27-48
SWARTHMORE COLLEGE
LOAD IN POUNDS X10³
ELONGATION IN INCHES
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
50 100 150 200 250 300 350

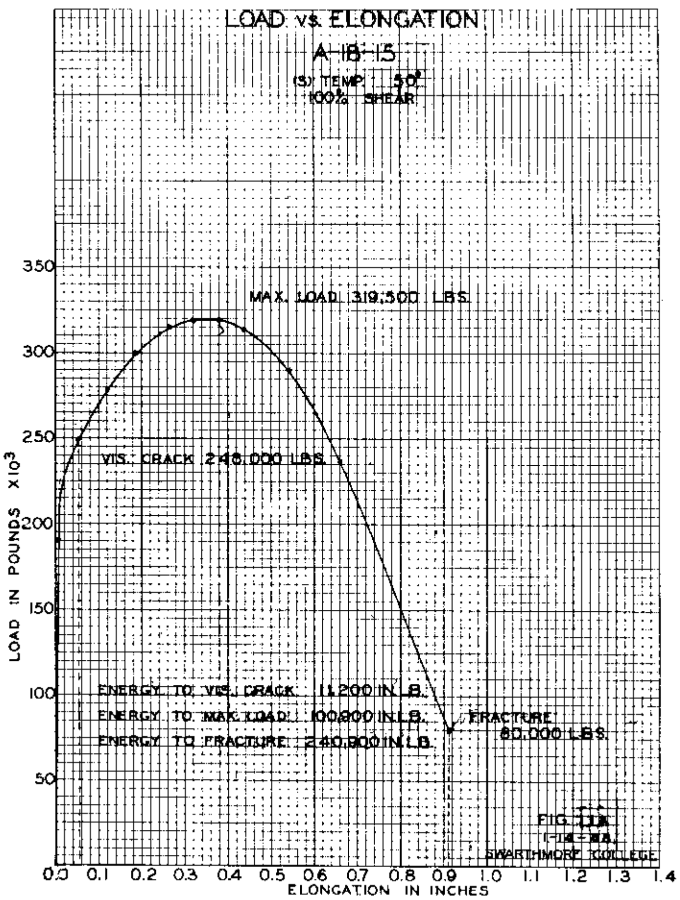

LOAD vs. ELONGATION
A-19-9
(S) TEMP. 42.4°
100% SHEAR
MAX. LOAD
VIS. CRACK 230,000 LBS.
ENERGY TO VIS. CRACK 4,000 IN. LB.
ENERGY TO MAX. LOAD 95,900 IN. LB.
ENERGY TO FRACTURE 234,500 IN. LB.
FRACTURE
60,000 LBS.
FIG. 6A
2-18-48
SWARTHMORE COLLEGE
LOAD IN POUNDS X10³
ELONGATION IN INCHES
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
50 100 150 200 250 300 350

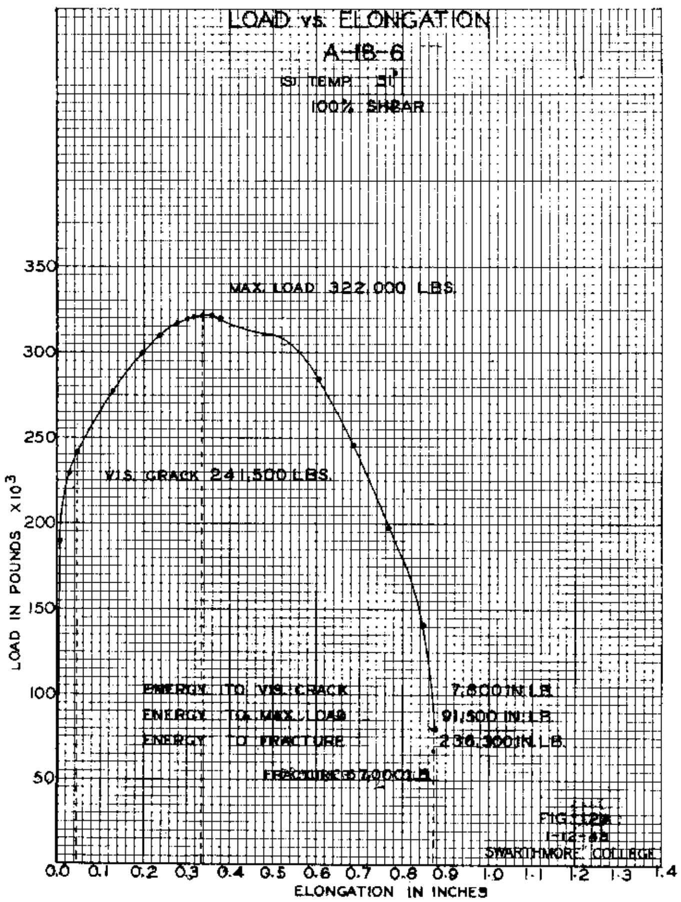

LOAD vs. ELONGATION
A-19-1
(S) TEMP. 42.5° +0.5 -0.5
0% SHEAR
MAX. LOAD
FRACTURE 265,500 LBS.
VIS. CRACK 230,000 LBS.
ENERGY TO VIS. CRACK 2,800 IN. LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 22,400 IN. LB.
FIG. 7A
2-18-48
SWARTHMORE COLLEGE
LOAD IN POUNDS X10³
ELONGATION IN INCHES
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
50 100 150 200 250 300 350

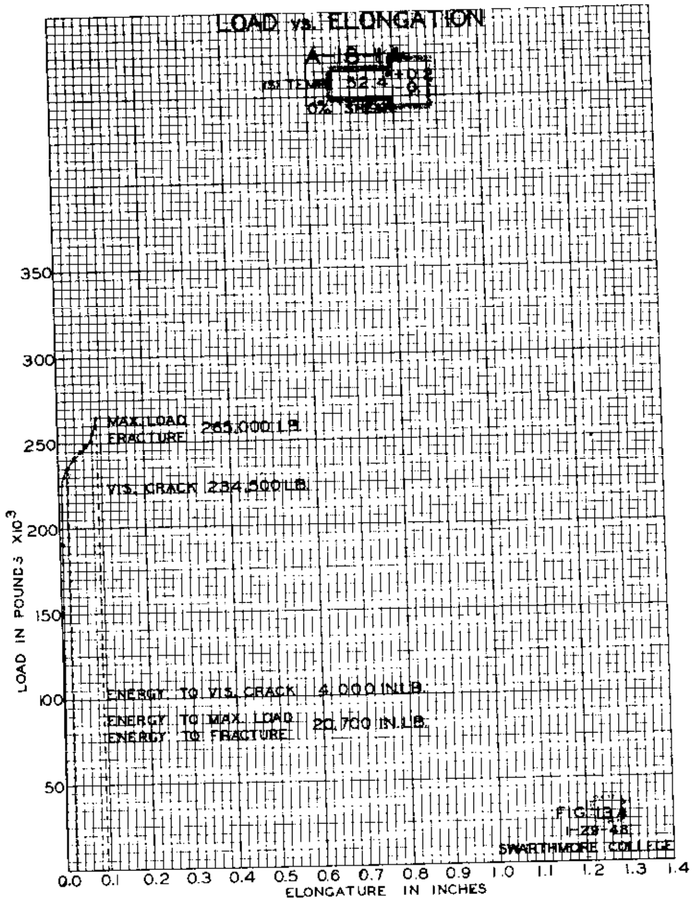

LOAD vs. ELONGATION
A-19-4
(S) TEMP. 45.5° +0.5 -0.6
0% SHEAR
MAX. LOAD
FRACTURE 256,000 LBS.
VIS. CRACK 230,000 LBS.
ENERGY TO VIS. CRACK 100 IN. LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 24,400 IN. LB.
SWARTHMORE COLLEGE
LOAD IN POUNDS X10³
ELONGATION IN INCHES
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
50 100 150 200 250 300 350

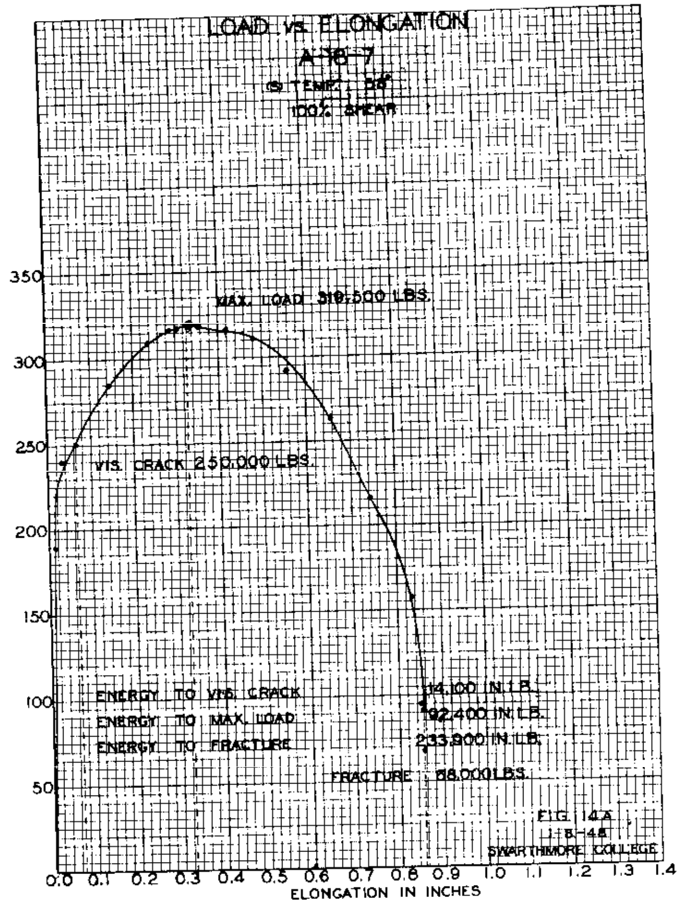

LOAD vs. ELONGATION
A-19-12
(S) TEMP. 48.4° +2.8 -0.8
100% SHEAR
MAX. LOAD 328,000 LBS.
VIS. CRACK 230,000 LBS.
FRACTURE 131,000 LBS.
ENERGY TO VIS. CRACK 1,200 IN.LB.
ENERGY TO MAX. LOAD 117,300 IN.LB.
ENERGY TO FACTURE 249,200 IN.LB.
2-12-48
SWARTHMORE COLLEGE
LOAD IN POUNDS X10³
ELONGATION IN INCHES

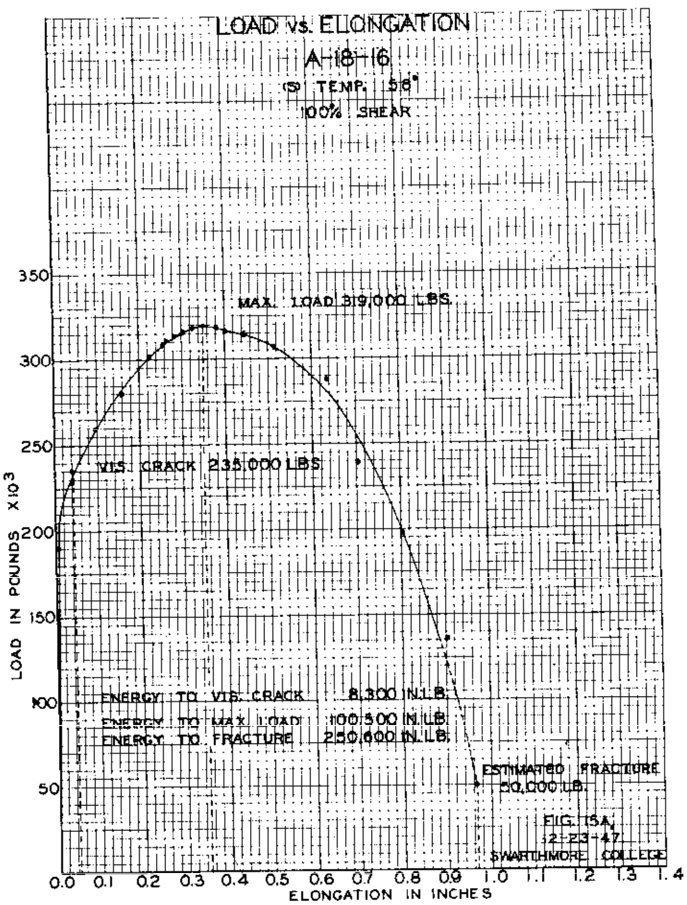

LOAD vs. ELONGATION
0% SHEAR
MAX. LOAD
FRACTURE 283,000 LBS.
VIS. CRACK 233,500 LBS.
ENERGY TO VIS. CRACK 10,300 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 43,100 IN.LB.
11-13-47
SWARTHMORE COLLEGE
LOAD IN POUNDS X10³
ELONGATION IN INCHES

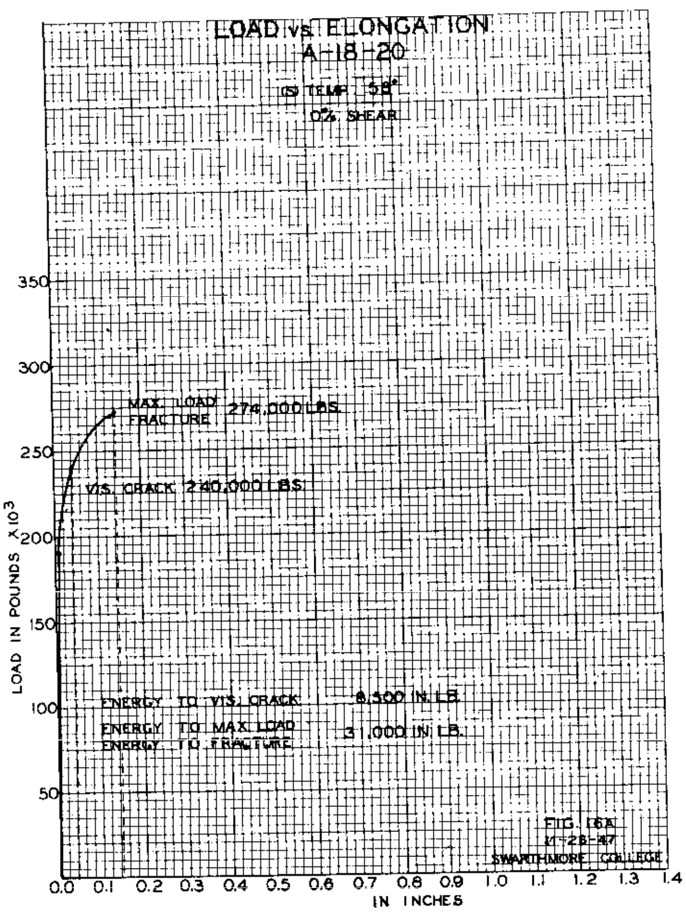

LOAD vs. ELONGATION
A-18-15
(S) TEMP. 50°
100% SHEAR
MAX. LOAD 319,500 LBS.
VIS. CRACK 248,000 LBS.
FRACTURE 80,000 LBS.
ENERGY TO VIS. CRACK 11,200 IN.LB.
ENERGY TO MAX. LOAD 100,800 IN.LB.
ENERGY TO FRACTURE 240,800 IN.LB.
SWARTHMORE COLLEGE
LOAD IN POUNDS X10³
ELONGATION IN INCHES

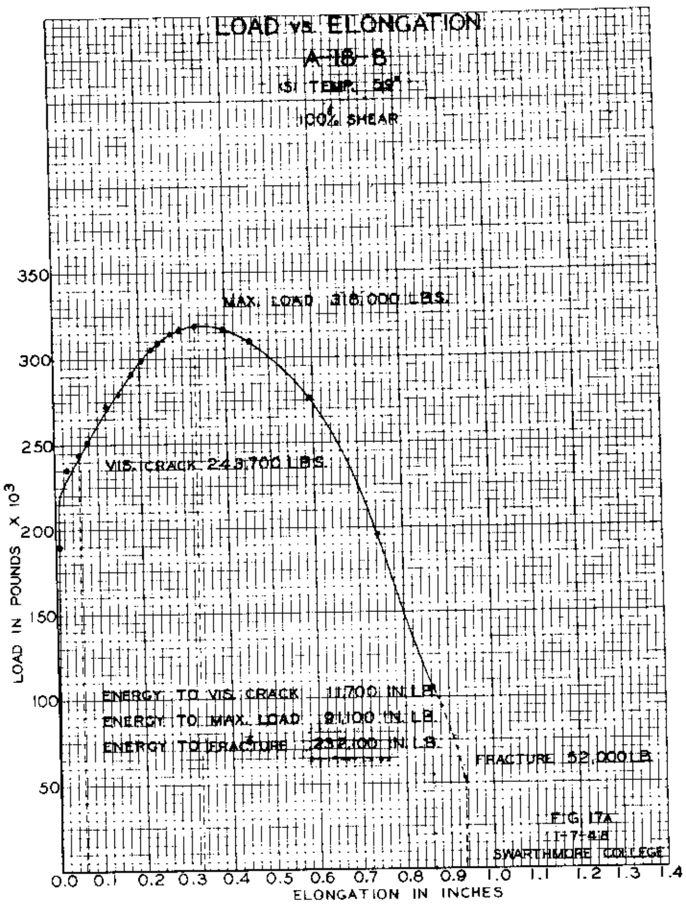

LOAD vs. ELONGATION
A-18-6
(S) TEMP. 51°
100% SHEAR
MAX. LOAD 322,000 LBS.
VIS. CRACK 241,500 LBS.
ENERGY TO VIS. CRACK 7,800 IN.LB.
ENERGY TO MAX. LOAD 91,500 IN.LB.
ENERGY TO FRACTURE 236,300 IN.LB.
SWARTHMORE COLLEGE
LOAD IN POUNDS X10³
ELONGATION IN INCHES

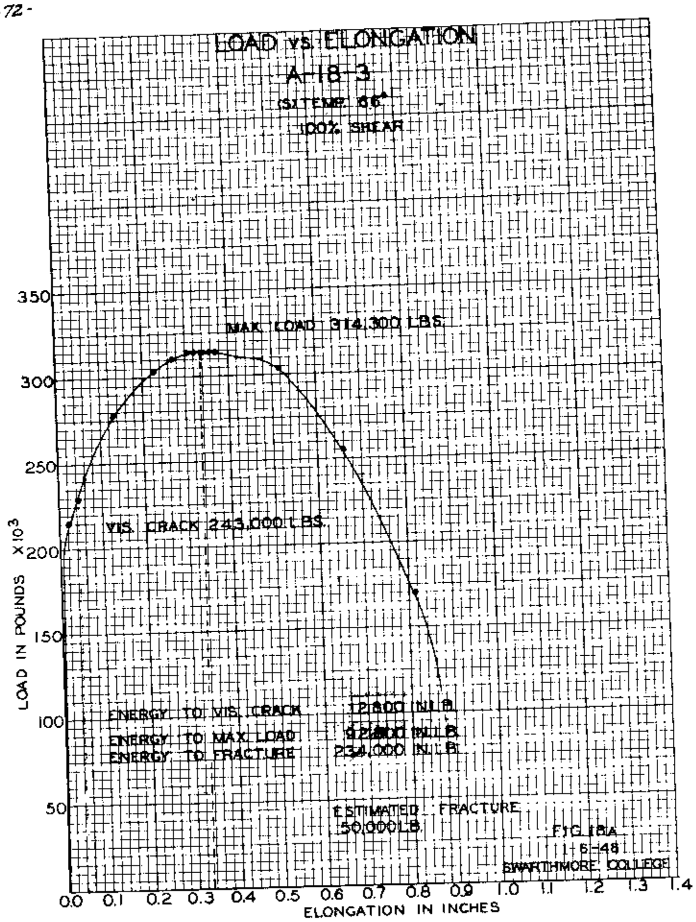

LOAD vs. ELONGATION
(S) TEMP. 52.4
0% SHEAR
MAX. LOAD
FRACTURE 265,000 LB.
VIS. CRACK 234,500 LB.
ENERGY TO VIS. CRACK 4,000 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 20,700 IN.LB.
FIG. 13A
1-29-48
SWARTHMORE COLLEGE
LOAD IN POUNDS X10³
ELONGATURE IN INCHES

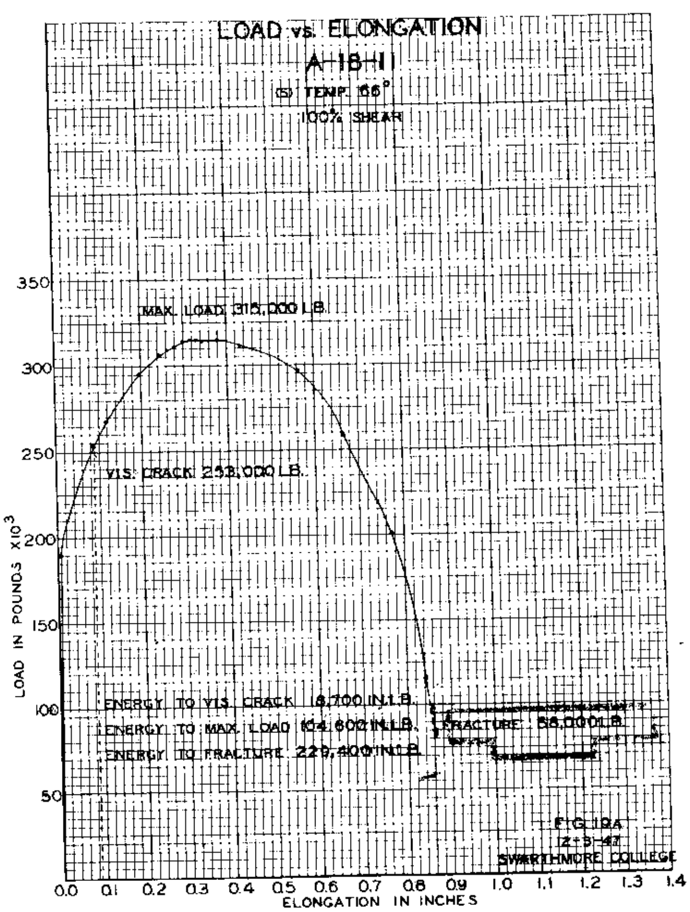

LOAD vs. ELONGATION
A-18-7
(S) TEMP. 58°
100% SHEAR
MAX. LOAD 319,500 LBS.
VIS. CRACK 250,000 LBS.
ENERGY TO VIS. CRACK 14,100 IN.LB.
ENERGY TO MAX. LOAD 92,400 IN.LB.
ENERGY TO FRACTURE 233,900 IN.LB.
FRACTURE 88,000 LBS.
FIG. 14A
1-8-48
SWARTHMORE COLLEGE
ELONGATION IN INCHES

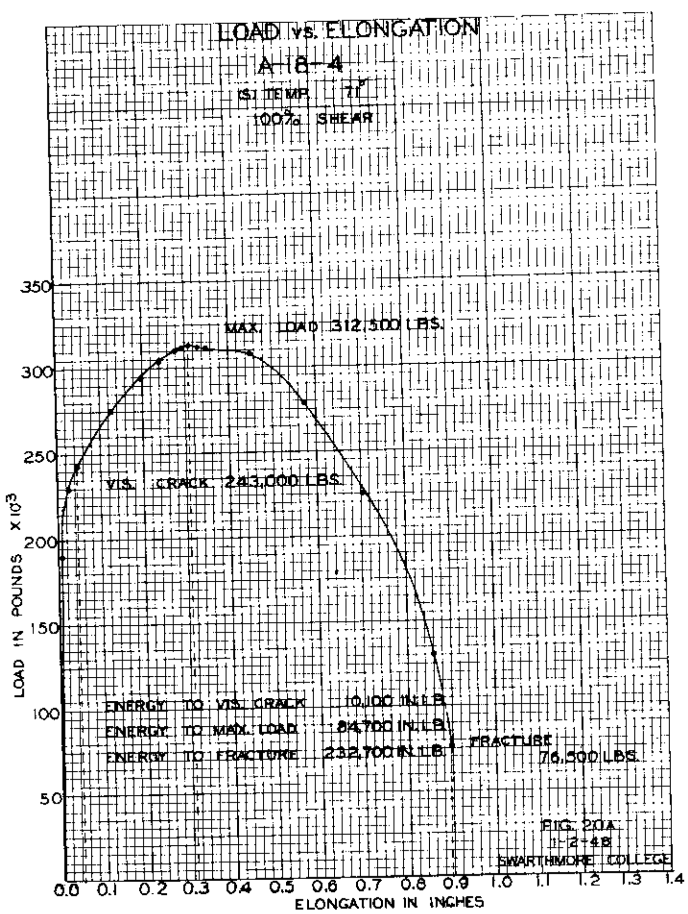

LOAD vs. ELONGATION
A-18-16
(S) TEMP. 58°
100% SHEAR
MAX. LOAD 319,000 LBS.
VIS. CRACK 235,000 LBS.
ENERGY TO VIS. CRACK 8,300 IN.LB.
ENERGY TO MAX. LOAD 100,500 IN.LB.
ENERGY TO FRACTURE 250,600 IN.LB.
ESTIMATED FRACTURE
50,000 LB.
FIG. 15A
12-23-47
SWARTHMORE COLLEGE
LOAD IN POUNDS X10³
ELONGATION IN INCHES

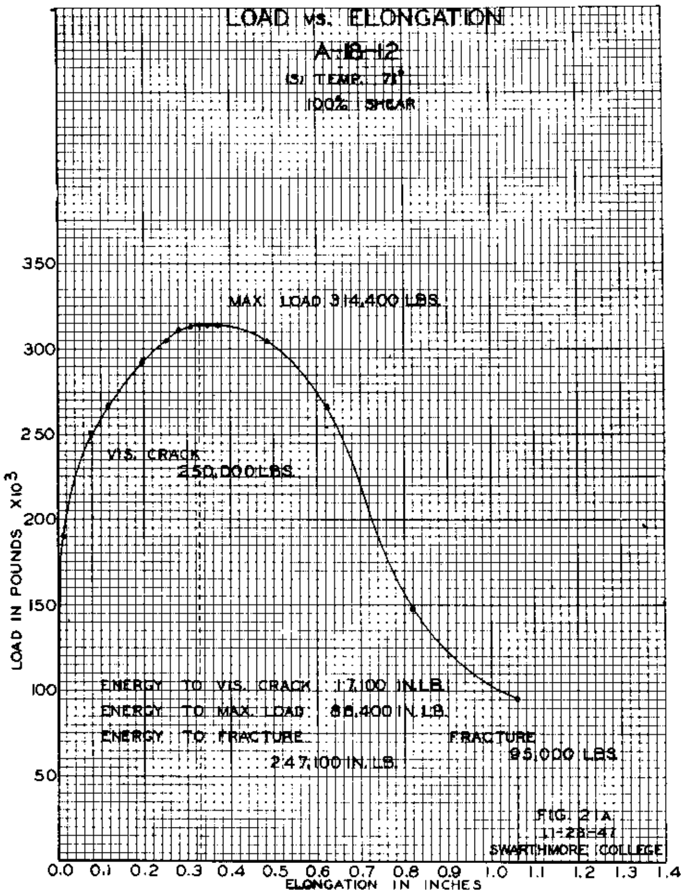

LOAD vs. ELONGATION
A-18-20
(S) TEMP. 58°
0% SHEAR
MAX. LOAD
FRACTURE 274,000 LBS.
VIS. CRACK 240,000 LBS.
ENERGY TO VIS. CRACK 8,500 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 31,000 IN.LB.
FIG. 16A
11-26-47
SWARTHMORE COLLEGE
LOAD IN POUNDS X10³
IN INCHES

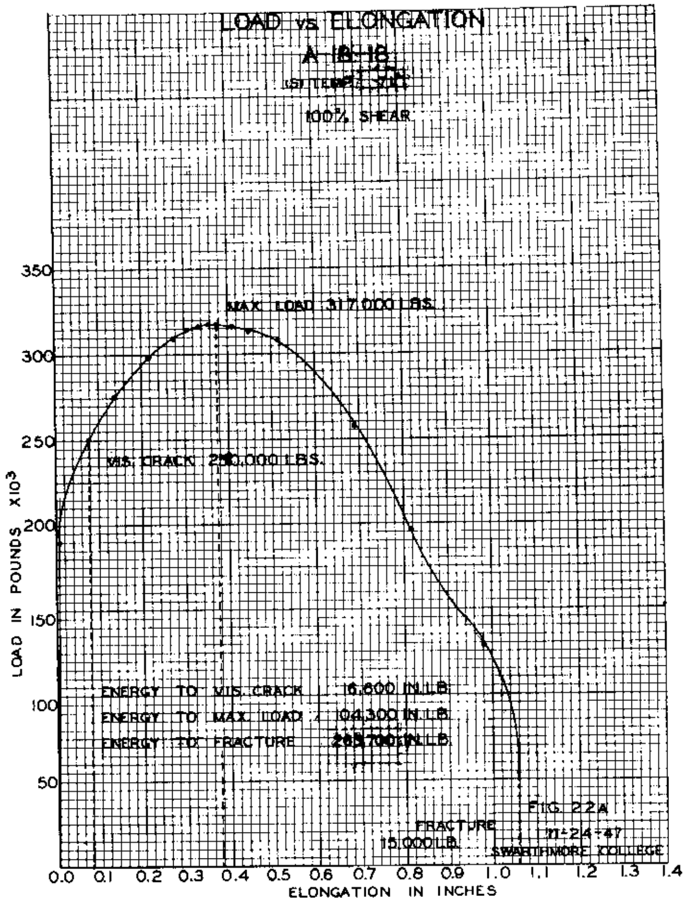

LOAD vs. ELONGATION
A-18-8
(S) TEMP. 59°
100% SHEAR
MAX. LOAD 318,000 LBS.
VIS. CRACK 243,700 LBS.
ENERGY TO VIS. CRACK 11,700 IN.LB.
ENERGY TO MAX. LOAD 91,100 IN.LB.
ENERGY TO FRACTURE 232,100 IN.LB.
FRACTURE 52,000 LB.
FIG. 17A
1-7-48
SWARTHMORE COLLEGE
LOAD IN POUNDS X 10³
ELONGATION IN INCHES

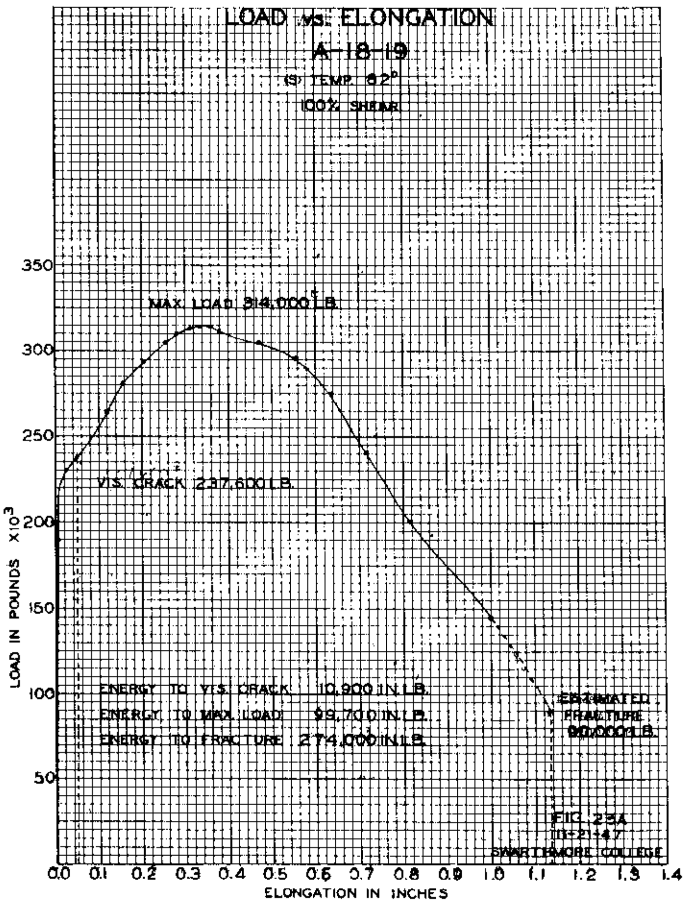

LOAD vs. ELONGATION
A-18-3
(S) TEMP. 66°
100% SHEAR
MAX. LOAD 314,300 LBS.
VIS. CRACK 243,000 LBS.
ENERGY TO VIS. CRACK 12,800 IN.LB.
ENERGY TO MAX. LOAD 92,800 IN.LB.
ENERGY TO FRACTURE 234,000 IN.LB.
ESTIMATED FRACTURE 50,000 LB.
FIG. 18A
1-6-48
SWARTHMORE COLLEGE
LOAD IN POUNDS X 10³
ELONGATION IN INCHES

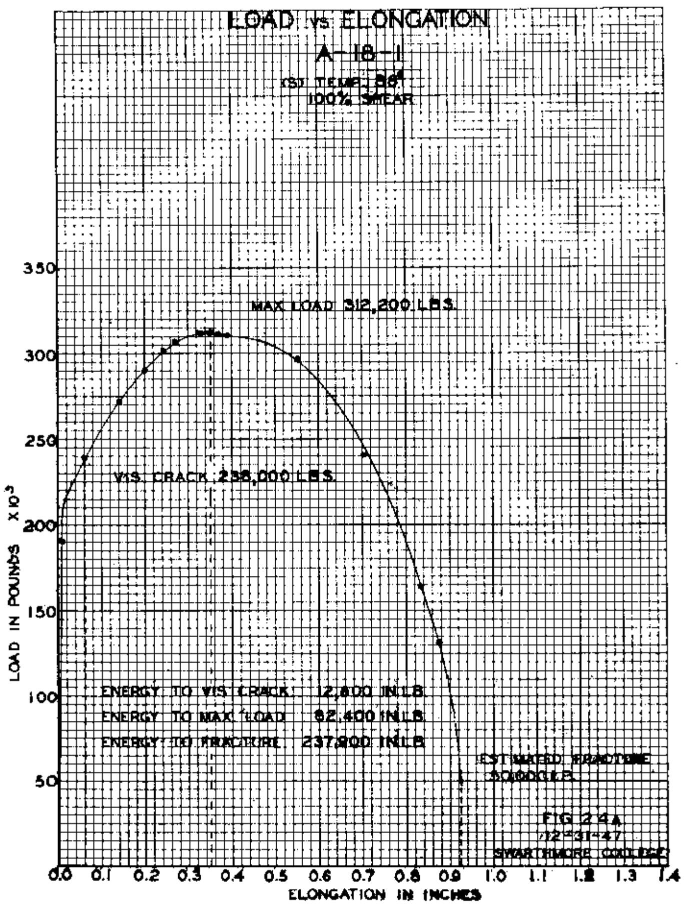

LOAD vs. ELONGATION
A-18-1
(S) TEMP. 66°
100% SHEAR
MAX. LOAD 315,000 LB.
VIS. CRACK 253,000 LB.
ENERGY TO VIS. CRACK 8,700 IN.LB.
ENERGY TO MAX. LOAD 104,600 IN.LB.
ENERGY TO FRACTURE 229,400 IN.LB.
FRACTURE 88,000 LB.
FIG. 19A
12-3-47
SWARTHMORE COLLEGE
LOAD IN POUNDS X10³
ELONGATION IN INCHES

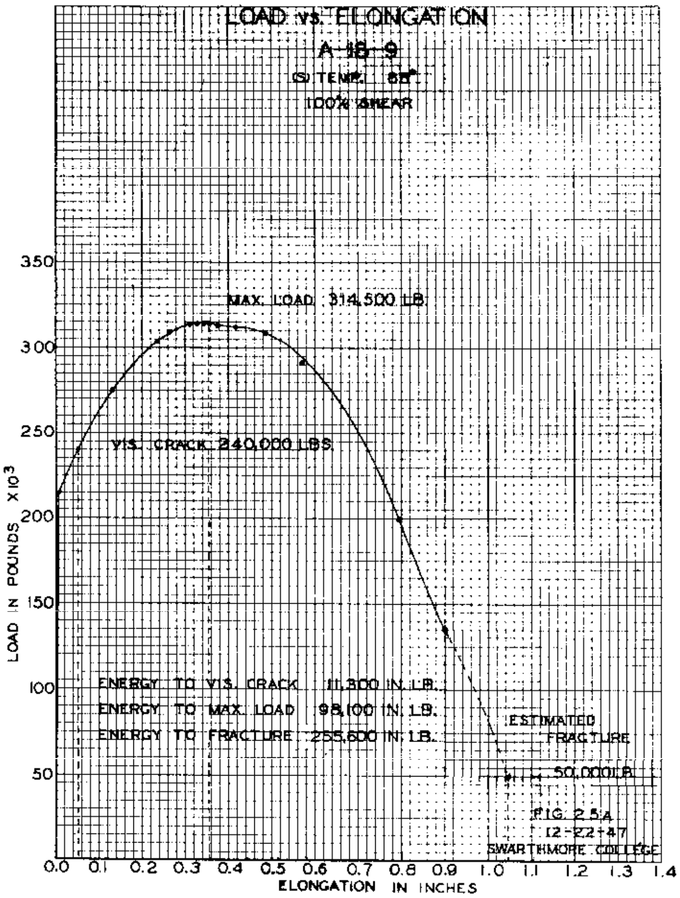

LOAD vs. ELONGATION
A-18-4
(S) TEMP. 71°
100% SHEAR
MAX. LOAD 312,500 LBS.
VIS. CRACK 243,000 LBS.
ENERGY TO VIS. CRACK 10,100 IN.LB.
ENERGY TO MAX. LOAD 84,700 IN.LB.
ENERGY TO FRACTURE 232,700 IN.LB.
FRACTURE 76,500 LBS.
FIG. 20A
1-2-48
SWARTHMORE COLLEGE
LOAD IN POUNDS X 10³
ELONGATION IN INCHES

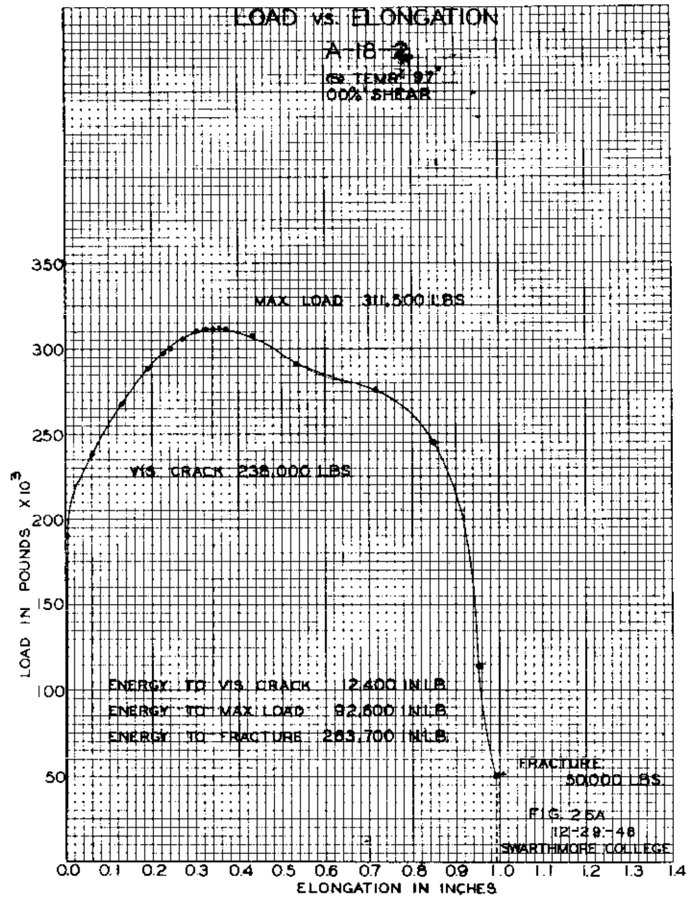

LOAD vs. ELONGATION
A-18-12
(S) TEMP. 71°
100% SHEAR
MAX. LOAD 314,400 LBS.
VIS. CRACK
250,000 LBS.
ENERGY TO VIS. CRACK 17,100 IN.LB.
ENERGY TO MAX. LOAD 86,400 IN.LB.
ENERGY TO FRACTURE
247,100 IN.LB.
FRACTURE
95,000 LBS.
FIG. 21A
SWARTHMORE COLLEGE
LOAD IN POUNDS X10³
ELONGATION IN INCHES

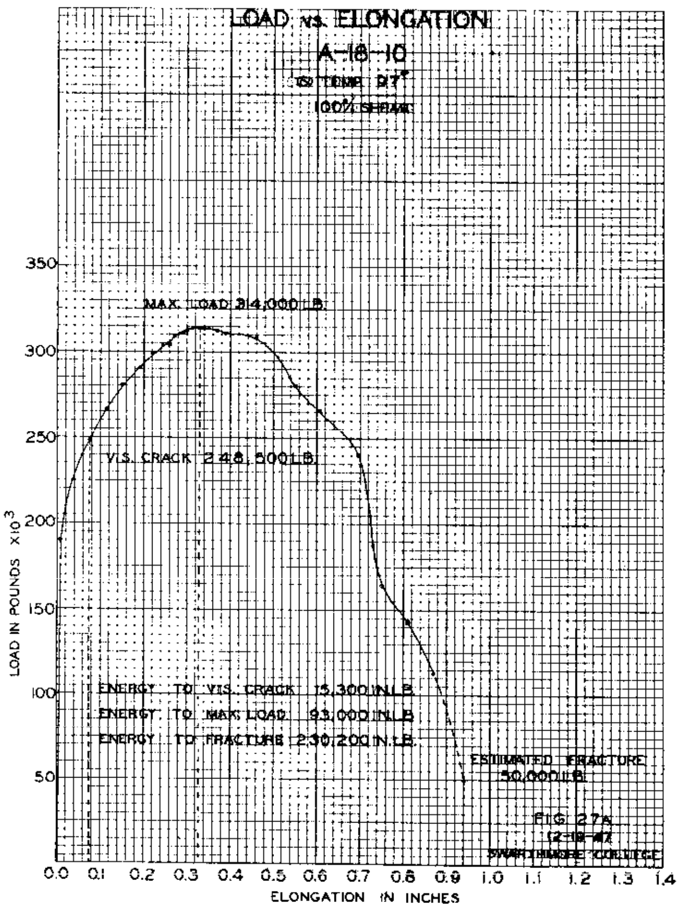

LOAD vs ELONGATION
A-18-18
100% SHEAR
MAX. LOAD 317,000 LBS.
VIS. CRACK 250,000 LBS.
ENERGY TO VIS. CRACK 16,600 IN.LB.
ENERGY TO MAX. LOAD 104,300 IN.LB.
ENERGY TO FRACTURE
FRACTURE
15,000 LB.
FIG. 22A
11-24-47
SWARTHMORE COLLEGE
LOAD IN POUNDS X10³
ELONGATION IN INCHES


LOAD vs. ELONGATION
A-18-19
(S) TEMP. 82°
100% SHEAR
MAX. LOAD 314,000 LB.
VIS. CRACK 237,600 LB.
ENERGY TO VIS. CRACK 10,900 IN.LB.
ENERGY TO MAX. LOAD 99,700 IN.LB.
ENERGY TO FRACTURE 274,000 IN.LB.
ESTIMATED
FRACTURE
90,000 LB.
FIG. 23A
SWARTHMORE COLLEGE
LOAD IN POUNDS X10³
ELONGATION IN INCHES


LOAD vs ELONGATION
A-18-1
(S) TEMP. 86°
100% SHEAR
MAX. LOAD 312,200 LBS.
VIS. CRACK 235,000 LBS.
ENERGY TO VIS. CRACK 12,800 IN.LB.
ENERGY TO MAX. LOAD 82,400 IN.LB.
ENERGY TO FRACTURE 237,900 IN.LB.
ESTIMATED FRACTURE
50,000 LB.
FIG. 24A
12-31-47
SWARTHMORE COLLEGE
LOAD IN POUNDS X10³
ELONGATION IN INCHES


LOAD vs. ELONGATION
A-18-9
@ TEMP. 88°
100% SHEAR
MAX. LOAD 314,500 LB.
VIS. CRACK 240,000 LBS.
ENERGY TO VIS. CRACK 11,300 IN. LB.
ENERGY TO MAX. LOAD 98,100 IN. LB.
ENERGY TO FRACTURE 255,600 IN. LB.
ESTIMATED FRACTURE
50,000 LB.
FIG. 25A
12-22-47
SWARTHMORE COLLEGE
LOAD IN POUNDS X10^3
ELONGATION IN INCHES


LOAD vs. ELONGATION
A-18-2
@ TEMP. 97°
00% SHEAR
MAX. LOAD 311,500 LBS
VIS. CRACK 238,000 LBS
ENERGY TO VIS. CRACK 12,400 IN. LB.
ENERGY TO MAX. LOAD 92,600 IN. LB.
ENERGY TO FRACTURE 263,700 IN. LB.
FRACTURE
50000 LBS
FIG. 25A
12-29-46
SWARTHMORE COLLEGE
LOAD IN POUNDS X10^3
ELONGATION IN INCHES


LOAD vs. ELONGATION
A-18-10
@ TEMP. 97°
100% SHEAR
MAX. LOAD 314,000 LB.
VIS. CRACK 248,500 LB.
ENERGY TO VIS. CRACK 15,300 IN. LB.
ENERGY TO MAX. LOAD 93,000 IN. LB.
ENERGY TO FRACTURE 230,200 IN. LB.
ESTIMATED FRACTURE
50,000 LB.
FIG. 27A
12-18-47
SWARTHMORE COLLEGE
LOAD IN POUNDS X10^3
ELONGATION IN INCHES

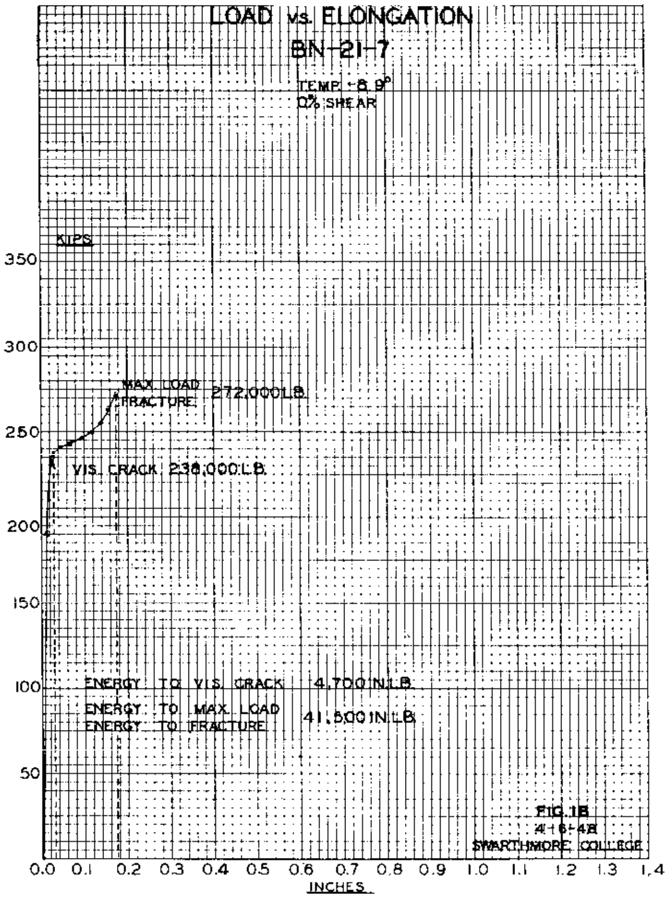


FIG. 1B
4-16-48
SWARTHMORE COLLEGE

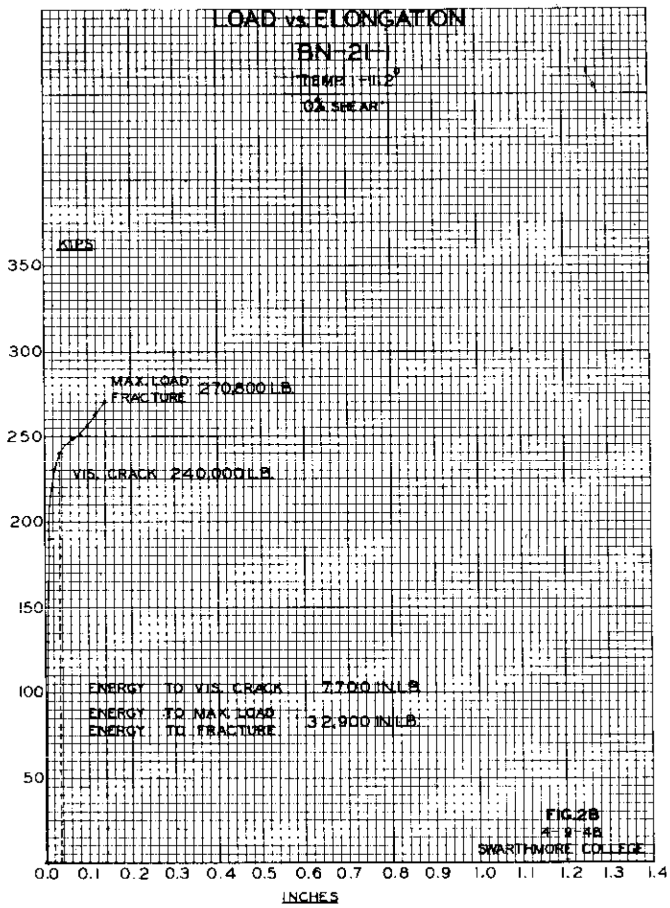


FIG. 2B
4-9-48
SWARTHMORE COLLEGE

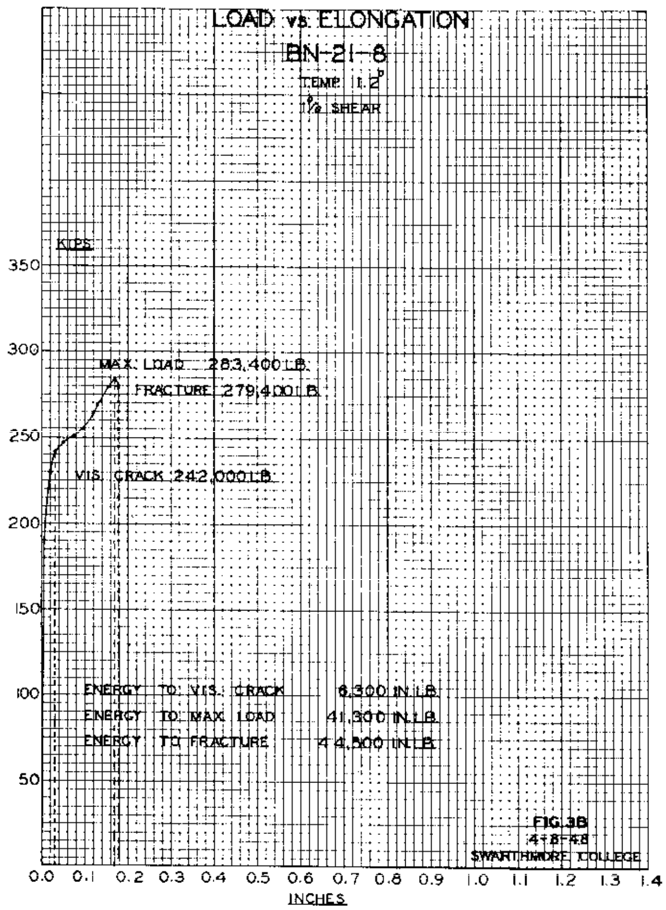


FIG. 3B
4-8-48
SWARTHMORE COLLEGE

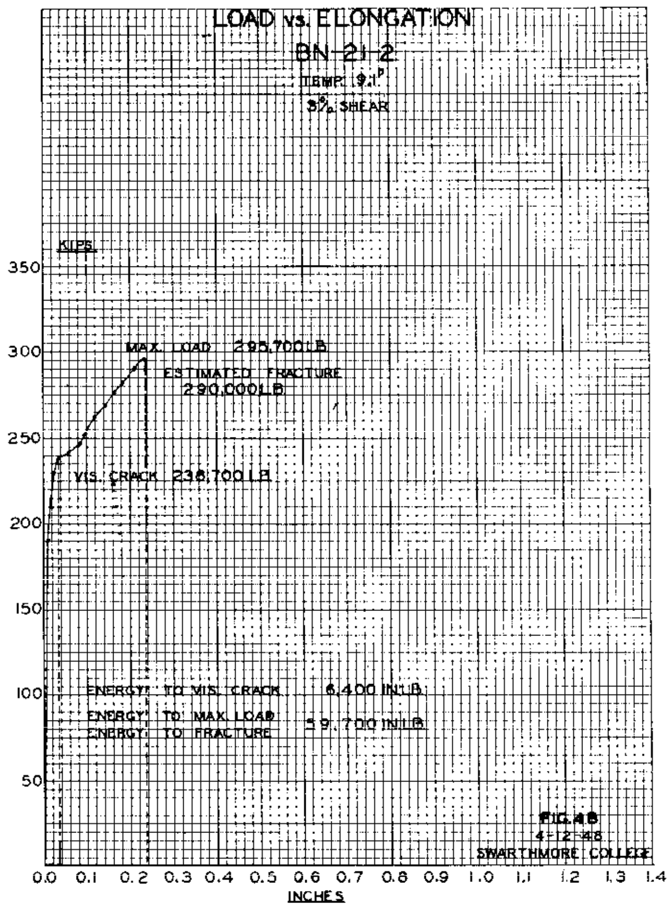
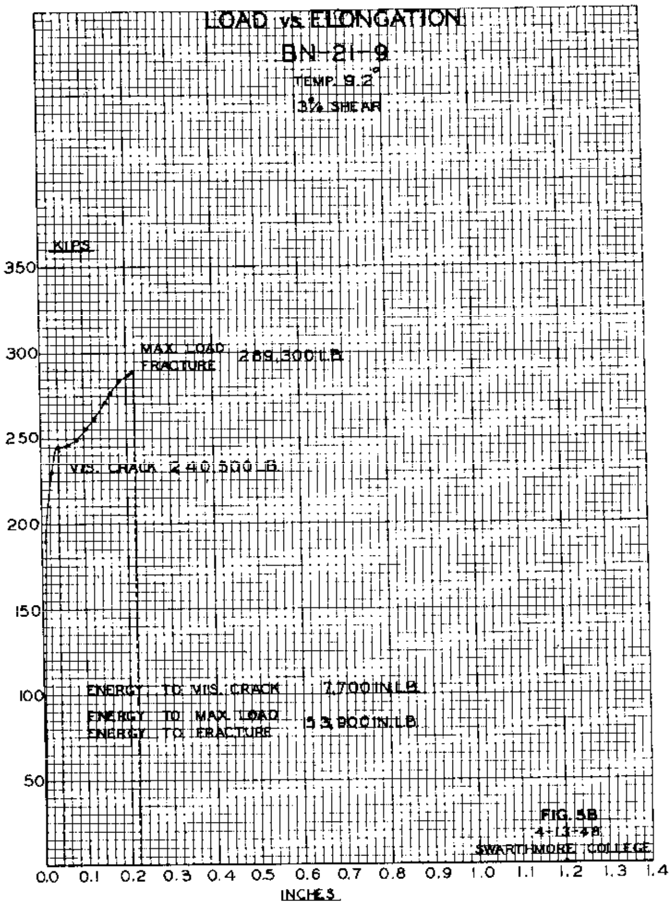
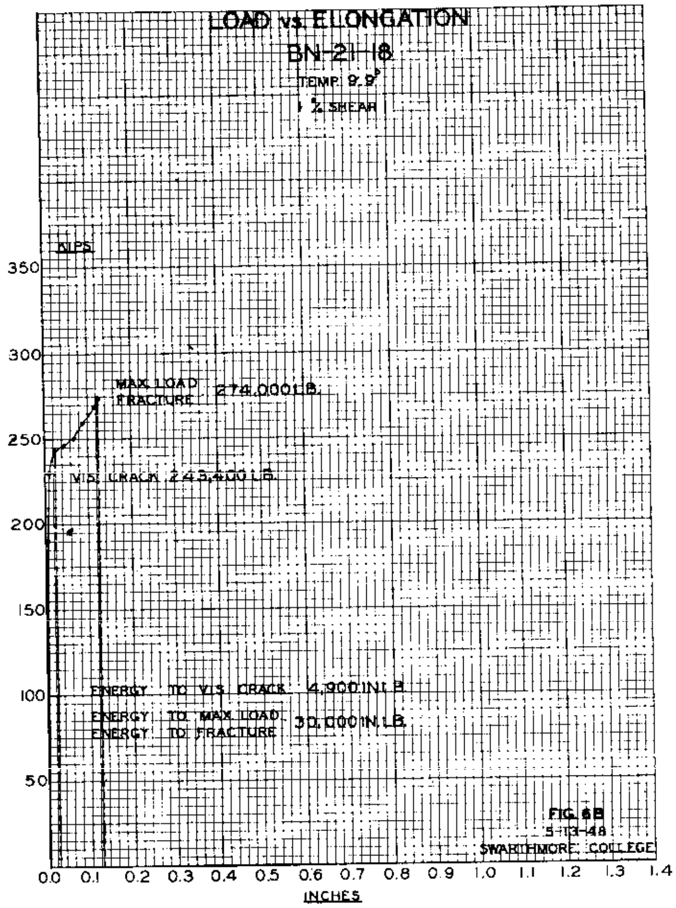
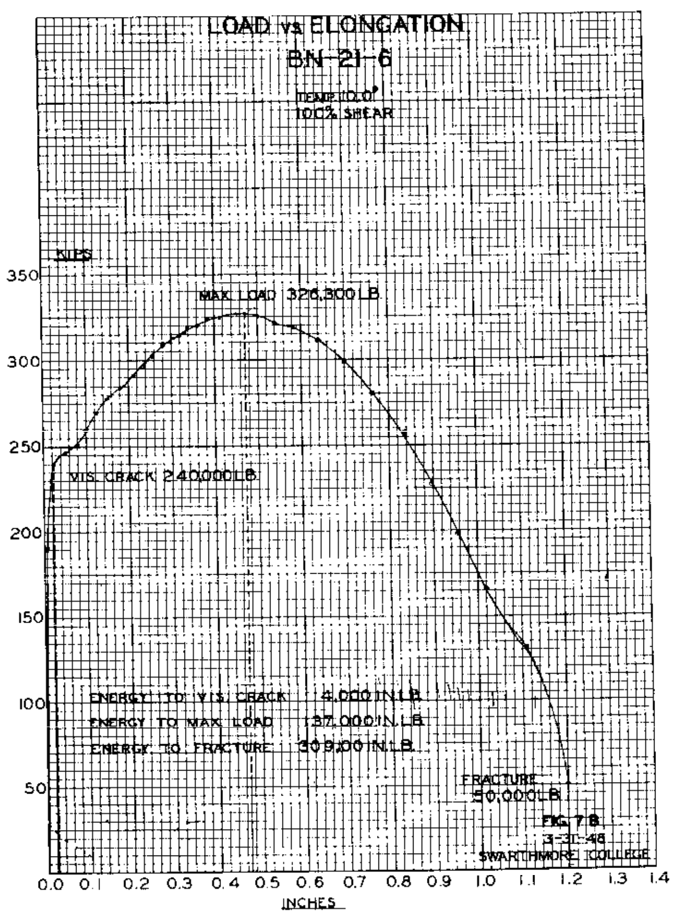
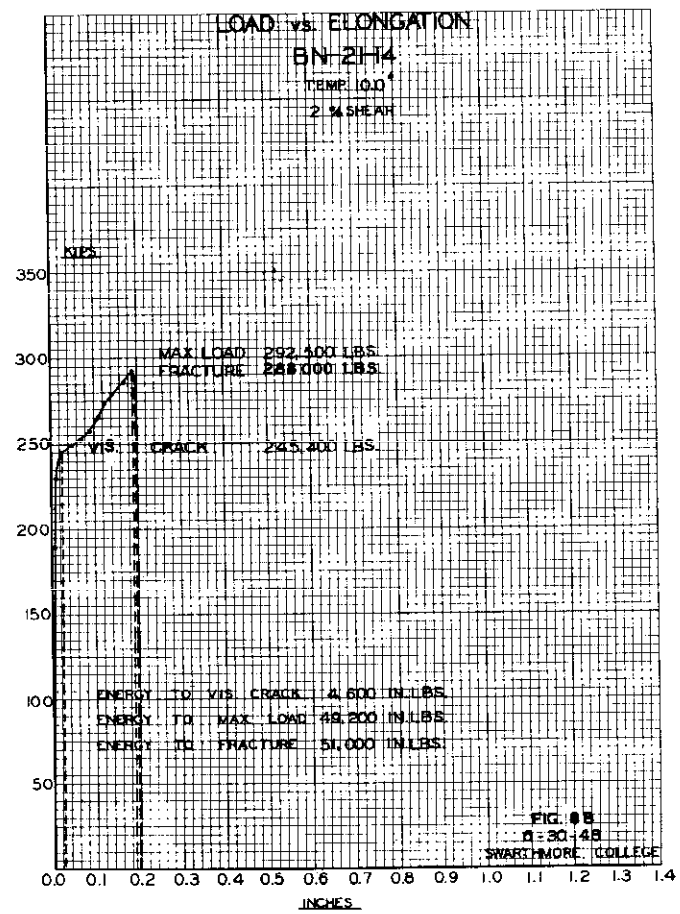


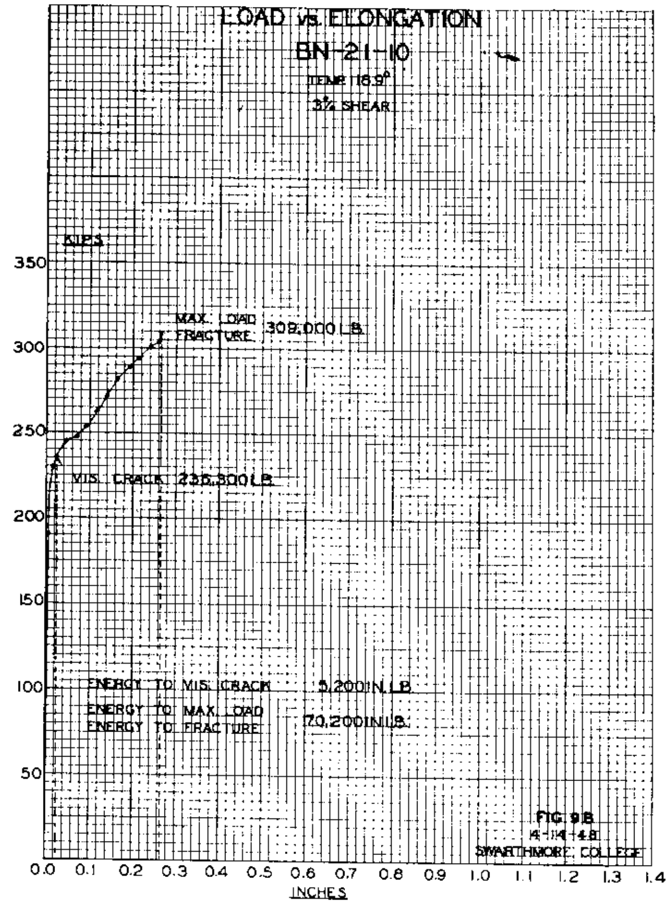
FIG. 4B
4-12-48
SWARTHMORE COLLEGE

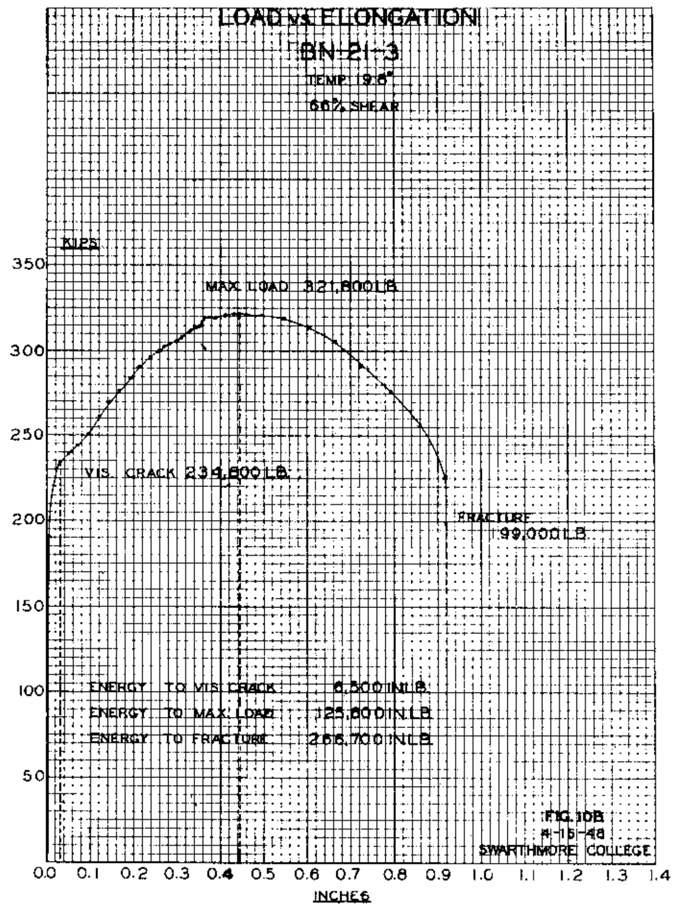

LOAD vs ELONGATION
BN-21-9
TEMP. 9.2°
3% SHEAR
KIPS
MAX. LOAD
FRACTURE
289,300 LB.
VIS. CRACK 240,500 LB.
ENERGY TO VIS. CRACK 7,700 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE
53,900 IN.LB.
FIG. 5B
4-13-48
SWARTHMORE COLLEGE
INCHES

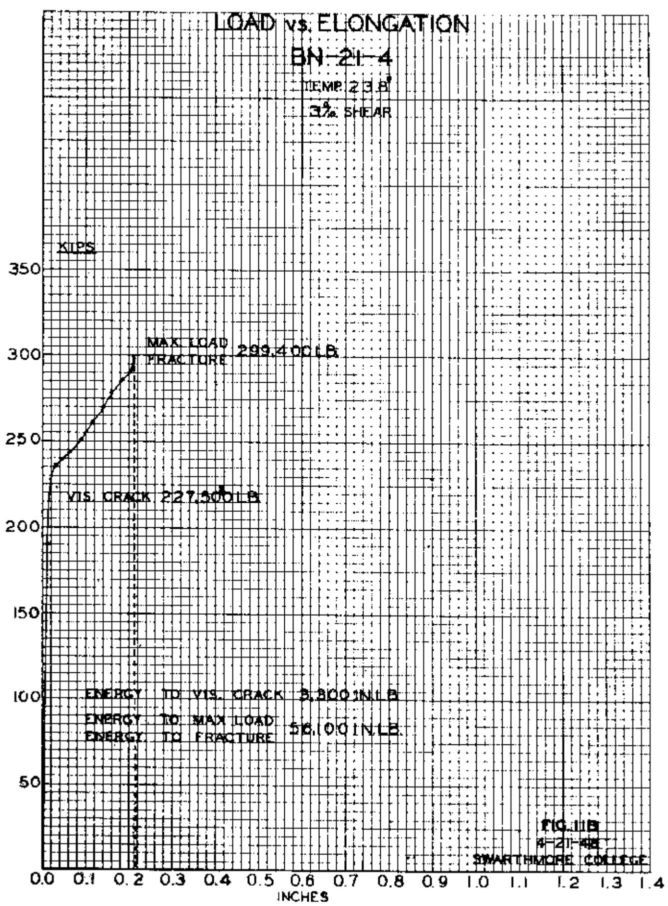

LOAD vs ELONGATION
BN-21-18
TEMP. 9.9°
1 % SHEAR
KIPS
MAX. LOAD
FRACTURE
274,000 LB.
VIS. CRACK 243,400 LB.
ENERGY TO VIS. CRACK 4,900 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE
30,000 IN.LB.
FIG. 6B
5-13-48
SWARTHMORE COLLEGE
INCHES

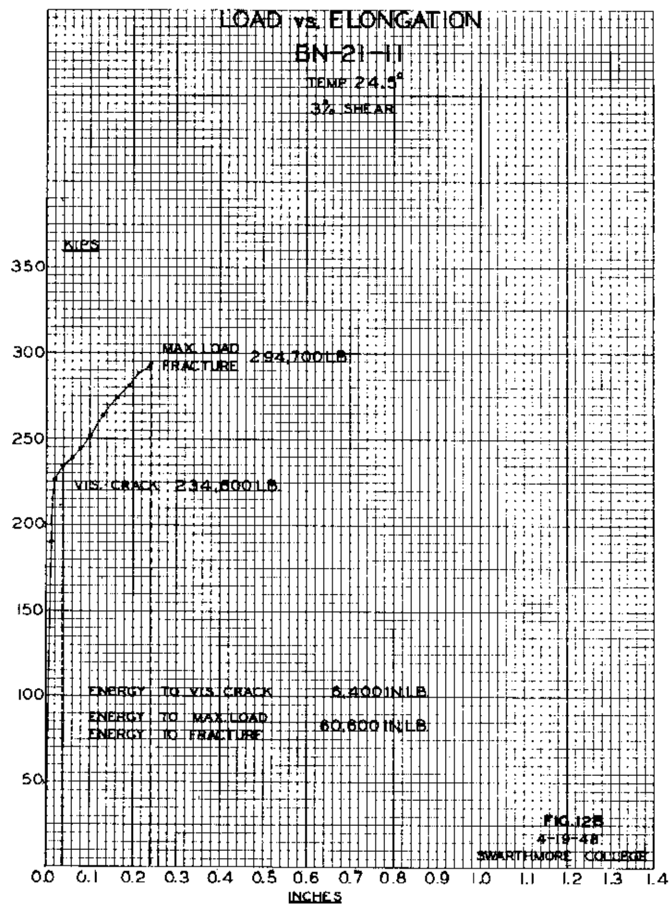

LOAD vs ELONGATION
BN-21-6
TEMP. 10.0°
100% SHEAR
KIPS
MAX. LOAD 326,300 LB.
VIS. CRACK 240,000 LB.
ENERGY TO VIS. CRACK 4,000 IN.LB.
ENERGY TO MAX. LOAD 137,000 IN.LB.
ENERGY TO FRACTURE 309,00 IN.LB.
FRACTURE
50,000 LB.
FIG. 7B
3-31-48
SWARTHMORE COLLEGE
INCHES

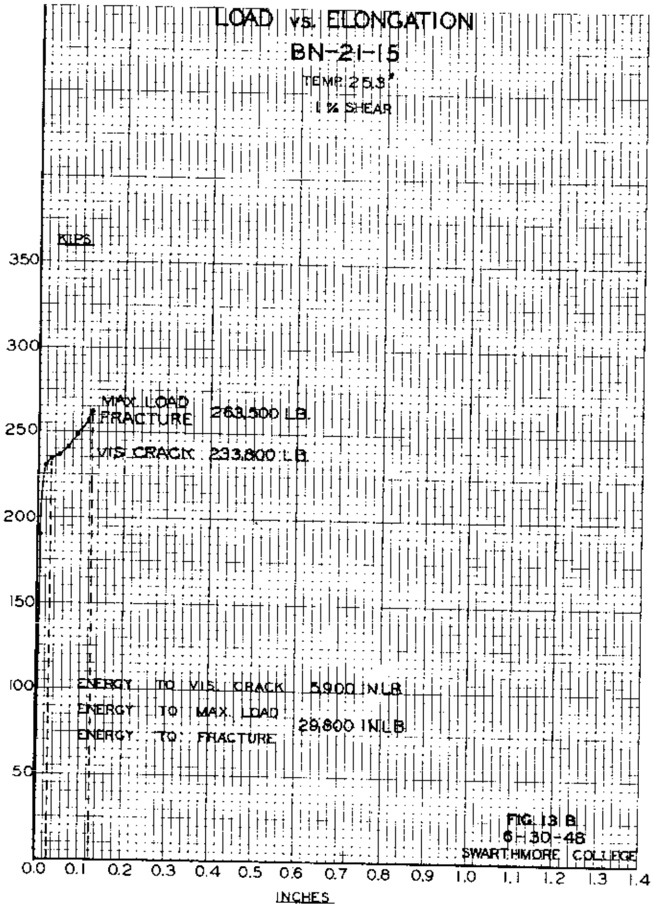

LOAD vs ELONGATION
BN-21-14
TEMP. 10.0°
2 % SHEAR
KIPS
MAX. LOAD 292,400 LBS.
FRACTURE 288,000 LBS.
VIS. CRACK 245,400 LBS.
ENERGY TO VIS. CRACK 4,600 IN.LBS.
ENERGY TO MAX. LOAD 49,200 IN.LBS.
ENERGY TO FRACTURE 51,000 IN.LBS.
FIG. 8B
6-30-48
SWARTHMORE COLLEGE
INCHES

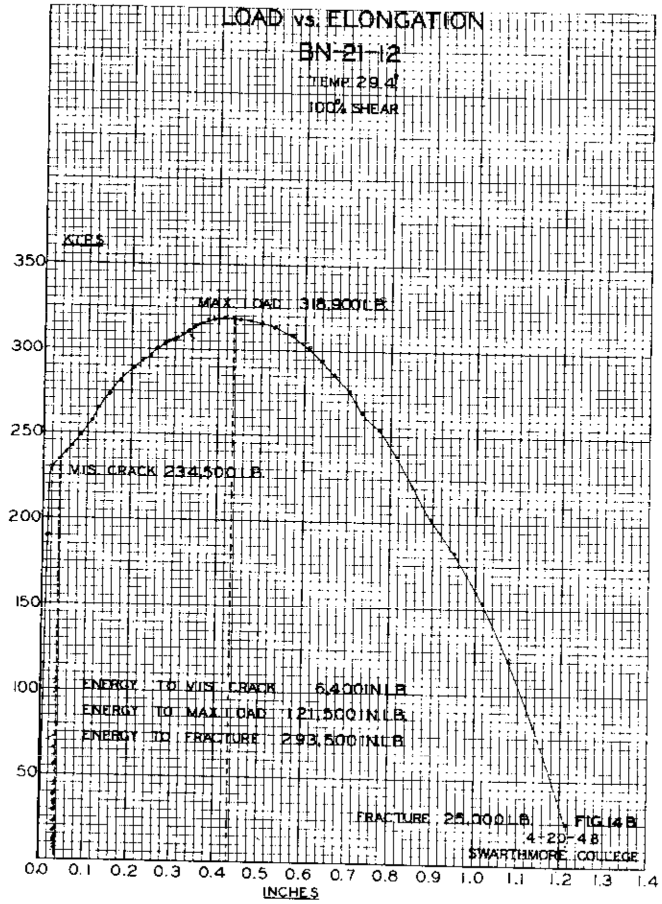

LOAD vs. ELONGATION
BN-21-10
TEMP 16.9°
3% SHEAR
KIPS
350
300
250
200
150
100
50
MAX. LOAD
FRACTURE 309,000 LB.
VIS. CRACK 235,300 LB.
ENERGY TO VIS. CRACK 5,200 IN. LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 70,200 IN. LB.
FIG. 9B
4-14-48
SWARTHMORE COLLEGE
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
INCHES

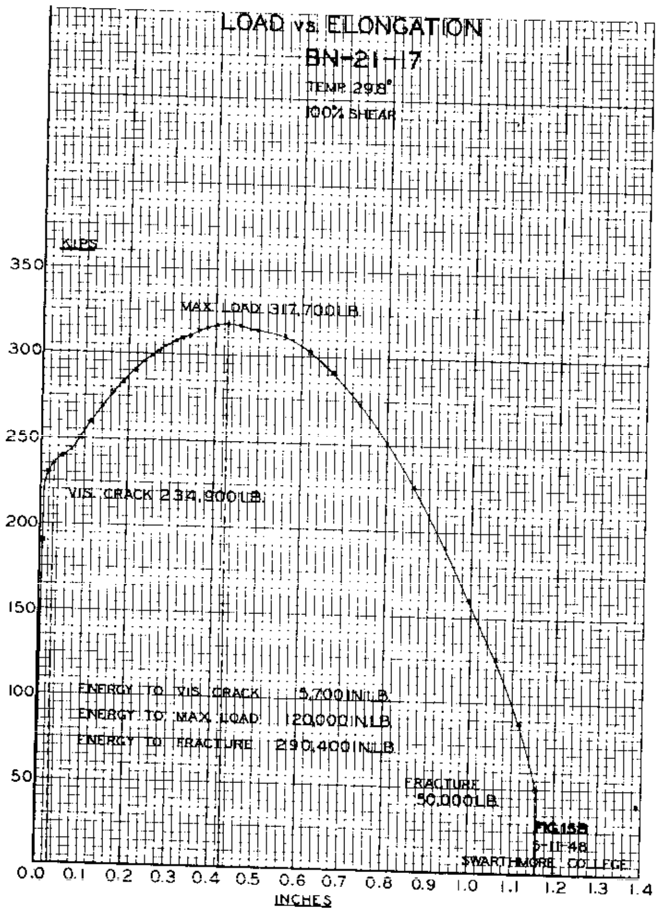

LOAD vs. ELONGATION
BN-21-3
TEMP 19.6°
66% SHEAR
KIPS
350
300
250
200
150
100
50
MAX. LOAD 321,800 LB.
VIS. CRACK 234,800 LB.
FRACTURE
199,000 LB.
ENERGY TO VIS. CRACK 6,300 IN. LB.
ENERGY TO MAX. LOAD 125,800 IN. LB.
ENERGY TO FRACTURE 266,700 IN. LB.
FIG. 10B
4-16-48
SWARTHMORE COLLEGE
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
INCHES

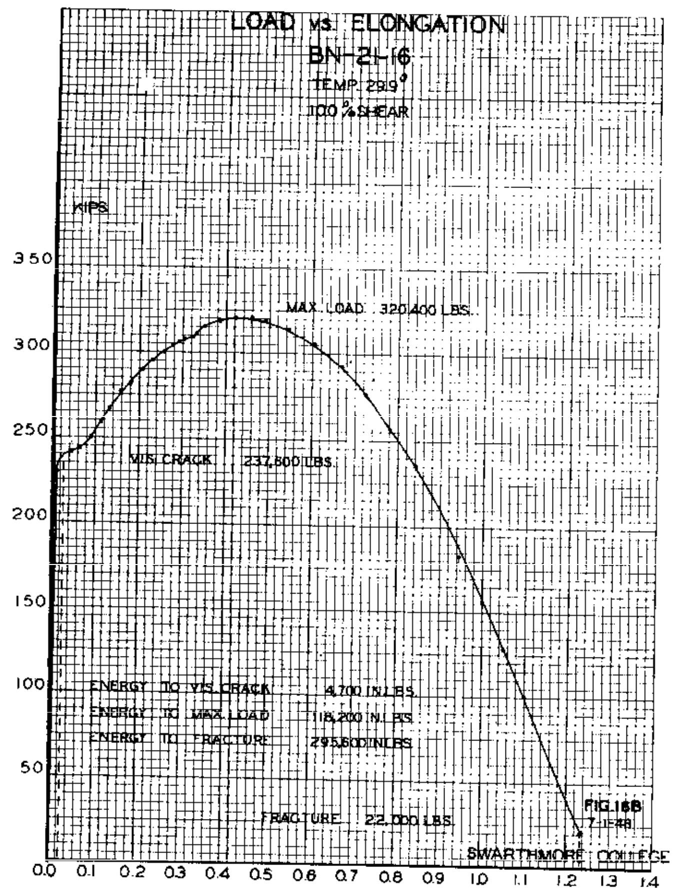

LOAD vs. ELONGATION
BN-21-4
TEMP 23.8°
3% SHEAR
KIPS
350
300
250
200
150
100
50
MAX. LOAD
FRACTURE 299,400 LB.
VIS. CRACK 227,500 LB.
ENERGY TO VIS. CRACK 3,300 IN. LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 56,100 IN. LB.
FIG. 11B
4-21-48
SWARTHMORE COLLEGE
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
INCHES

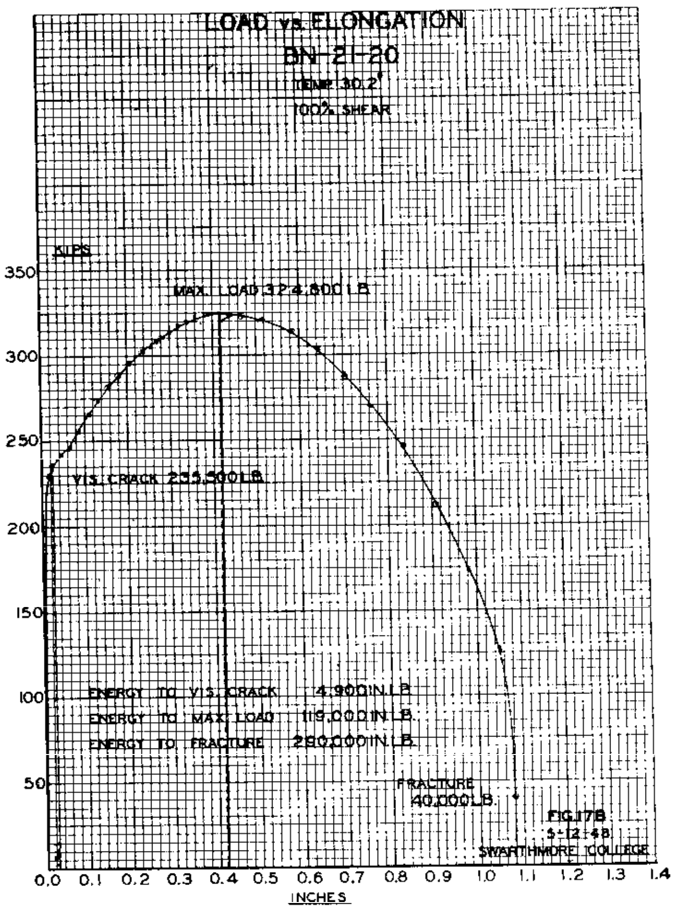

LOAD vs. ELONGATION
BN-21-11
TEMP 24.5°
3% SHEAR
KIPS
350
300
250
200
150
100
50
MAX. LOAD
FRACTURE 294,700 LB.
VIS. CRACK 234,600 LB.
ENERGY TO VIS. CRACK 6,400 IN. LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 60,600 IN. LB.
FIG. 12B
4-19-48
SWARTHMORE COLLEGE
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
INCHES

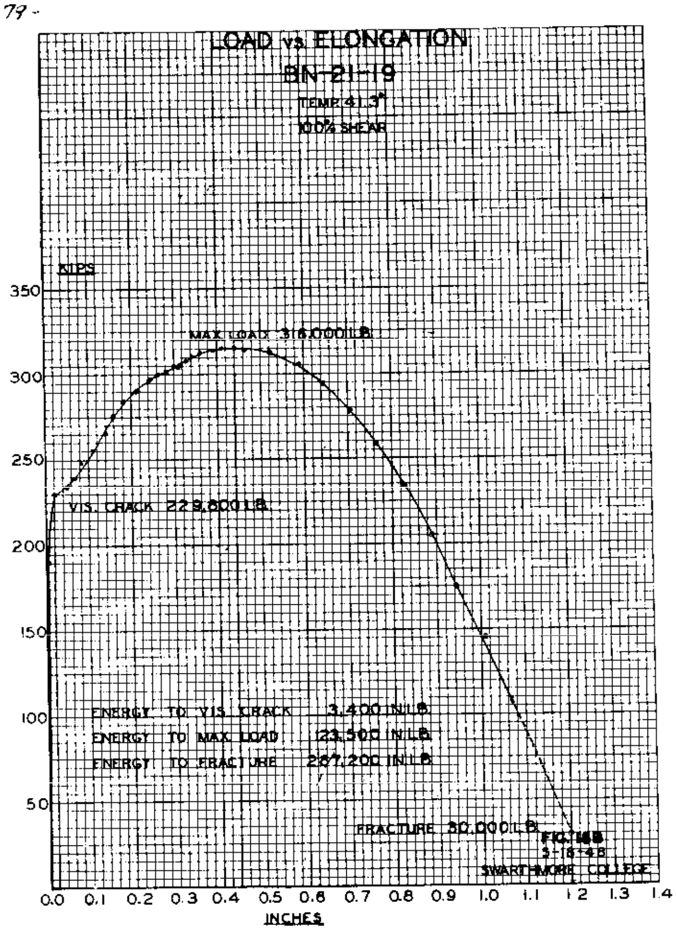

LOAD vs. ELONGATION
BN-21-15
TEMP 25.3°
1% SHEAR
KIPS
350
300
250
200
150
100
50
MAX. LOAD
FRACTURE 263,500 LB.
VIS. CRACK 233,800 LB.
ENERGY TO VIS. CRACK 5900 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 29,800 IN.LB.
FIG. 13 B
6-30-48
SWARTHMORE COLLEGE
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
INCHES

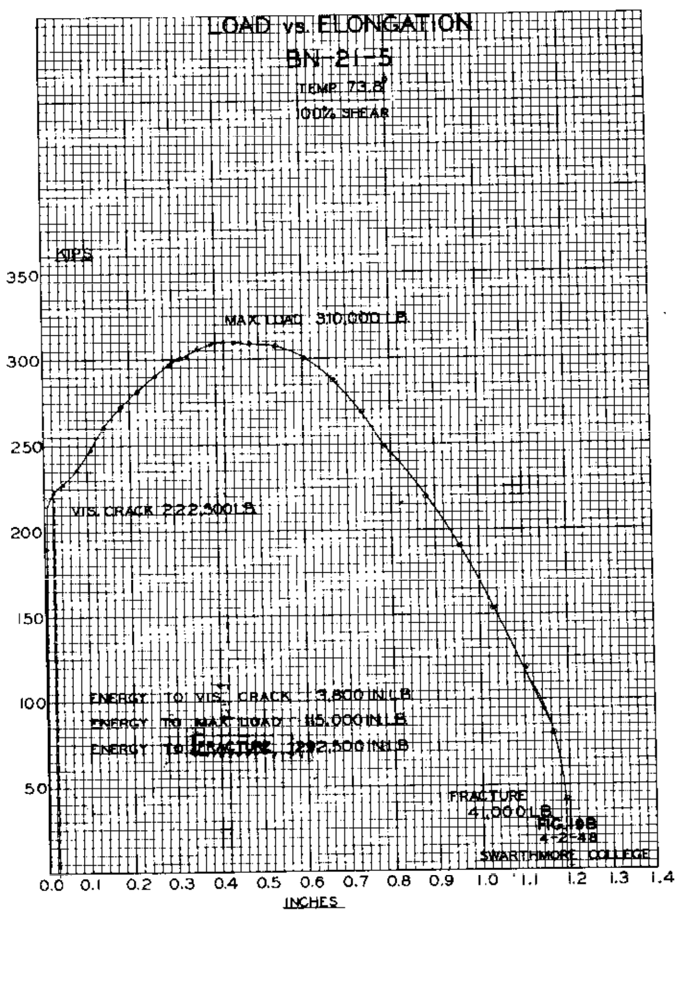

LOAD vs. ELONGATION
BN-21-12
TEMP 29.4°
100% SHEAR
KIPS
350
300
250
200
150
100
50
MAX. LOAD 318,900 LB.
VIS. CRACK 234,500 LB.
ENERGY TO VIS. CRACK 6,400 IN.LB.
ENERGY TO MAX. LOAD 121,500 IN.LB.
ENERGY TO FRACTURE 293,500 IN.LB.
FRACTURE 25,000 LB.
FIG. 14 B
4-20-48
SWARTHMORE COLLEGE
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
INCHES

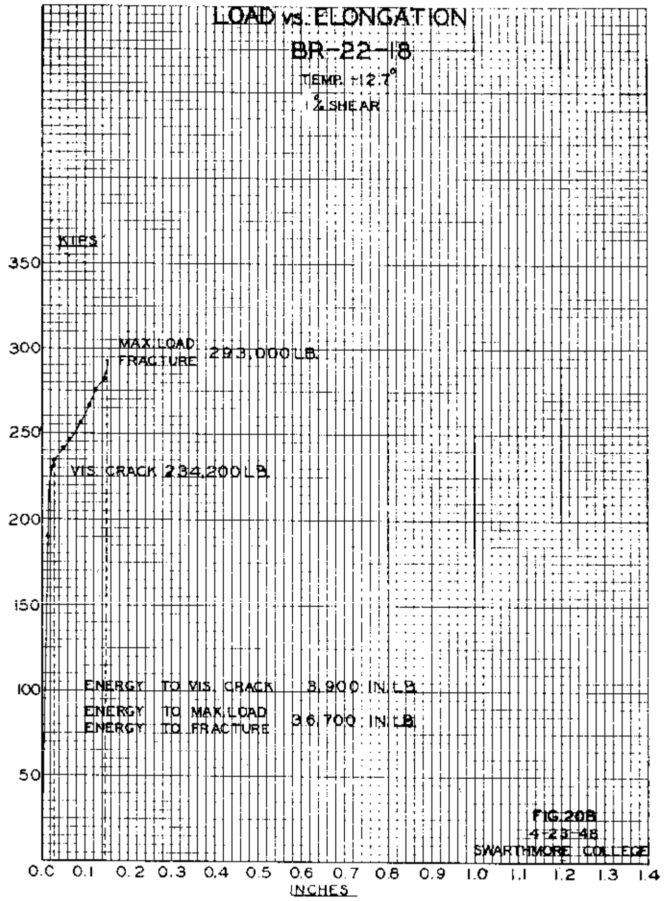

LOAD vs. ELONGATION
BN-21-17
TEMP 29.8°
100% SHEAR
KIPS
350
300
250
200
150
100
50
MAX. LOAD 317,700 LB.
VIS. CRACK 234,900 LB.
ENERGY TO VIS. CRACK 5,700 IN.LB.
ENERGY TO MAX. LOAD 120,000 IN.LB.
ENERGY TO FRACTURE 290,400 IN.LB.
FRACTURE
50,000 LB.
FIG. 15B
5-11-48
SWARTHMORE COLLEGE
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
INCHES

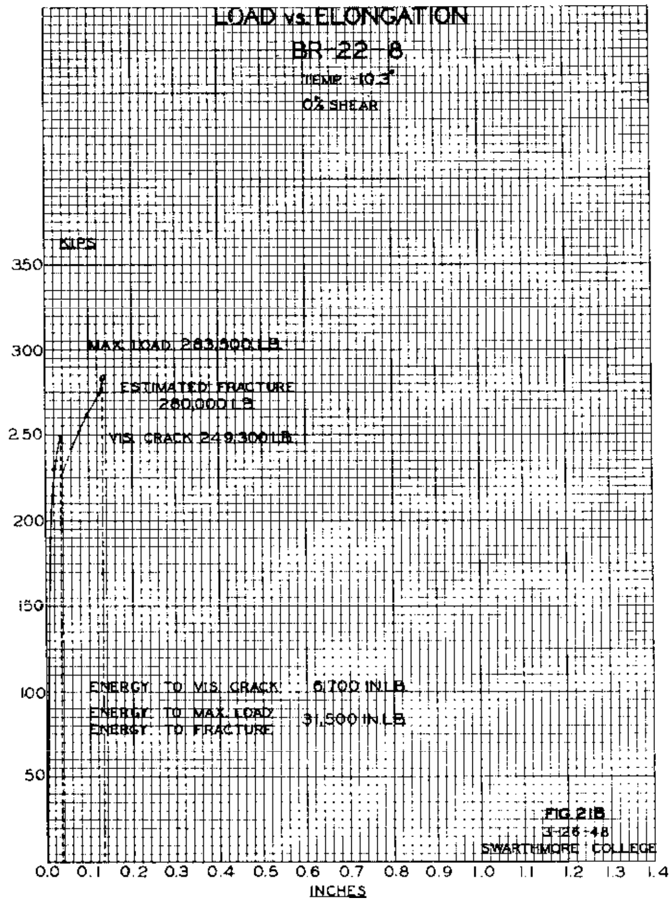

LOAD vs. ELONGATION
BN-21-16
TEMP 29.9°
100 % SHEAR
KIPS
350
300
250
200
150
100
50
MAX. LOAD 320,400 LBS.
VIS. CRACK 237,800 LBS.
ENERGY TO VIS. CRACK 4,700 IN.LBS.
ENERGY TO MAX. LOAD 118,200 IN.LBS.
ENERGY TO FRACTURE 295,600 IN.LBS.
FRACTURE 22,000 LBS.
FIG. 16B
7-1-48
SWARTHMORE COLLEGE
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4

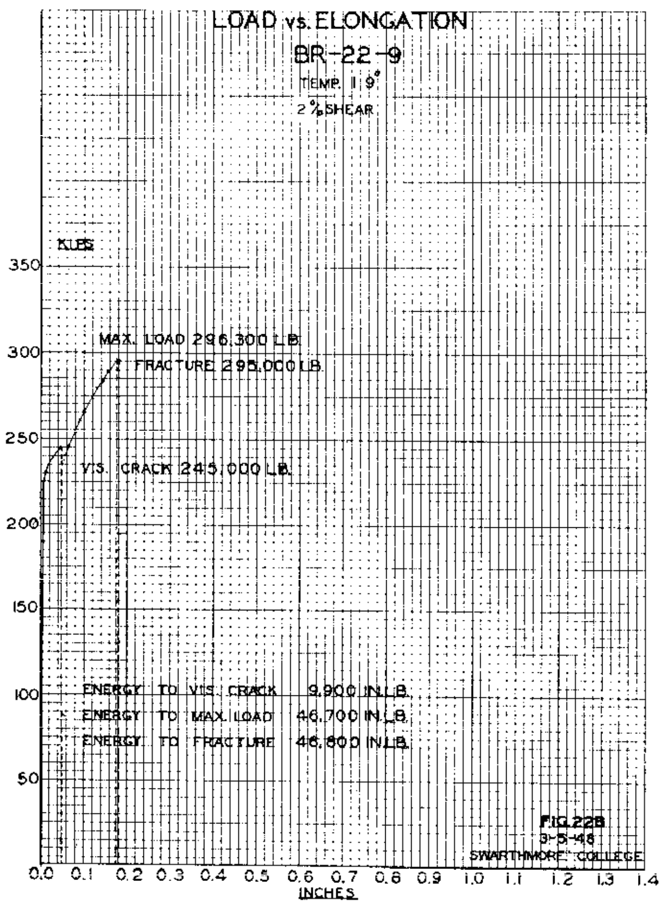

LOAD vs. ELONGATION
BN-21-20
TEMP 30.2°
100% SHEAR
KIPS
MAX. LOAD 324,800 LB.
VIS. CRACK 233,500 LB.
ENERGY TO VIS. CRACK 4,900 IN.LB.
ENERGY TO MAX. LOAD 119,000 IN.LB.
ENERGY TO FRACTURE 290,000 IN.LB.
FRACTURE 40,000 LB.
FIG. 17B
5-12-48
SWARTHMORE COLLEGE
INCHES

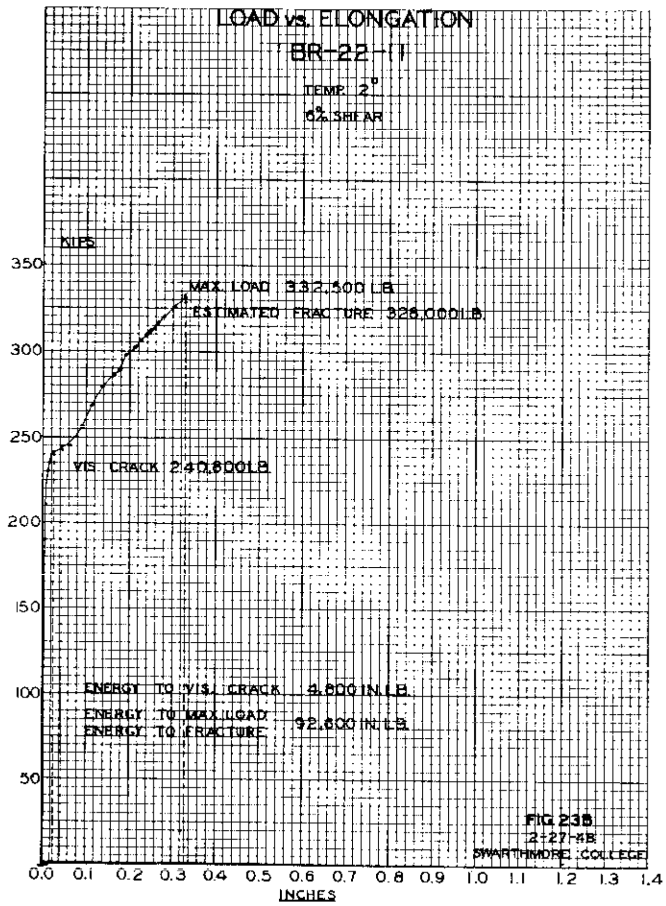

LOAD vs. ELONGATION
BN-21-19
TEMP 41.3°
100% SHEAR
KIPS
MAX. LOAD 316,000 LB.
VIS. CRACK 229,800 LB.
ENERGY TO VIS. CRACK 3,400 IN.LB.
ENERGY TO MAX. LOAD 123,500 IN.LB.
ENERGY TO FRACTURE 267,200 IN.LB.
FRACTURE 30,000 LB.
FIG. 16B
5-18-48
SWARTHMORE COLLEGE
INCHES

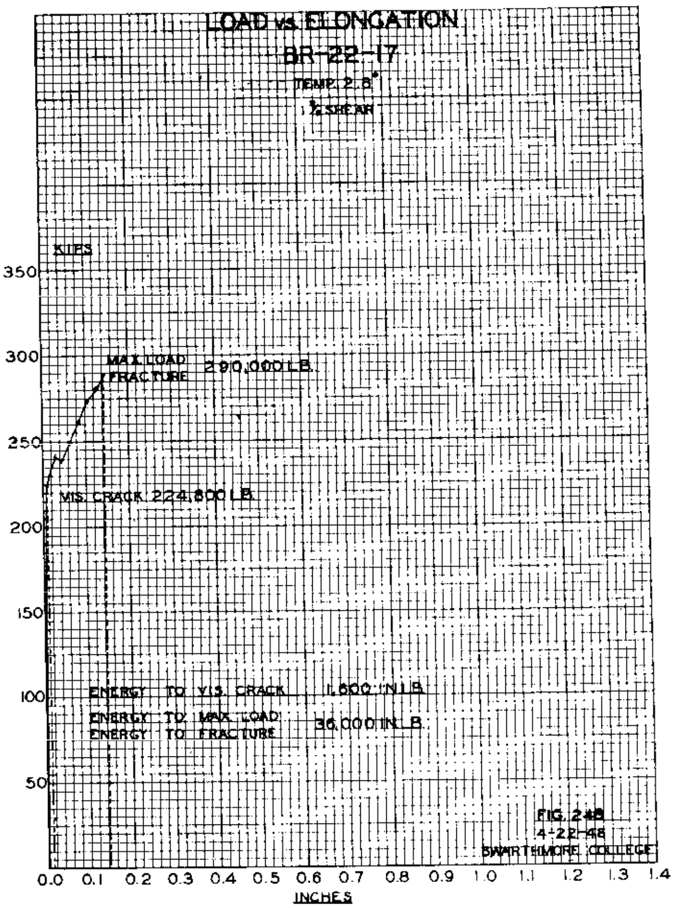

LOAD vs. ELONGATION
BN-21-5
TEMP 73.8°
100% SHEAR
KIPS
MAX. LOAD 310,000 LB.
VIS. CRACK 222,500 LB.
ENERGY TO VIS. CRACK 3,800 IN.LB.
ENERGY TO MAX. LOAD 115,000 IN.LB.
ENERGY TO FRACTURE 292,500 IN.LB.
FRACTURE 41,000 LB.
FIG. 18B
4-2-48
SWARTHMORE COLLEGE
INCHES

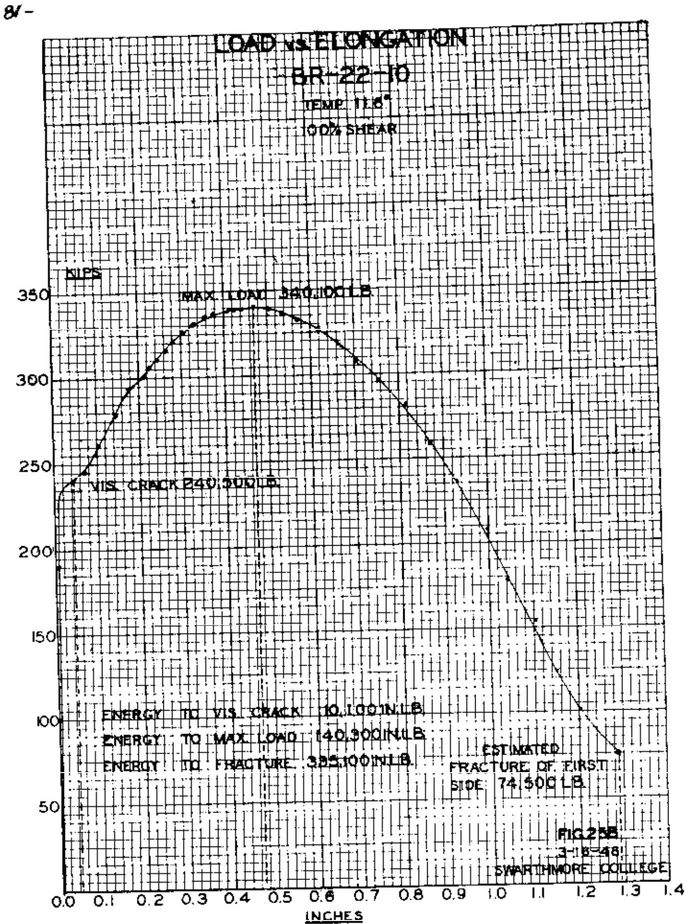

LOAD vs. ELONGATION
BR-22-18
TEMP. -12.7°
1% SHEAR
KIPS
MAX. LOAD
FRACTURE 293,000 LB.
VIS. CRACK 234,200 LB.
ENERGY TO VIS. CRACK 3,900 IN. LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 36,700 IN. LB.
FIG. 20B
4-23-48
SWARTHMORE COLLEGE
INCHES

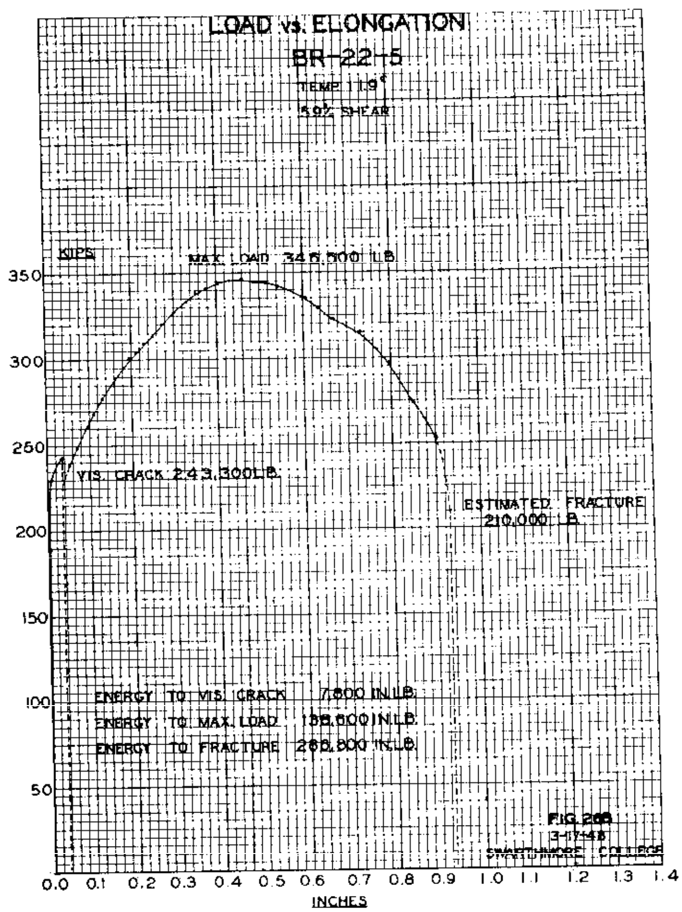

LOAD vs. ELONGATION
BR-22-8
TEMP. -10.3°
0% SHEAR
KIPS
MAX. LOAD 283,500 LB.
ESTIMATED FRACTURE
280,000 LB.
VIS. CRACK 249,300 LB.
ENERGY TO VIS. CRACK 6,700 IN. LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 31,500 IN. LB.
FIG. 21B
3-26-48
SWARTHMORE COLLEGE
INCHES

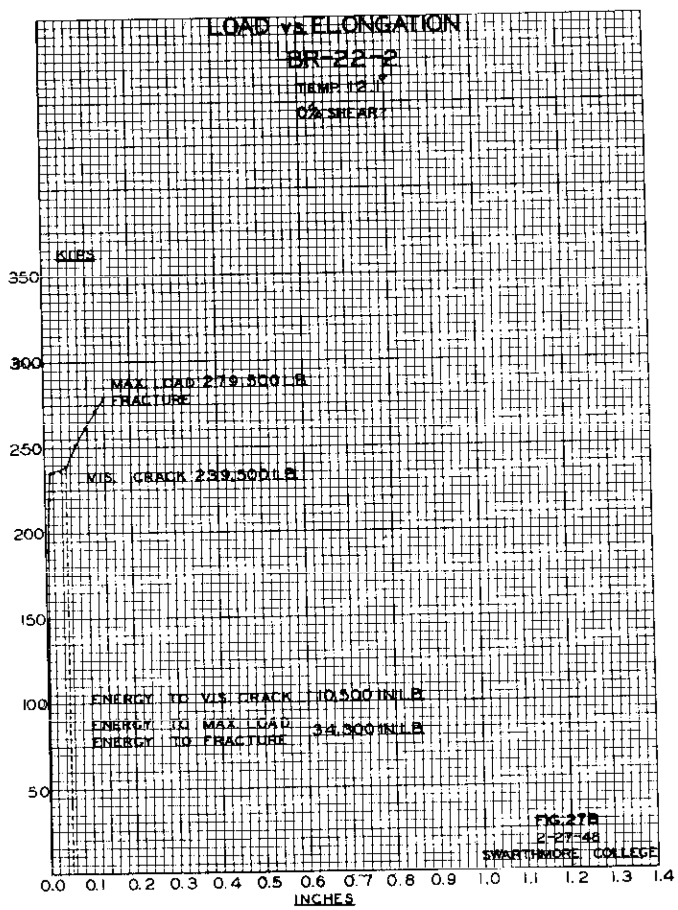

LOAD vs. ELONGATION
BR-22-9
TEMP. 1.9°
2% SHEAR
KIPS
MAX. LOAD 296,300 LB.
FRACTURE 295,000 LB.
VIS. CRACK 245,000 LB.
ENERGY TO VIS. CRACK 9,900 IN. LB.
ENERGY TO MAX. LOAD 46,700 IN. LB.
ENERGY TO FRACTURE 46,800 IN. LB.
FIG. 22B
3-5-48
SWARTHMORE COLLEGE
INCHES

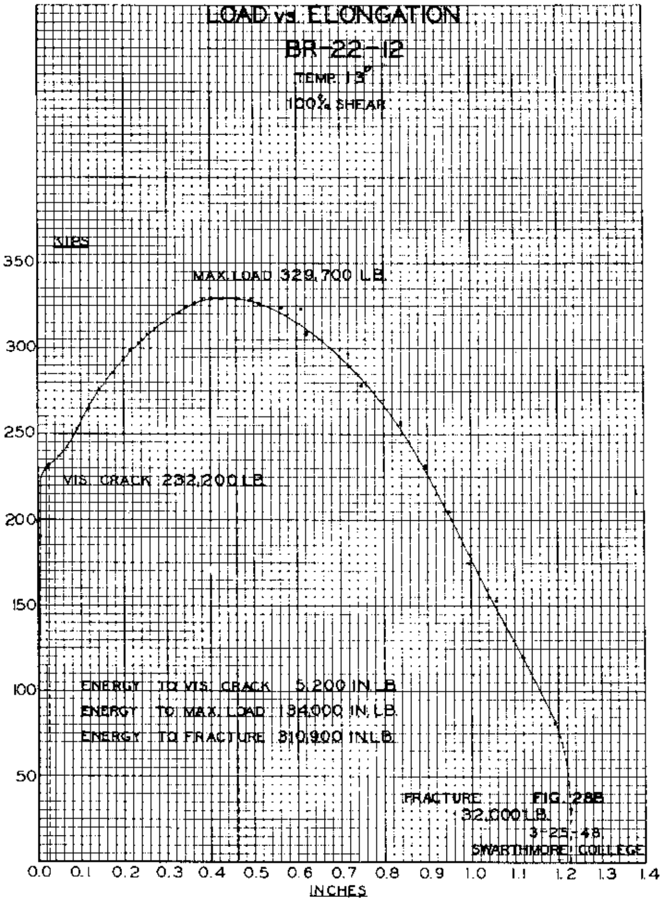

LOAD vs. ELONGATION
BR-22-11
TEMP. 2°
6% SHEAR
KIPS
MAX. LOAD 332,500 LB.
ESTIMATED FRACTURE 328,000 LB.
VIS. CRACK 240,800 LB.
ENERGY TO VIS. CRACK 4,800 IN. LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 92,600 IN. LB.
FIG. 23B
2-27-48
SWARTHMORE COLLEGE
INCHES

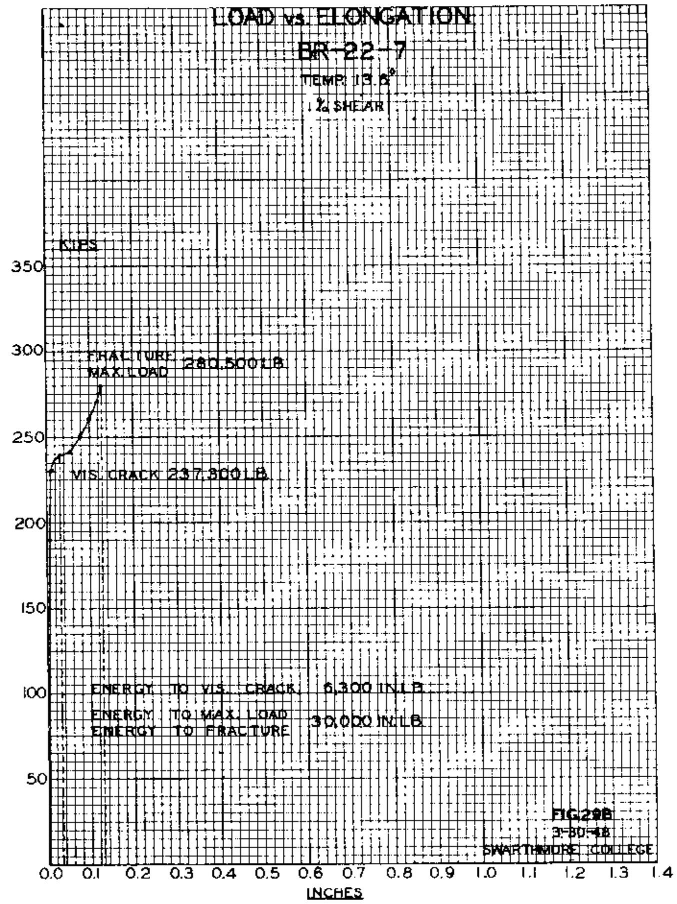

LOAD vs ELONGATION
BR-22-17
TEMP 2.8°
1% SHEAR
KIPS
MAX LOAD
FRACTURE 290,000 LB.
VIS. CRACK 224,800 LB.
ENERGY TO VIS. CRACK 1,600 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 36,000 IN. LB.
FIG. 24B
4-22-48
SWARTHMORE COLLEGE
INCHES

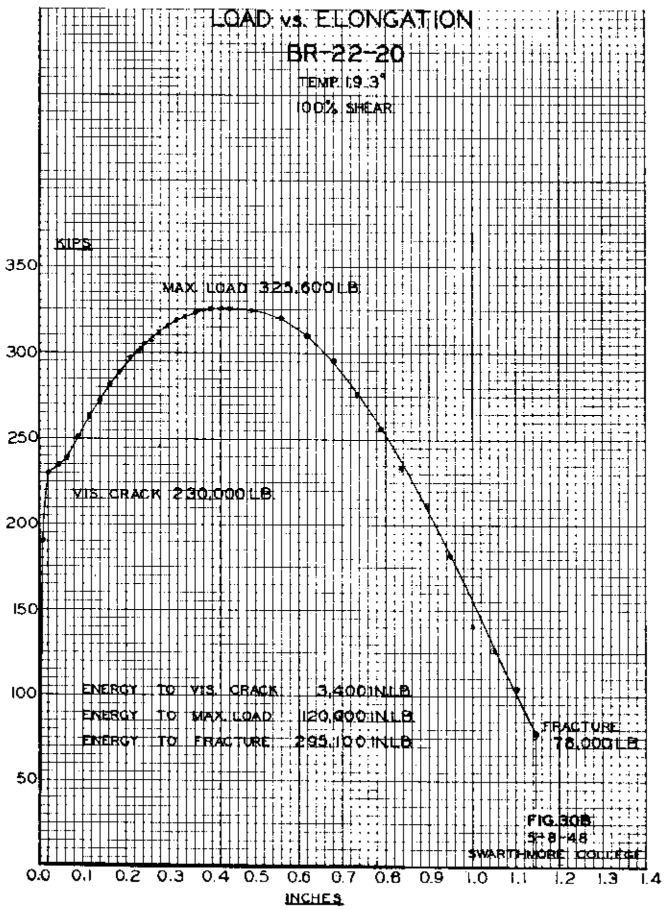

LOAD vs ELONGATION
BR-22-10
TEMP 11.6°
100% SHEAR
KIPS
MAX. LOAD 340,100 LB.
VIS. CRACK 240,500 LB.
ENERGY TO VIS. CRACK 10,100 IN.LB.
ENERGY TO MAX. LOAD 140,300 IN.LB.
ENERGY TO FRACTURE 395,100 IN.LB.
ESTIMATED
FRACTURE OF FIRST
SIDE 74,500 LB.
FIG.25B
3-18-48
SWARTHMORE COLLEGE
INCHES

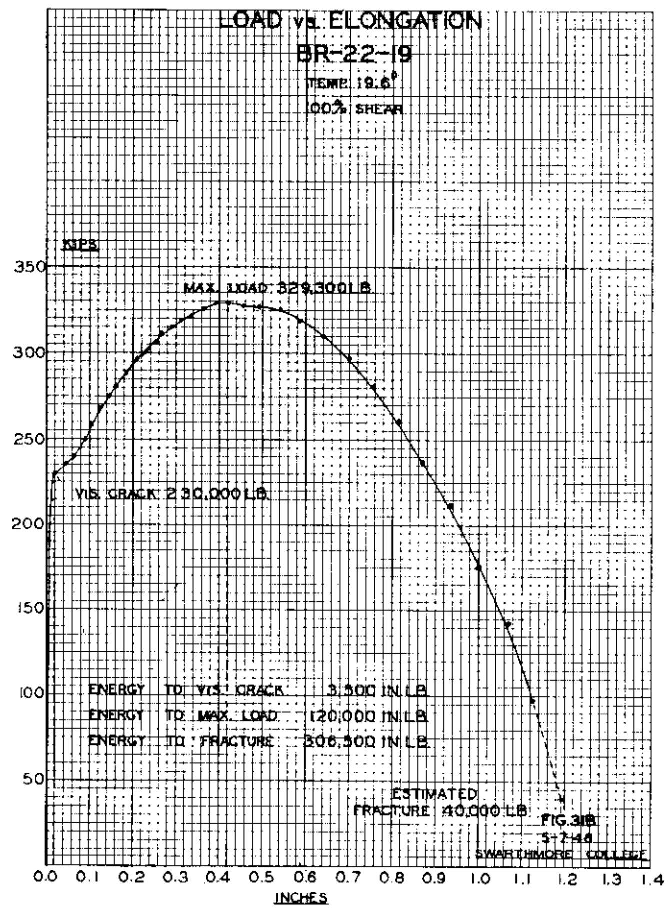

LOAD vs. ELONGATION
BR-22-5
TEMP 11.9°
59% SHEAR
KIPS
MAX. LOAD 346,500 LB.
VIS. CRACK 243,300 LB.
ESTIMATED FRACTURE
210,000 LB.
ENERGY TO VIS. CRACK 7,800 IN.LB.
ENERGY TO MAX. LOAD 138,800 IN.LB.
ENERGY TO FRACTURE 266,800 IN.LB.
FIG. 26B
3-17-48
SWARTHMORE COLLEGE
INCHES

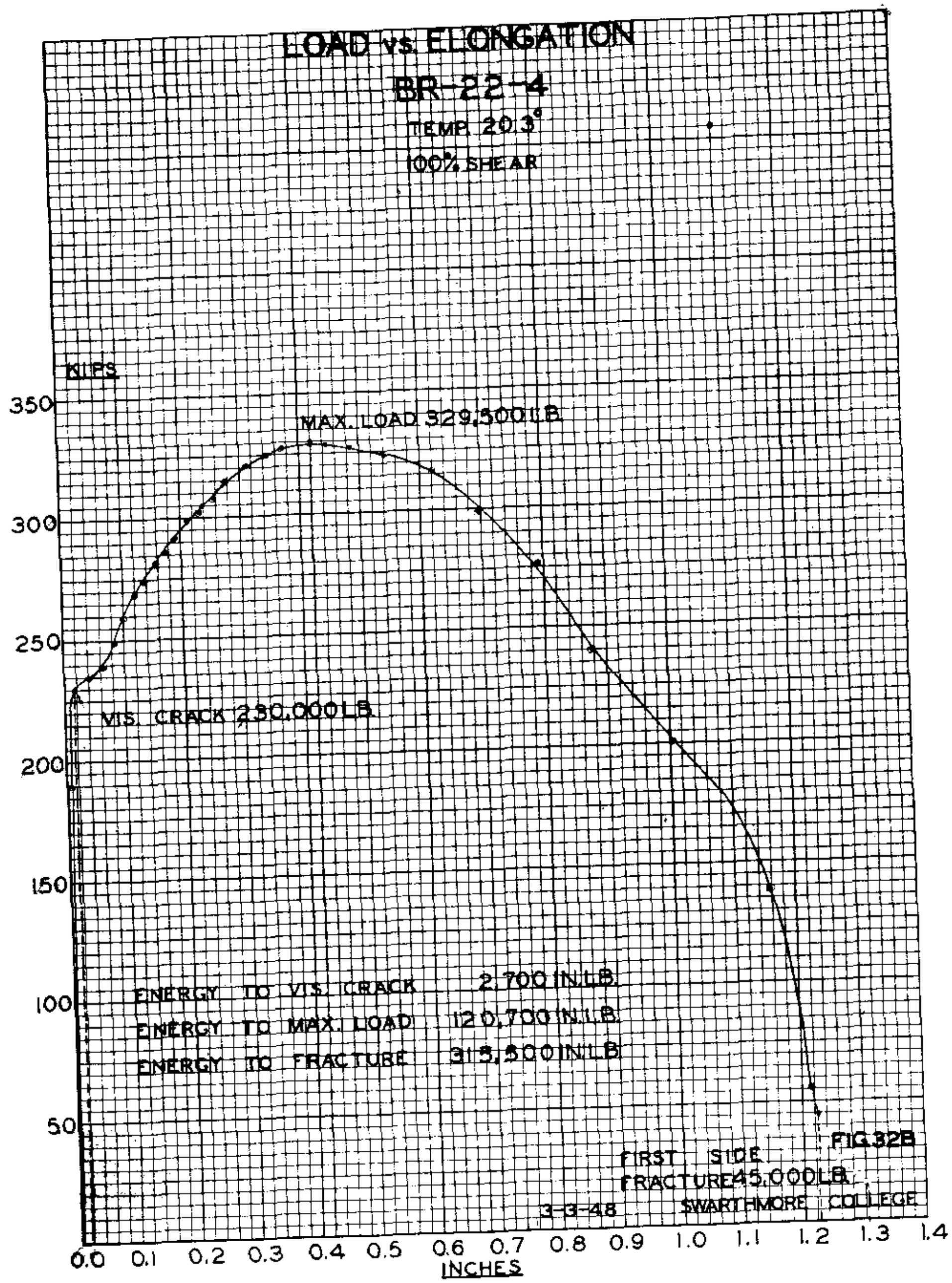

LOAD vs ELONGATION
BR-22-2
TEMP 12.1°
0% SHEAR?
KIPS
MAX. LOAD 279,500 LB.
FRACTURE
VIS. CRACK 239,500 LB.
ENERGY TO VIS. CRACK 10,500 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 34,300 IN.LB.
FIG.27B
2-27-48
SWARTHMORE COLLEGE
INCHES

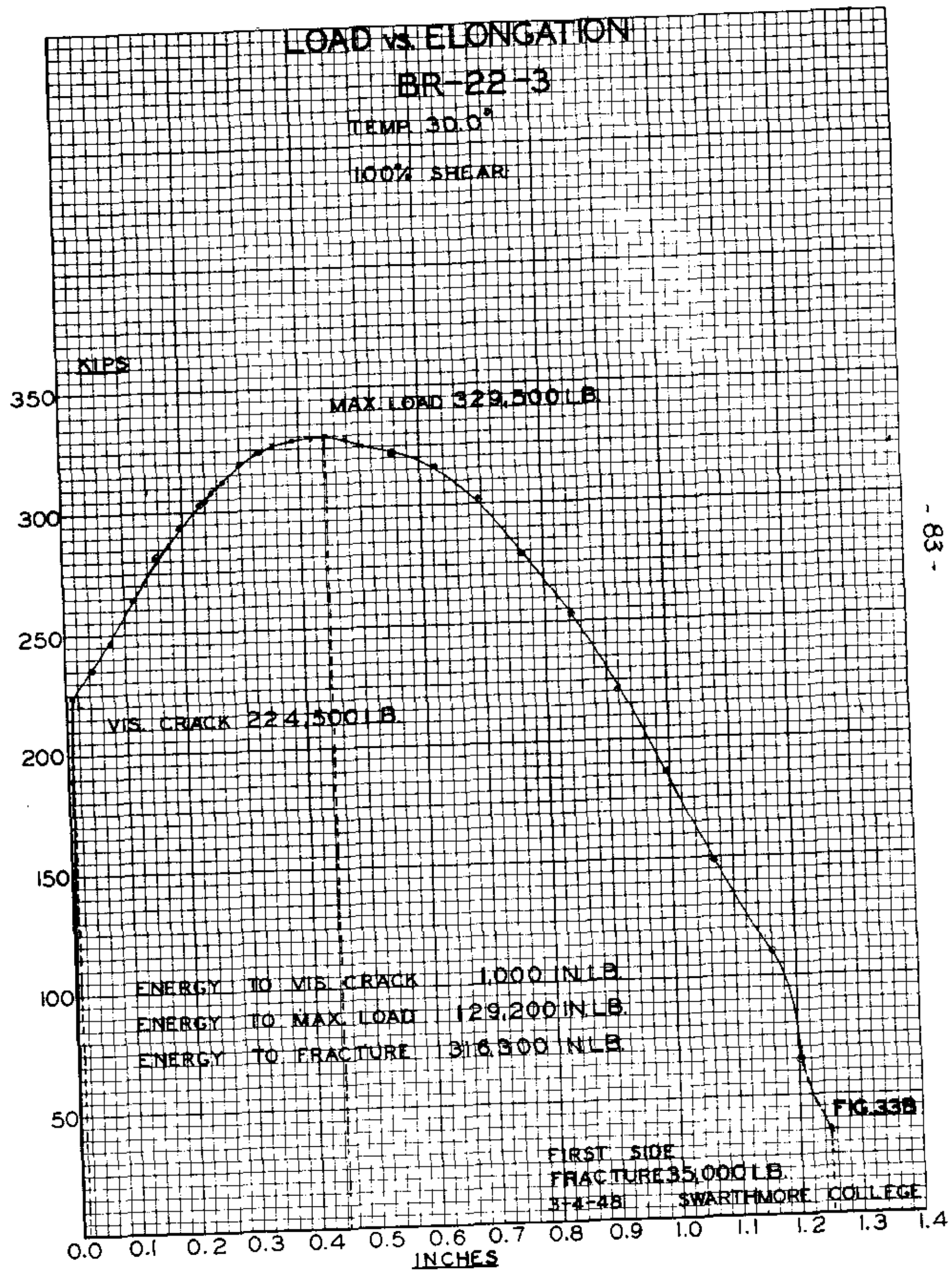

LOAD vs. ELONGATION
BR-22-12
TEMP. 13°
100% SHEAR
KIPS
MAX. LOAD 329,700 LB.
VIS. CRACK 232,200 LB.
ENERGY TO VIS. CRACK 5,200 IN.LB.
ENERGY TO MAX. LOAD 134,000 IN.LB.
ENERGY TO FRACTURE 310,900 IN.LB.
FRACTURE 32,000 LB.
FIG. 28B
3-25-48
SWARTHMORE COLLEGE
350
300
250
200
150
100
50
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
INCHES

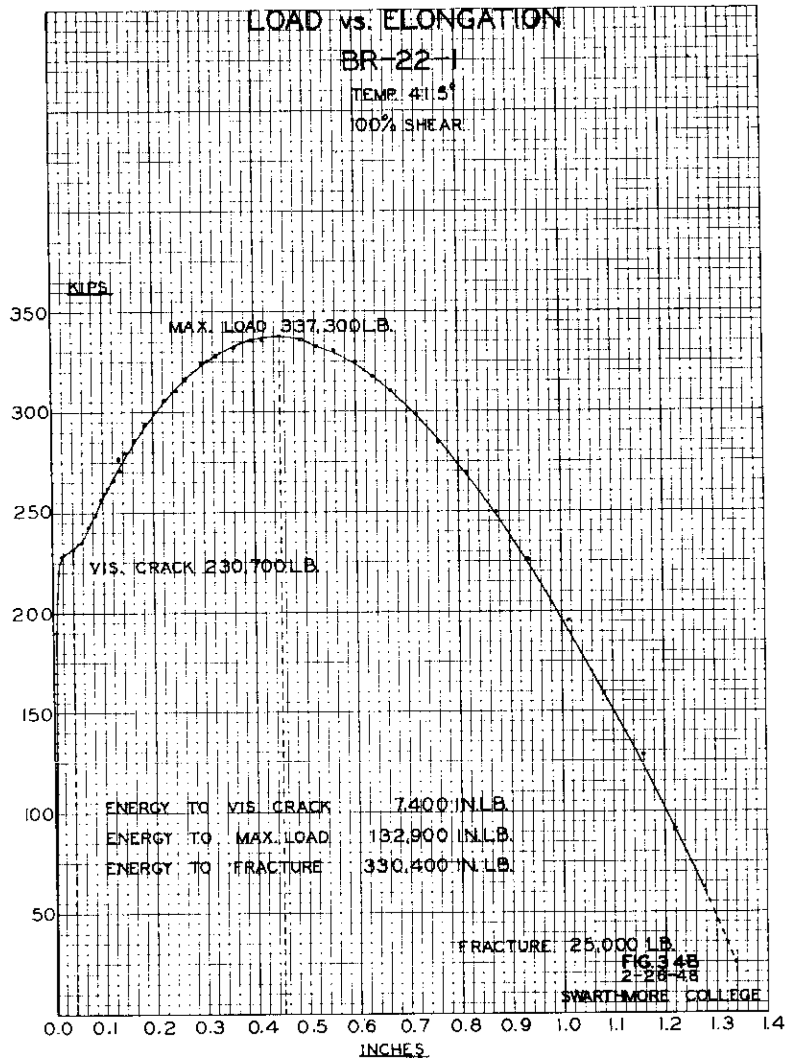

LOAD vs. ELONGATION
BR-22-7
TEMP. 13.6°
1% SHEAR
KIPS
FRACTURE
MAX. LOAD 280,500 LB.
VIS. CRACK 237,300 LB.
ENERGY TO VIS. CRACK 6,300 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 30,000 IN.LB.
FIG. 29B
3-30-48
SWARTHMORE COLLEGE
350
300
250
200
150
100
50
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
INCHES

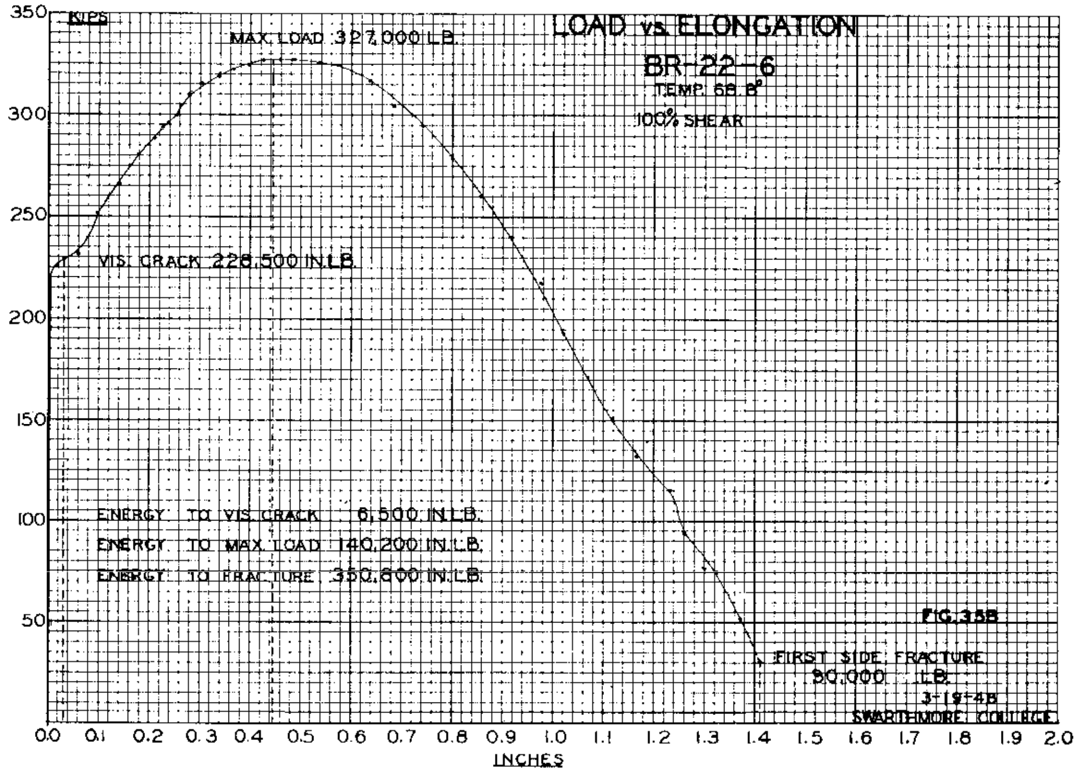

LOAD vs. ELONGATION
BR-22-20
TEMP. 19.3°
100% SHEAR
KIPS
MAX. LOAD 325,600 LB.
VIS. CRACK 230,000 LB.
ENERGY TO VIS. CRACK 3,400 IN.LB.
ENERGY TO MAX. LOAD 120,000 IN.LB.
ENERGY TO FRACTURE 295,100 IN.LB.
FRACTURE 78,000 LB.
FIG. 30B
5-8-48
SWARTHMORE COLLEGE
350
300
250
200
150
100
50
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
INCHES

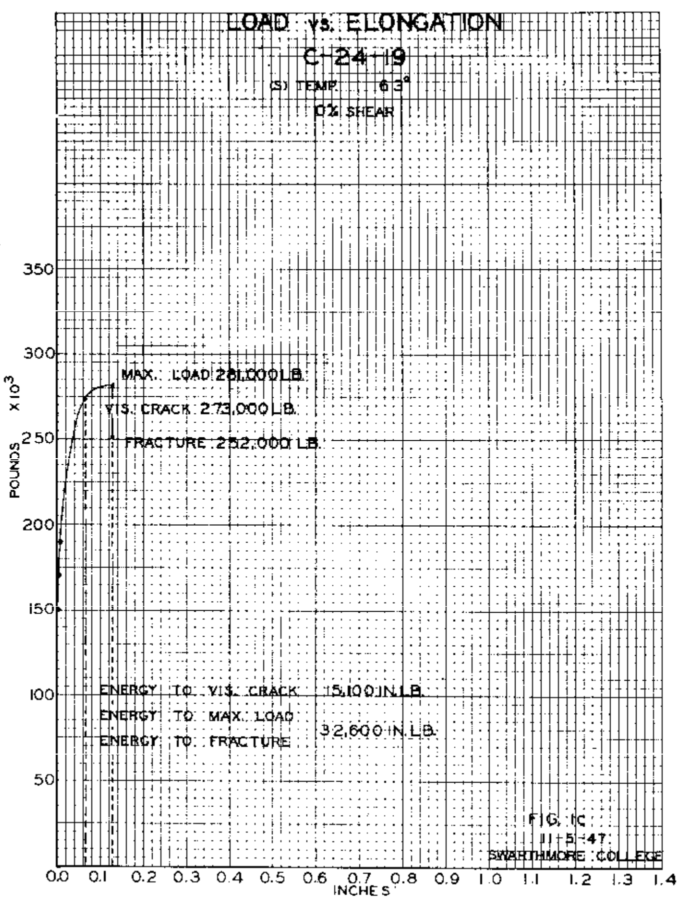

LOAD vs. ELONGATION
BR-22-19
TEMP. 19.6°
100% SHEAR
KIPS
MAX. LOAD 329,300 LB.
VIS. CRACK 230,000 LB.
ENERGY TO VIS. CRACK 3,500 IN.LB.
ENERGY TO MAX. LOAD 120,000 IN.LB.
ENERGY TO FRACTURE 306,500 IN.LB.
ESTIMATED
FRACTURE 40,000 LB.
FIG. 31B
5-7-48
SWARTHMORE COLLEGE
350
300
250
200
150
100
50
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
INCHES

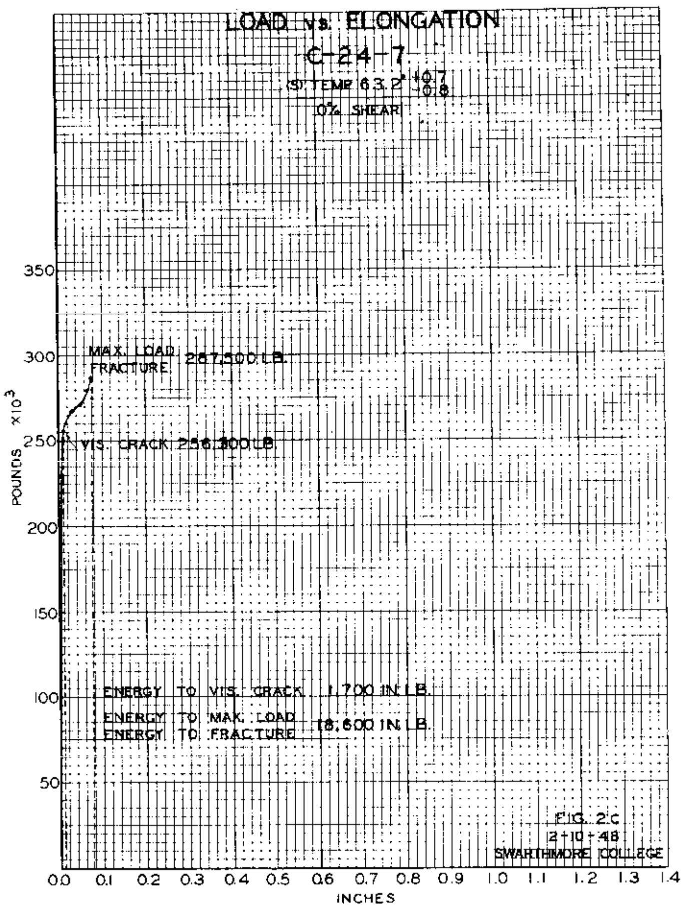

LOAD vs. ELONGATION
BR-22-4
TEMP. 20.3°
100% SHEAR
KIPS
350
300
250
200
150
100
50
MAX. LOAD 329,500 LB.
VIS. CRACK 230,000 LB.
ENERGY TO VIS. CRACK 2,700 IN.LB.
ENERGY TO MAX. LOAD 120,700 IN.LB.
ENERGY TO FRACTURE 315,500 IN.LB.
FIRST SIDE
FRACTURE 45,000 LB.
3-3-48
SWARTHMORE COLLEGE
FIG.32B
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
INCHES

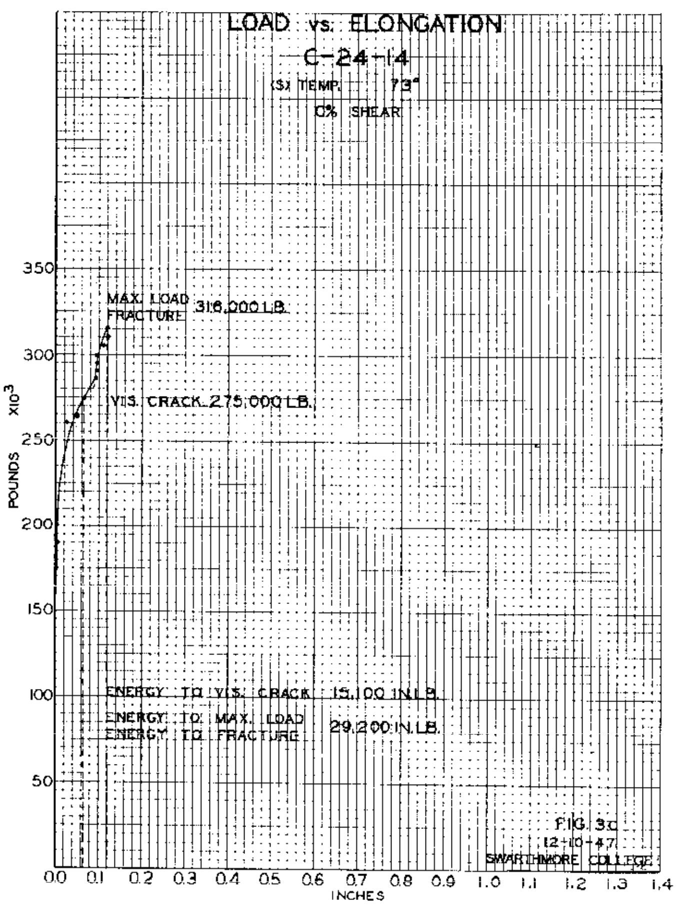

LOAD vs. ELONGATION
BR-22-3
TEMP. 30.0°
100% SHEAR
KIPS
350
300
250
200
150
100
50
MAX. LOAD 329,500 LB.
VIS. CRACK 224,500 LB.
ENERGY TO VIS. CRACK 1,000 IN.LB.
ENERGY TO MAX. LOAD 129,200 IN.LB.
ENERGY TO FRACTURE 316,300 IN.LB.
FIRST SIDE
FRACTURE 35,000 LB.
3-4-48
SWARTHMORE COLLEGE
FIG.33B
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
INCHES

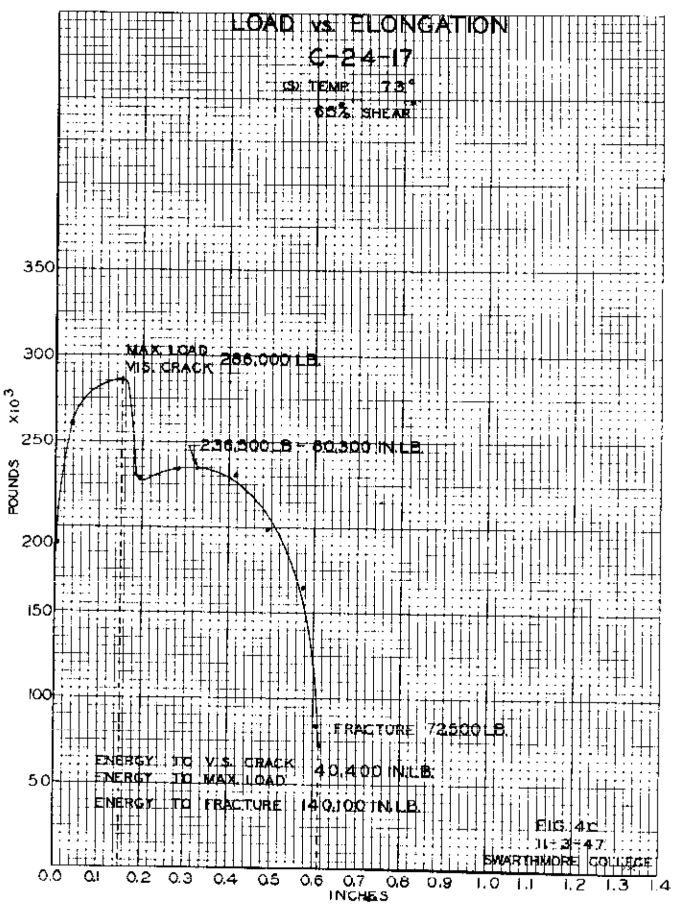

LOAD vs. ELONGATION
BR-22-1
TEMP. 41.5°
100% SHEAR
KIPS
MAX. LOAD 337,300 LB.
VIS. CRACK 230,700 LB.
ENERGY TO VIS. CRACK 7,400 IN. LB.
ENERGY TO MAX. LOAD 132,900 IN. LB.
ENERGY TO FRACTURE 330,400 IN. LB.
FRACTURE 25,000 LB.
FIG. 34B
2-28-48
SWARTHMORE COLLEGE
INCHES

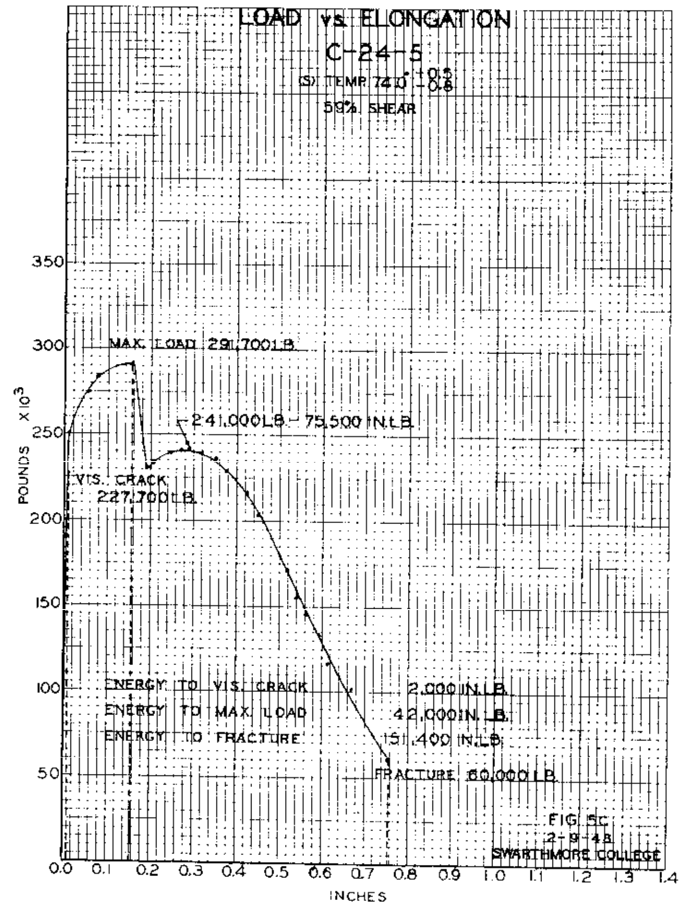

KIPS
MAX. LOAD 327,000 LB.
LOAD vs. ELONGATION
BR-22-6
TEMP. 68.8°
100% SHEAR
VIS. CRACK 228,500 IN. LB.
ENERGY TO VIS. CRACK 6,500 IN. LB.
ENERGY TO MAX. LOAD 140,200 IN. LB.
ENERGY TO FRACTURE 350,800 IN. LB.
FIG. 35B
FIRST SIDE FRACTURE 30,000 LB.
3-19-48
SWARTHMORE COLLEGE
INCHES

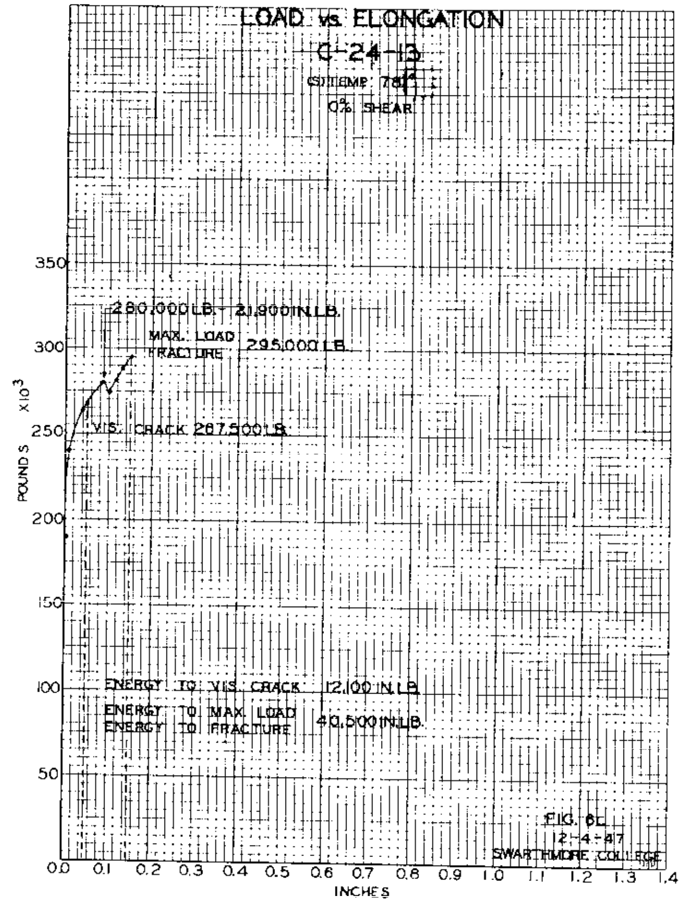

LOAD vs. ELONGATION
C-24-19
(S) TEMP. 63°
0% SHEAR
MAX. LOAD 281,000 LB.
VIS. CRACK 273,000 LB.
FRACTURE 252,000 LB.
ENERGY TO VIS. CRACK 15,100 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 32,600 IN.LB.
FIG. 1C
11-5-47
SWARTHMORE COLLEGE
POUNDS X10³
INCHES

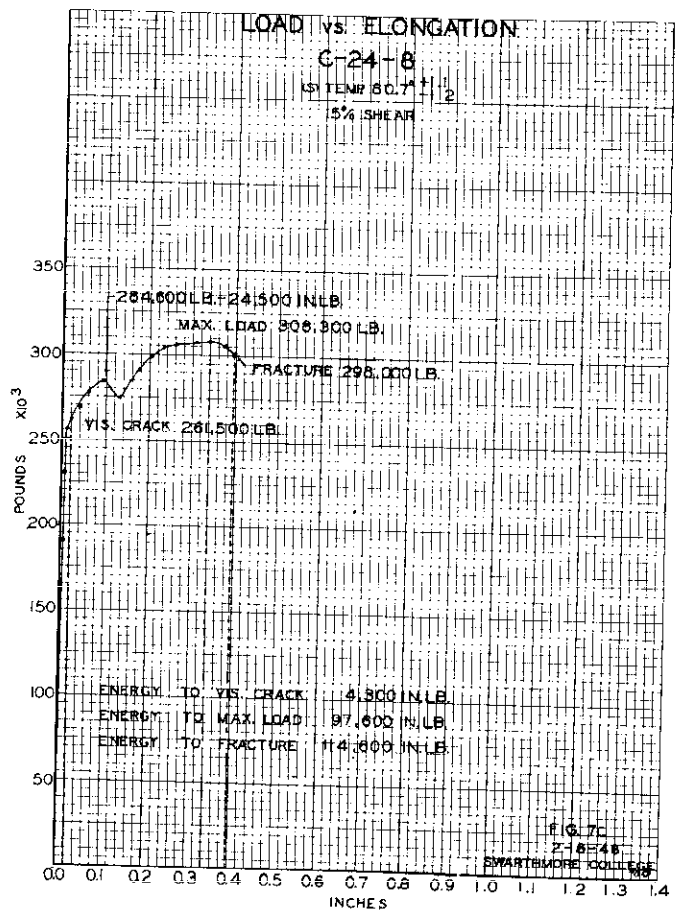

LOAD vs. ELONGATION
C-24-7
(S) TEMP. 63.2° +0.7 -0.8
0% SHEAR
MAX. LOAD
FRACTURE 287,500 LB.
VIS. CRACK 256,300 LB.
ENERGY TO VIS. CRACK 1,700 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 18,600 IN.LB.
FIG. 2C
2-10-48
SWARTHMORE COLLEGE
POUNDS X10³
INCHES

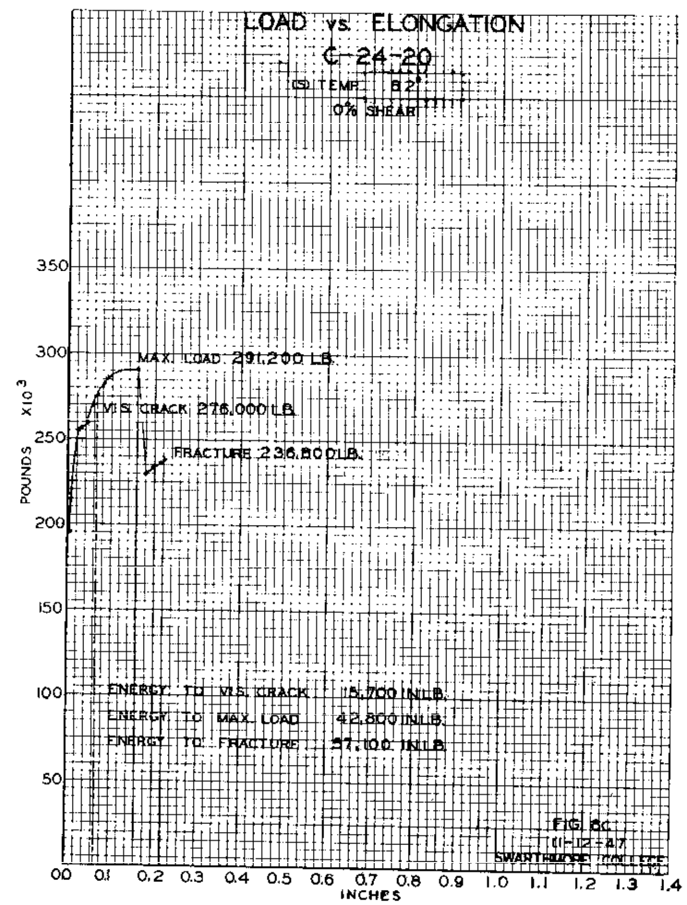

LOAD vs. ELONGATION
C-24-14
(S) TEMP. 73°
0% SHEAR
MAX. LOAD
FRACTURE 316,000 LB.
VIS. CRACK 275,000 LB.
ENERGY TO VIS. CRACK 15,100 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 29,200 IN.LB.
FIG. 3C
12-10-47
SWARTHMORE COLLEGE
POUNDS X10³
INCHES


LOAD vs. ELONGATION
C-24-17
(S) TEMP. 73°
65% SHEAR
MAX. LOAD
VIS. CRACK 285,000 LB.
236,300 LB - 80,300 IN.LB.
FRACTURE 72,500 LB.
ENERGY TO VIS. CRACK
ENERGY TO MAX. LOAD 40,400 IN.LB.
ENERGY TO FRACTURE 140,100 IN.LB.
FIG. 4C
11-3-47
SWARTHMORE COLLEGE
POUNDS X10³
INCHES


LOAD vs. ELONGATION
C-24-5
(S) TEMP. 74.0 +0.5 -0.8
59% SHEAR
MAX. LOAD 291,700 LB.
241,000 LB. - 75,500 IN.LB.
VIS. CRACK 227,700 LB.
ENERGY TO VIS. CRACK 2,000 IN.LB.
ENERGY TO MAX. LOAD 42,000 IN.LB.
ENERGY TO FRACTURE 151,400 IN.LB.
FRACTURE 60,000 LB.
FIG. 5C
2-9-48
SWARTHMORE COLLEGE
POUNDS X10^3
INCHES


LOAD vs. ELONGATION
C-24-13
(S) TEMP. 78
0% SHEAR
280,000 LB. - 21,900 IN.LB.
MAX. LOAD
FRACTURE 295,000 LB.
VIS. CRACK 267,500 LB.
ENERGY TO VIS. CRACK 12,100 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 40,500 IN.LB.
FIG. 6C
12-4-47
SWARTHMORE COLLEGE
POUNDS X10^3
INCHES


LOAD vs. ELONGATION
C-24-8
(S) TEMP. 80.7° ± 1/2
15% SHEAR
284,600 LB. - 24,500 IN.LB.
MAX. LOAD 308,300 LB.
FRACTURE 298,000 LB.
VIS. CRACK 261,500 LB.
ENERGY TO VIS. CRACK 4,800 IN.LB.
ENERGY TO MAX. LOAD 97,600 IN.LB.
ENERGY TO FRACTURE 114,600 IN.LB.
FIG. 7C
2-8-48
SWARTHMORE COLLEGE
POUNDS X10^3
INCHES


LOAD vs. ELONGATION
C-24-20
(S) TEMP. 82°
0% SHEAR
MAX. LOAD 291,200 LB.
VIS. CRACK 276,000 LB.
FRACTURE 236,800 LB.
ENERGY TO VIS. CRACK 15,700 IN.LB.
ENERGY TO MAX. LOAD 42,800 IN.LB.
ENERGY TO FRACTURE 57,100 IN.LB.
FIG. 8C
11-12-47
SWARTHMORE COLLEGE
POUNDS X10^3
INCHES

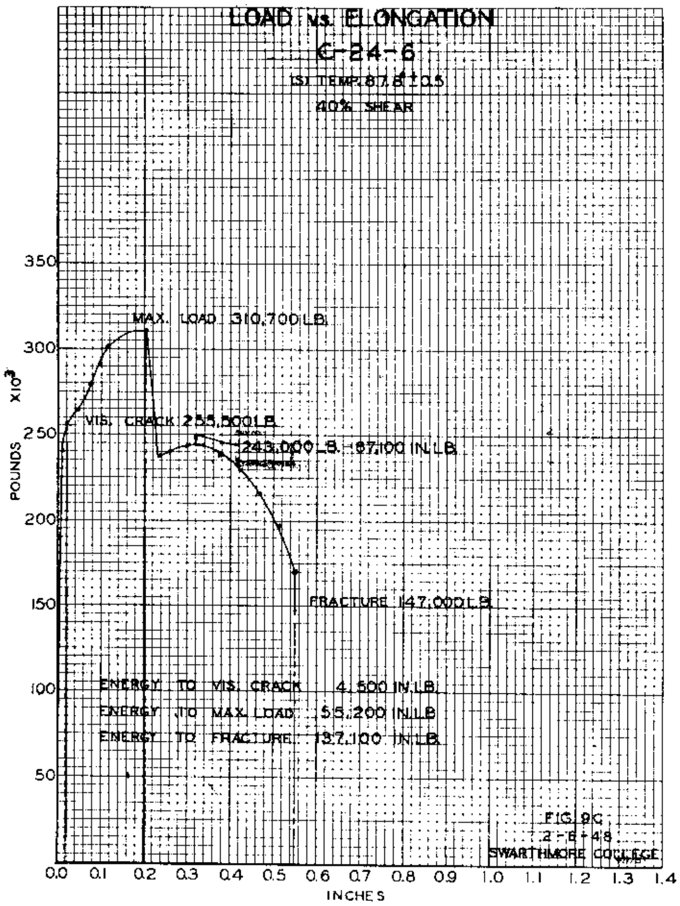


FIG. 9C
2-6-48
SWARTHMORE COLLEGE

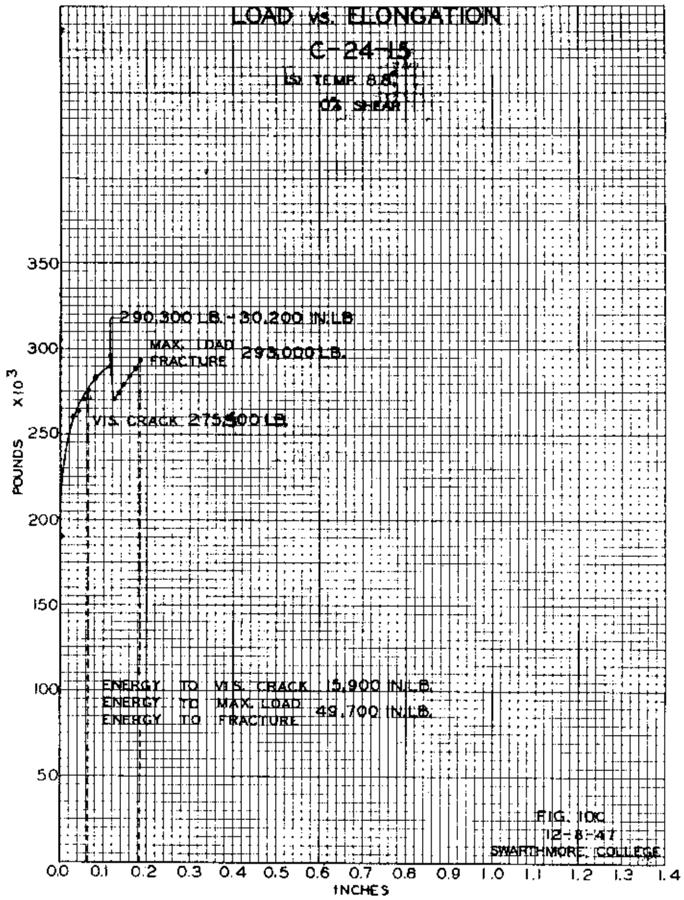


FIG. 10C
12-8-47
SWARTHMORE COLLEGE

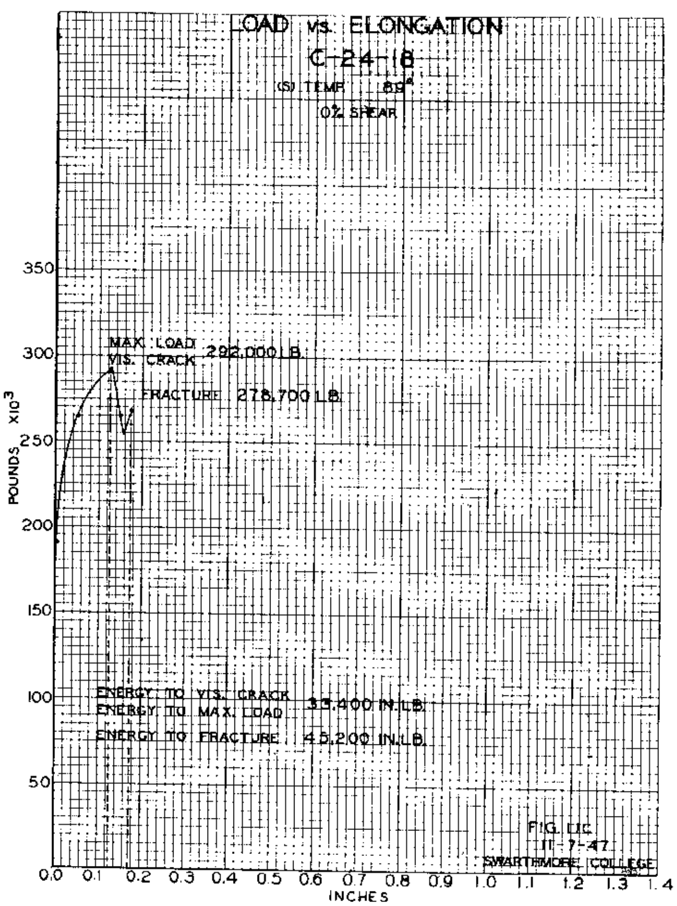


FIG. 11C
11-7-47
SWARTHMORE COLLEGE

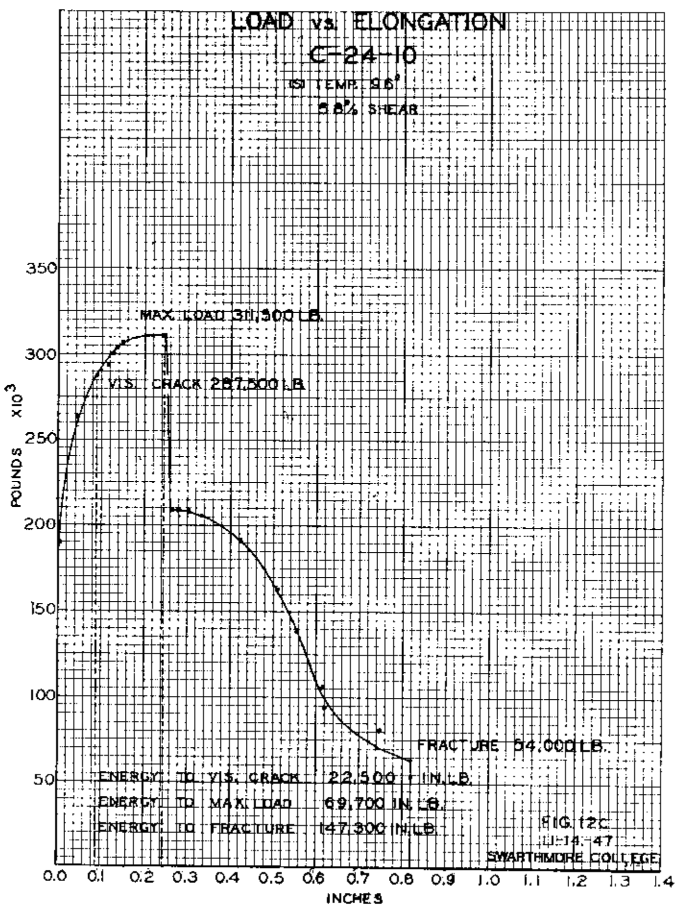
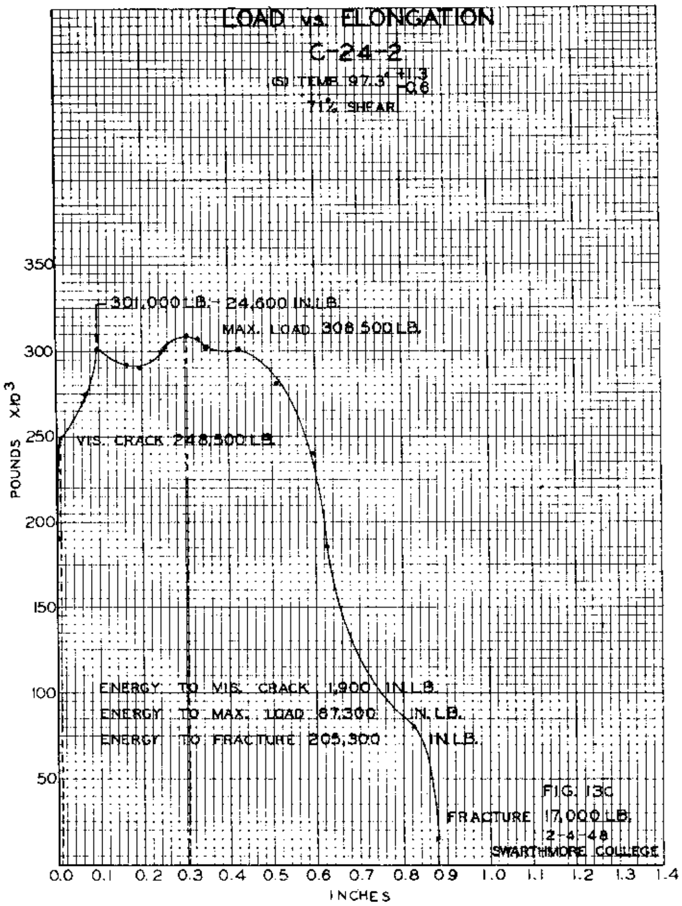
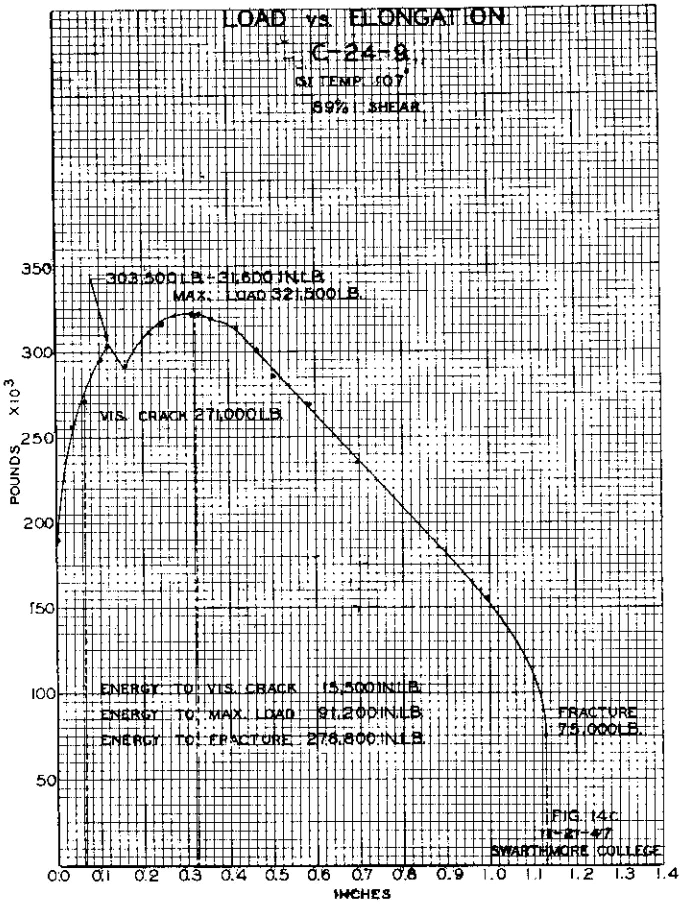
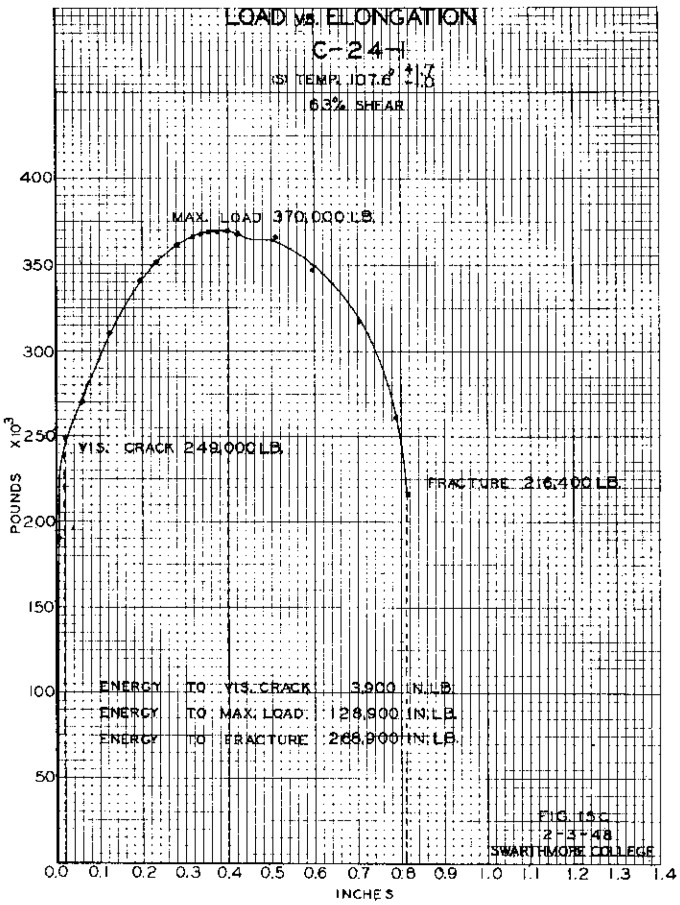
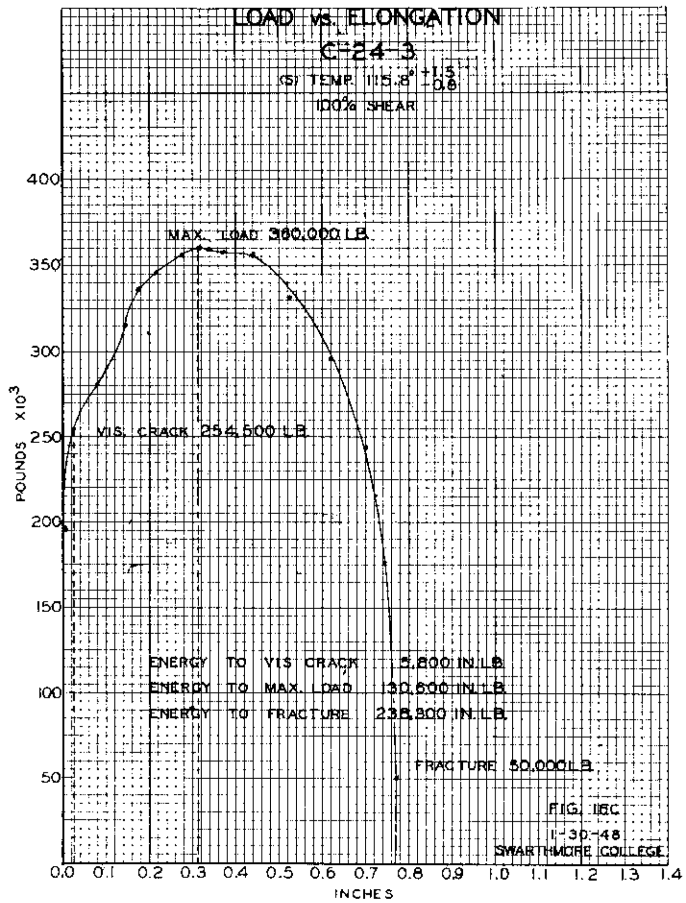


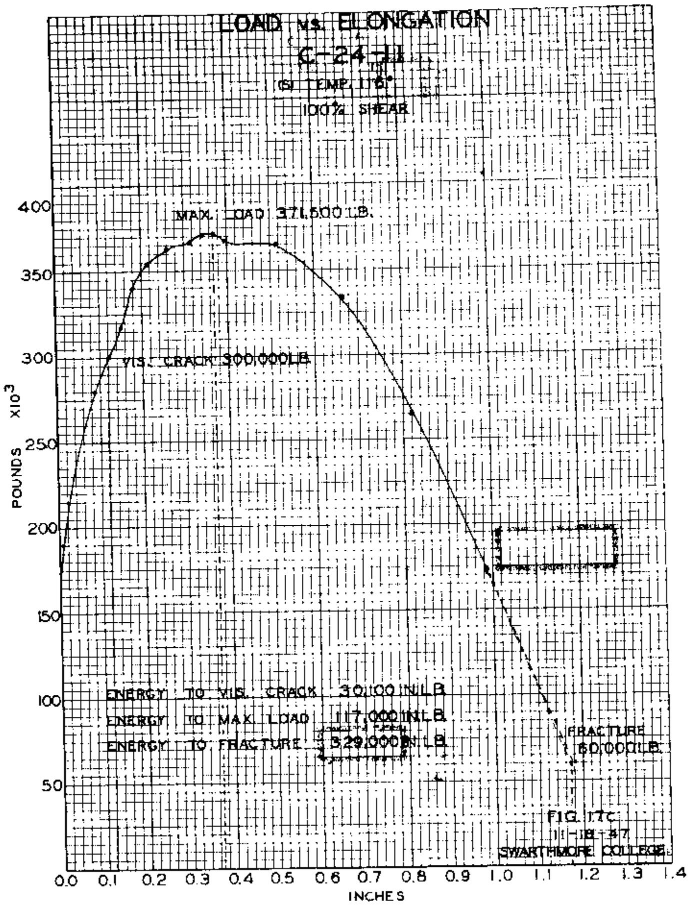
FIG. 12C
11-14-47
SWARTHMORE COLLEGE

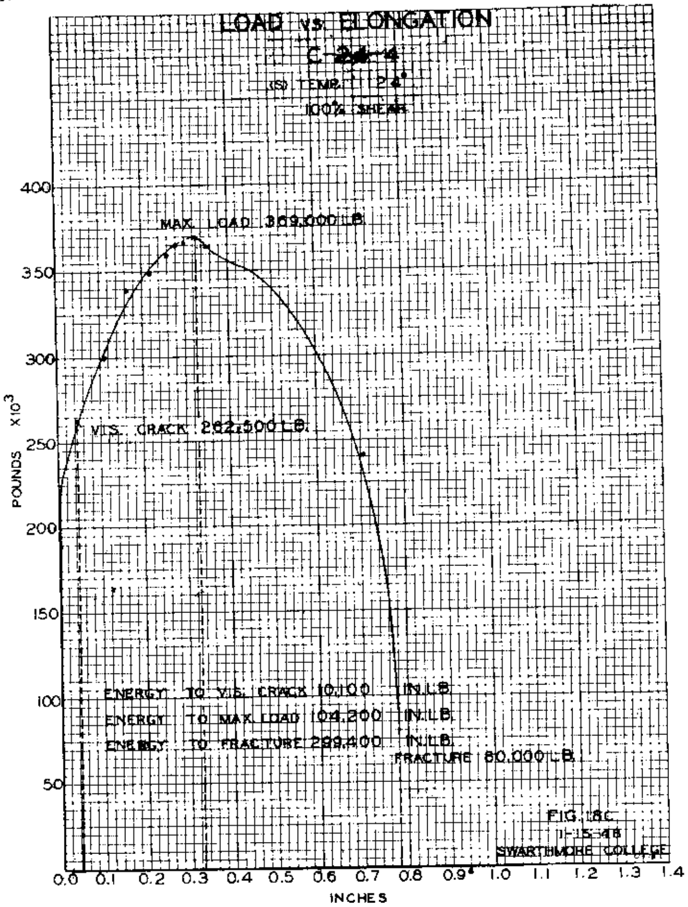

LOAD vs. ELONGATION
C-24-2
(S) TEMP. 97.3° +1.3 -0.6
71% SHEAR
301,000 LB. - 24,600 IN. LB.
MAX. LOAD 308,500 LB.
VIS. CRACK 248,500 LB.
ENERGY TO VIS. CRACK 1,900 IN. LB.
ENERGY TO MAX. LOAD 87,300 IN. LB.
ENERGY TO FRACTURE 205,300 IN. LB.
FRACTURE 17,000 LB.
POUNDS X10^3
INCHES
FIG. 13C
2-4-48
SWARTHMORE COLLEGE

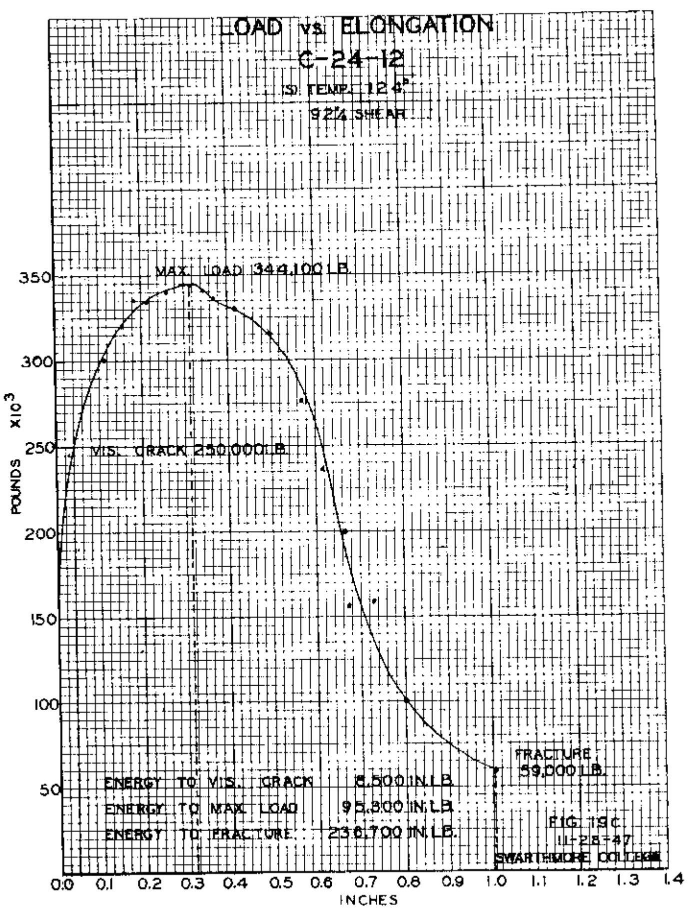

LOAD vs. ELONGATION
C-24-9
(S) TEMP. 107
89% SHEAR
303,500 LB. - 31,600 IN. LB.
MAX. LOAD 321,500 LB.
VIS. CRACK 271,000 LB.
ENERGY TO VIS. CRACK 15,500 IN. LB.
ENERGY TO MAX. LOAD 91,200 IN. LB.
ENERGY TO FRACTURE 278,800 IN. LB.
FRACTURE 75,000 LB.
POUNDS X10^3
INCHES
FIG. 14C
11-21-47
SWARTHMORE COLLEGE

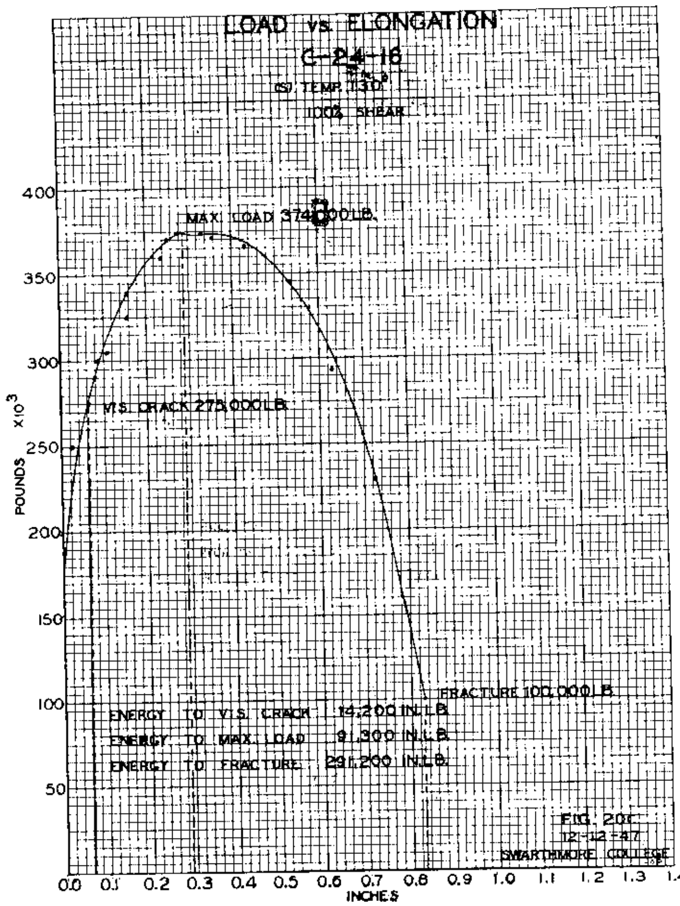

LOAD vs. ELONGATION
C-24-1
(S) TEMP. 107.6° +1.7 -1.0
63% SHEAR
MAX. LOAD 370,000 LB.
VIS. CRACK 249,000 LB.
FRACTURE 216,400 LB.
ENERGY TO VIS. CRACK 3,900 IN. LB.
ENERGY TO MAX. LOAD 128,900 IN. LB.
ENERGY TO FRACTURE 268,900 IN. LB.
POUNDS X10^3
INCHES
FIG. 15C
2-3-48
SWARTHMORE COLLEGE

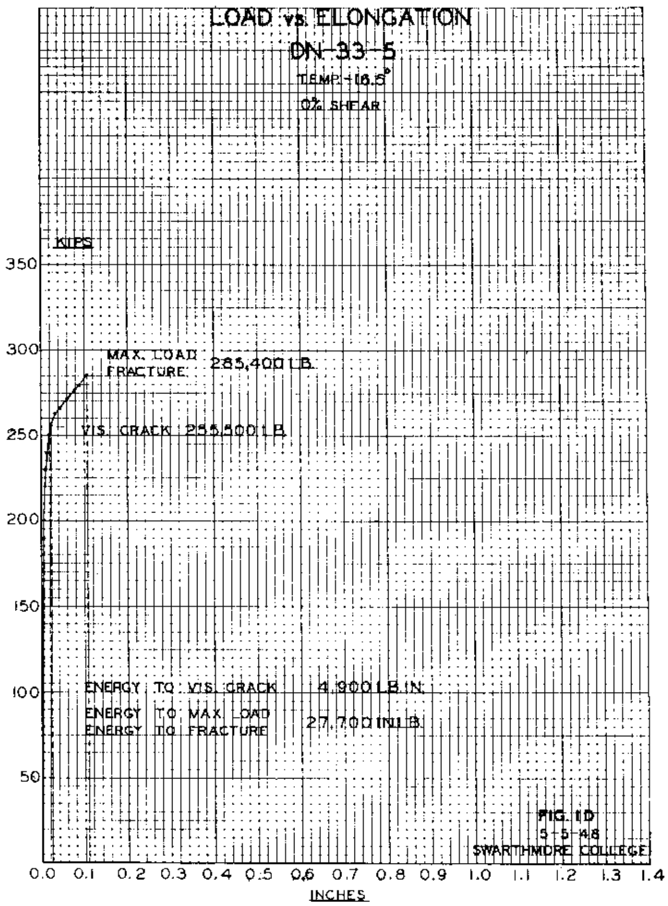

LOAD vs. ELONGATION
C-24-3
(S) TEMP. 115.8° +1.5 -0.8
100% SHEAR
MAX. LOAD 360,000 LB.
VIS. CRACK 254,500 LB.
ENERGY TO VIS. CRACK 5,800 IN. LB.
ENERGY TO MAX. LOAD 130,600 IN. LB.
ENERGY TO FRACTURE 238,300 IN. LB.
FRACTURE 50,000 LB.
POUNDS X10^3
INCHES
FIG. 16C
1-30-48
SWARTHMORE COLLEGE

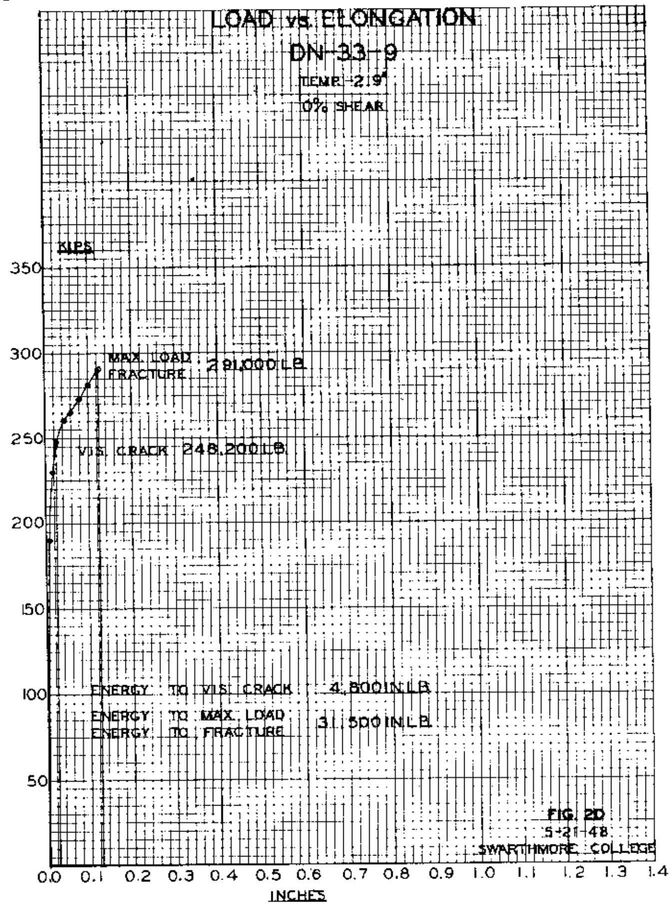

LOAD vs. ELONGATION
C-24-11
(S) TEMP. 116°
100% SHEAR
MAX. LOAD 371,500 LB.
VIS. CRACK 300,000 LB.
ENERGY TO VIS. CRACK 30,100 IN.LB.
ENERGY TO MAX. LOAD 117,000 IN.LB.
ENERGY TO FRACTURE 329,000 IN.LB.
FRACTURE 60,000 LB.
POUNDS X10^3
INCHES
FIG. 17C
11-18-47
SWARTHMORE COLLEGE

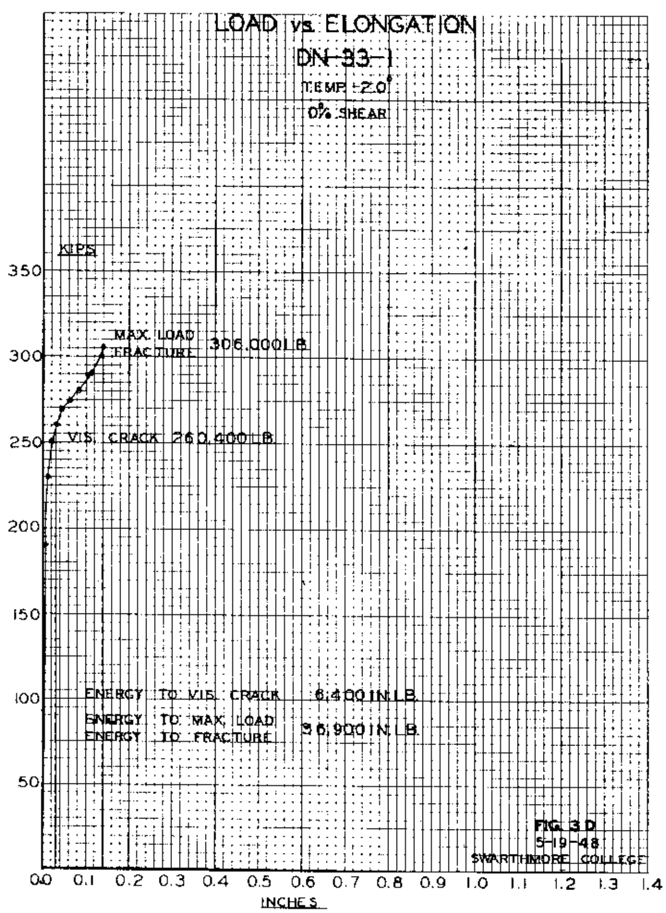

LOAD vs. ELONGATION
C-24-4
(S) TEMP. 112.4°
100% SHEAR
MAX. LOAD 369,000 LB.
VIS. CRACK 262,500 LB.
ENERGY TO VIS. CRACK 10,100 IN.LB.
ENERGY TO MAX. LOAD 104,200 IN.LB.
ENERGY TO FRACTURE 289,400 IN.LB.
FRACTURE 60,000 LB.
POUNDS X10^3
INCHES
FIG. 18C
11-15-48
SWARTHMORE COLLEGE

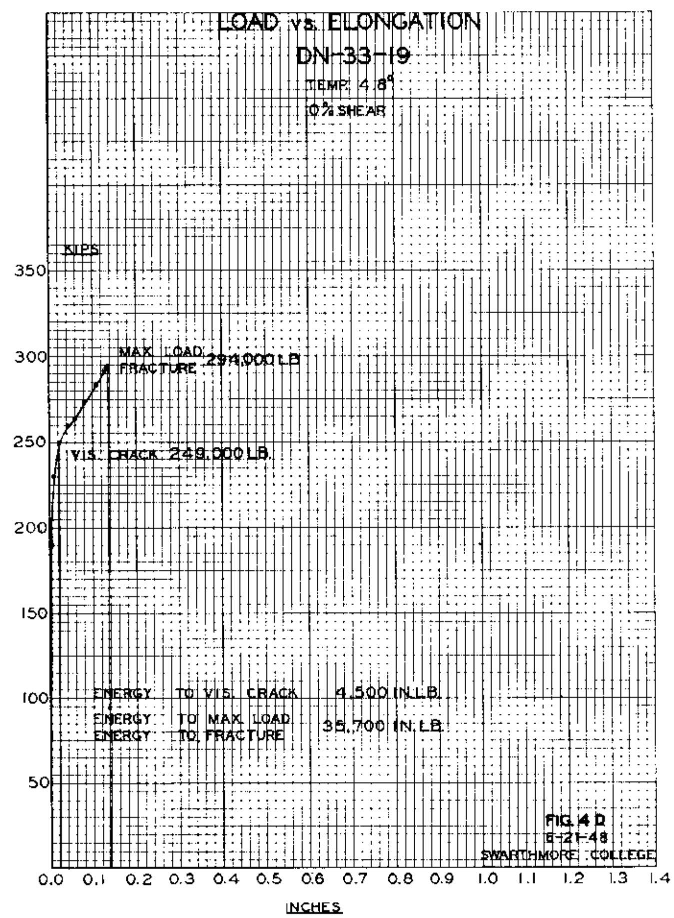

LOAD vs. ELONGATION
C-24-12
(S) TEMP. 124°
92% SHEAR
MAX. LOAD 344,100 LB.
VIS. CRACK 250,000 LB.
ENERGY TO VIS. CRACK 6,500 IN.LB.
ENERGY TO MAX. LOAD 95,300 IN.LB.
ENERGY TO FRACTURE 236,700 IN.LB.
FRACTURE 59,000 LB.
POUNDS X10^3
INCHES
FIG. 19C
11-28-47
SWARTHMORE COLLEGE

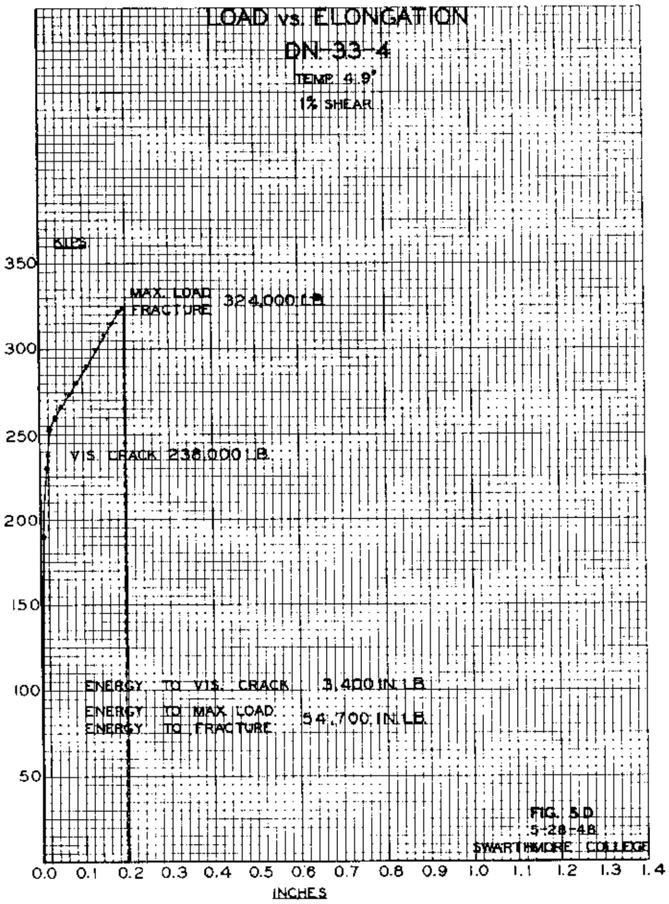

LOAD vs. ELONGATION
C-24-16
(S) TEMP. 130°
100% SHEAR
MAX. LOAD 374,000 LB.
VIS. CRACK 275,000 LB.
ENERGY TO VIS. CRACK 14,200 IN.LB.
ENERGY TO MAX. LOAD 91,300 IN.LB.
ENERGY TO FRACTURE 291,200 IN.LB.
FRACTURE 100,000 LB.
POUNDS X10^3
INCHES
FIG. 20C
12-12-47
SWARTHMORE COLLEGE

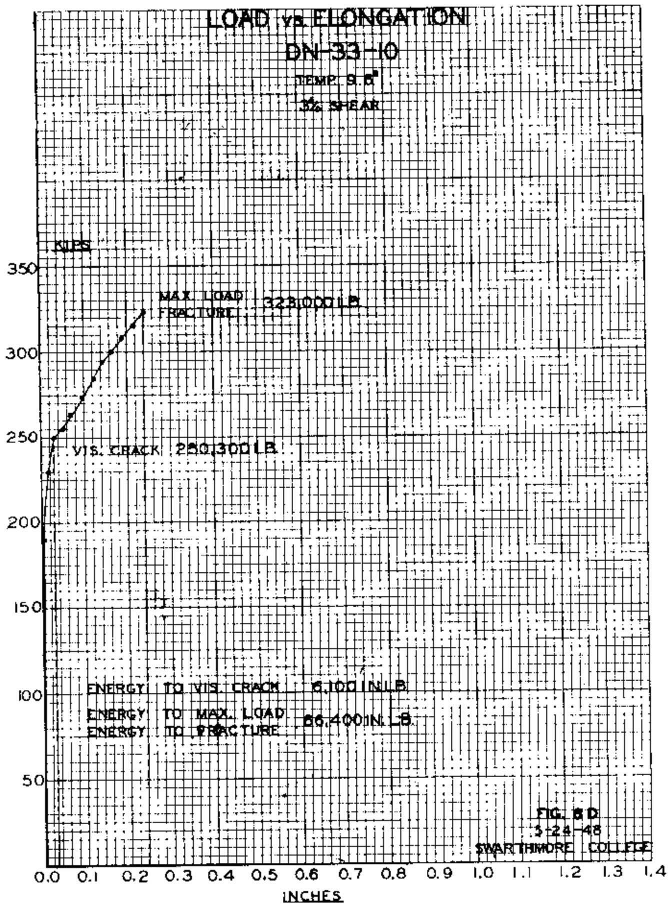

LOAD vs. ELONGATION
DN-33-5
TEMP. -16.5°
0% SHEAR
KIPS
MAX. LOAD
FRACTURE 285,400 LB.
VIS. CRACK 255,500 LB.
ENERGY TO VIS. CRACK 4,900 LB.IN.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 27,700 IN.LB.
FIG. 1D
5-5-48
SWARTHMORE COLLEGE
INCHES

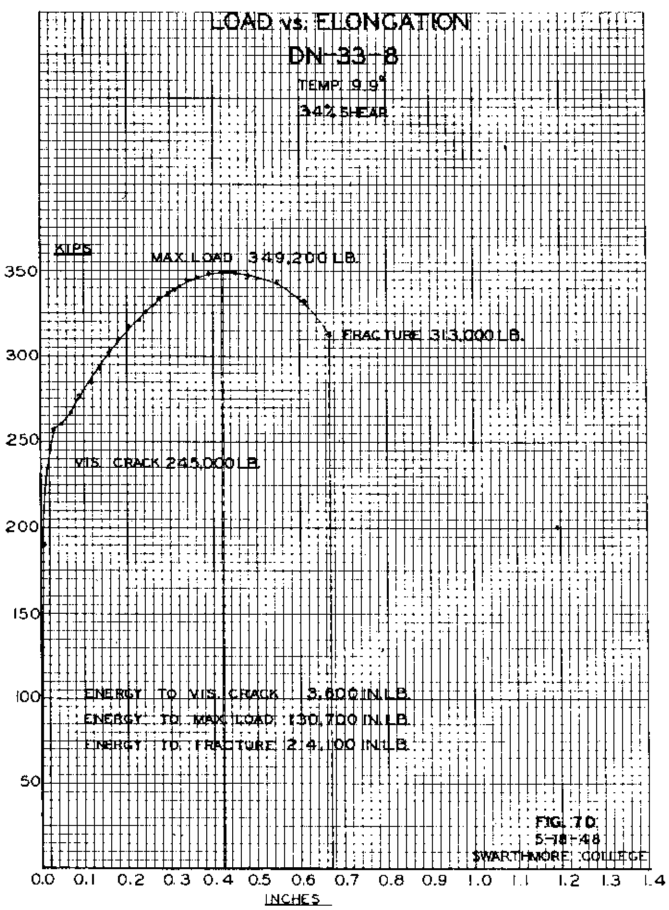

LOAD vs. ELONGATION
DN-33-9
TEMP. -2.9°
0% SHEAR
KIPS
MAX. LOAD
FRACTURE 291,000 LB.
VIS. CRACK 248,200 LB.
ENERGY TO VIS. CRACK 4,800 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 31,500 IN.LB.
FIG. 2D
5-21-48
SWARTHMORE COLLEGE
INCHES

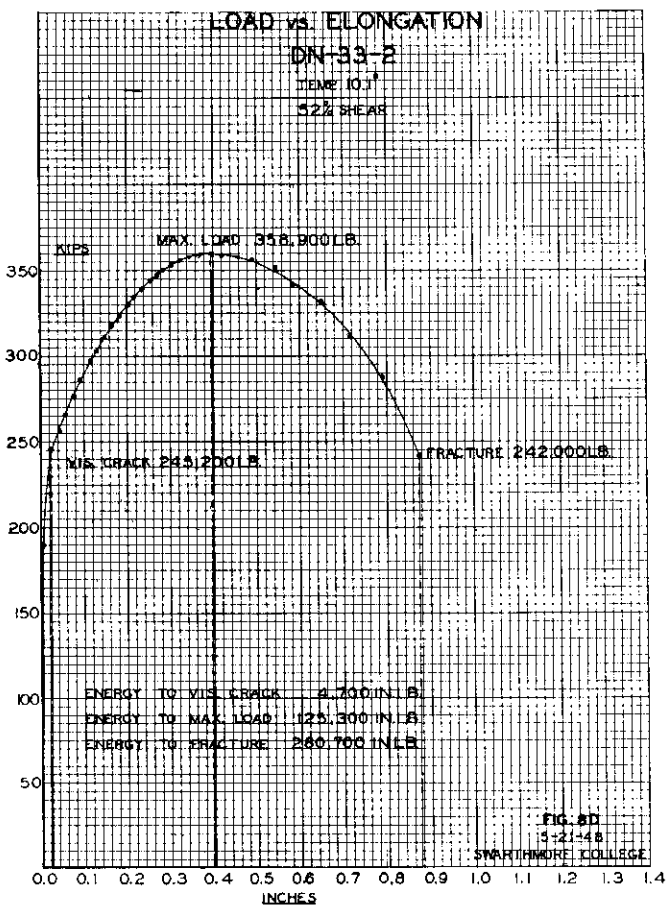

LOAD vs. ELONGATION
DN-33-1
TEMP. -2.0°
0% SHEAR
KIPS
MAX. LOAD
FRACTURE 306,000 LB.
VIS. CRACK 260,400 LB.
ENERGY TO VIS. CRACK 6,400 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 36,900 IN.LB.
FIG. 3D
5-19-48
SWARTHMORE COLLEGE
INCHES

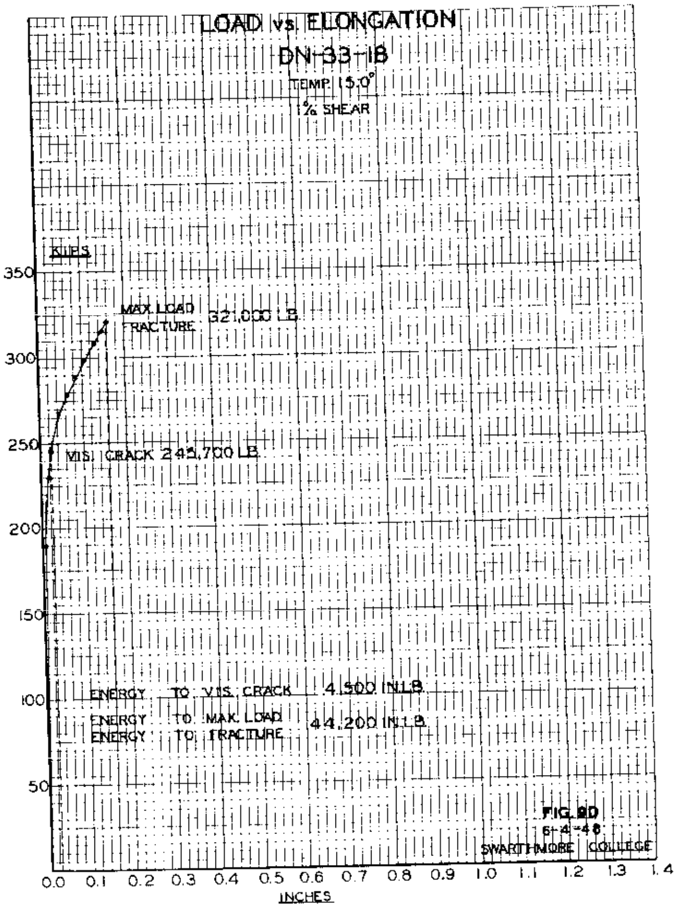

LOAD vs. ELONGATION
DN-33-19
TEMP. 4.8°
0% SHEAR
KIPS
MAX. LOAD
FRACTURE 294,000 LB.
VIS. CRACK 249,000 LB.
ENERGY TO VIS. CRACK 4,500 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 35,700 IN.LB.
FIG. 4D
5-21-48
SWARTHMORE COLLEGE
INCHES

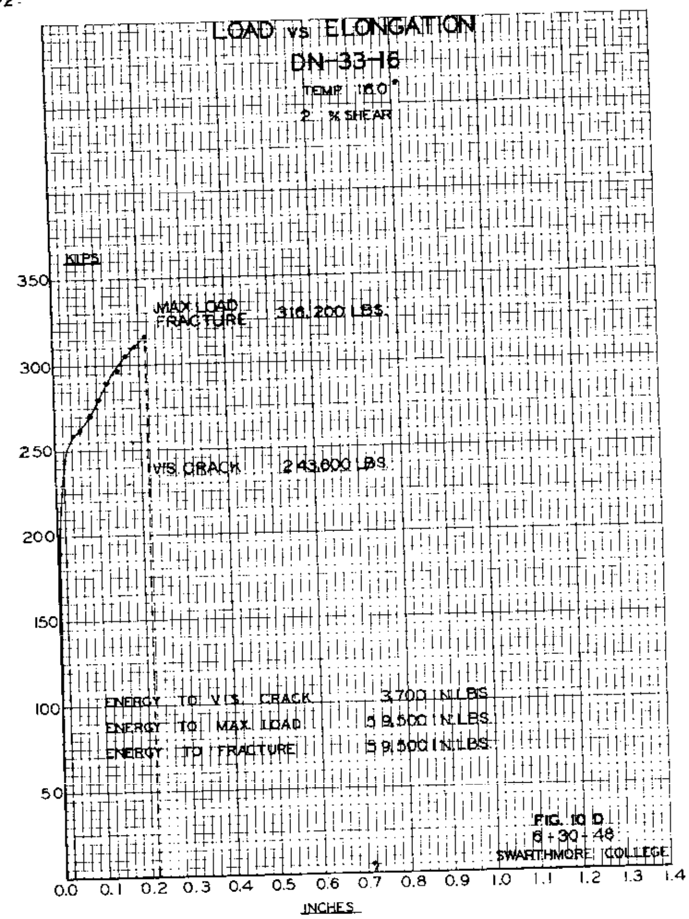

LOAD vs. ELONGATION
DN-33-4
TEMP. 4.9°
1% SHEAR
KIPS
MAX. LOAD
FRACTURE
324,000 LB.
VIS. CRACK 238,000 LB.
ENERGY TO VIS. CRACK 3,400 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE
54,700 IN.LB.
FIG. 5D
5-28-48
SWARTHMORE COLLEGE
INCHES

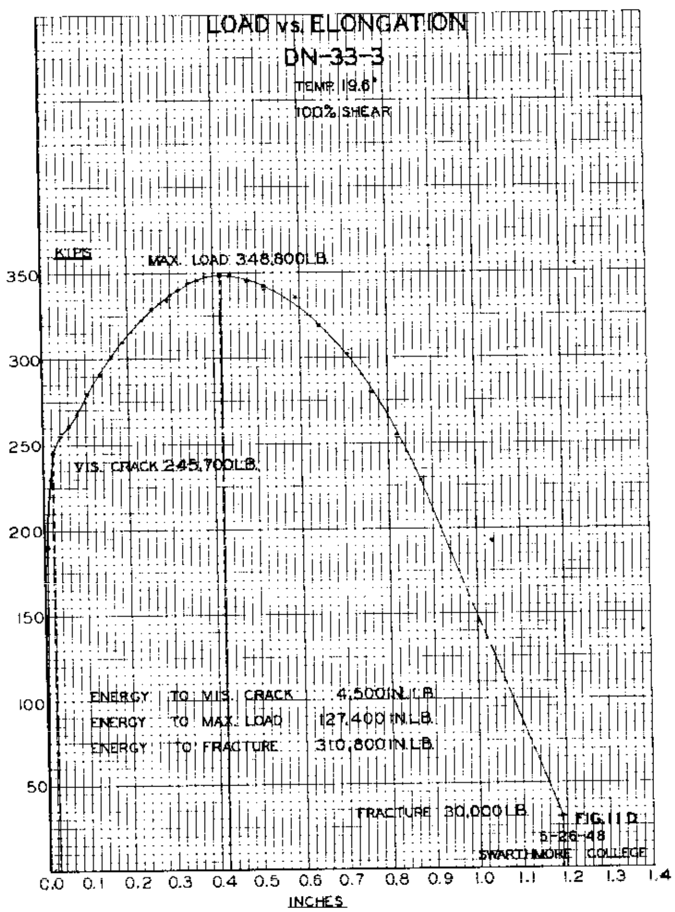

LOAD vs. ELONGATION
DN-33-10
TEMP. 9.8°
3% SHEAR
KIPS
MAX. LOAD
FRACTURE
323,000 LB.
VIS. CRACK 250,300 LB.
ENERGY TO VIS. CRACK 6,100 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE
66,400 IN.LB.
FIG. 6D
5-24-48
SWARTHMORE COLLEGE
INCHES

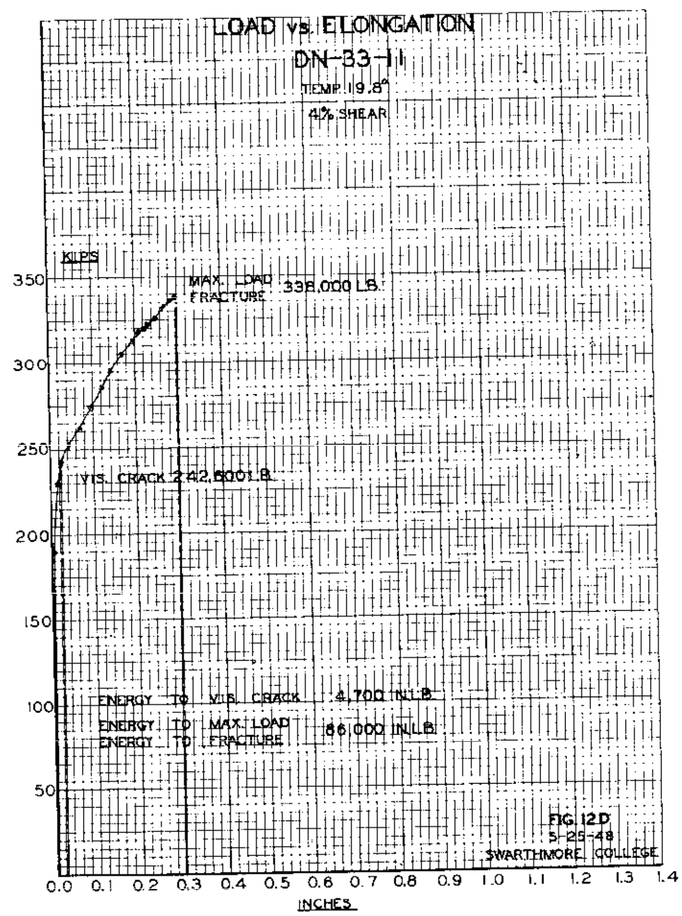

LOAD vs. ELONGATION
DN-33-8
TEMP. 9.9°
34% SHEAR
KIPS
MAX. LOAD 349,200 LB.
FRACTURE 313,000 LB.
VIS. CRACK 245,000 LB.
ENERGY TO VIS. CRACK 3,600 IN.LB.
ENERGY TO MAX. LOAD 130,700 IN.LB.
ENERGY TO FRACTURE 214,100 IN.LB.
FIG. 7D
5-18-48
SWARTHMORE COLLEGE
INCHES

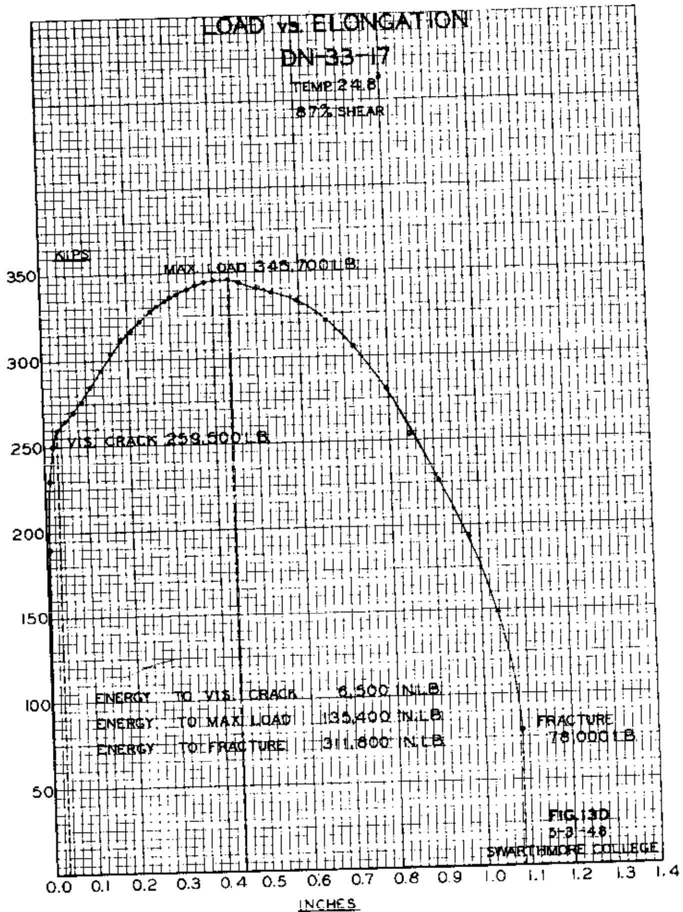

LOAD vs. ELONGATION
DN-33-2
TEMP. 10.1°
52% SHEAR
KIPS
MAX. LOAD 358,900 LB.
VIS. CRACK 245,200 LB.
FRACTURE 242,000 LB.
ENERGY TO VIS. CRACK 4,700 IN.LB.
ENERGY TO MAX. LOAD 125,300 IN.LB.
ENERGY TO FRACTURE 260,700 IN.LB.
FIG. 8D
5-21-48
SWARTHMORE COLLEGE
INCHES

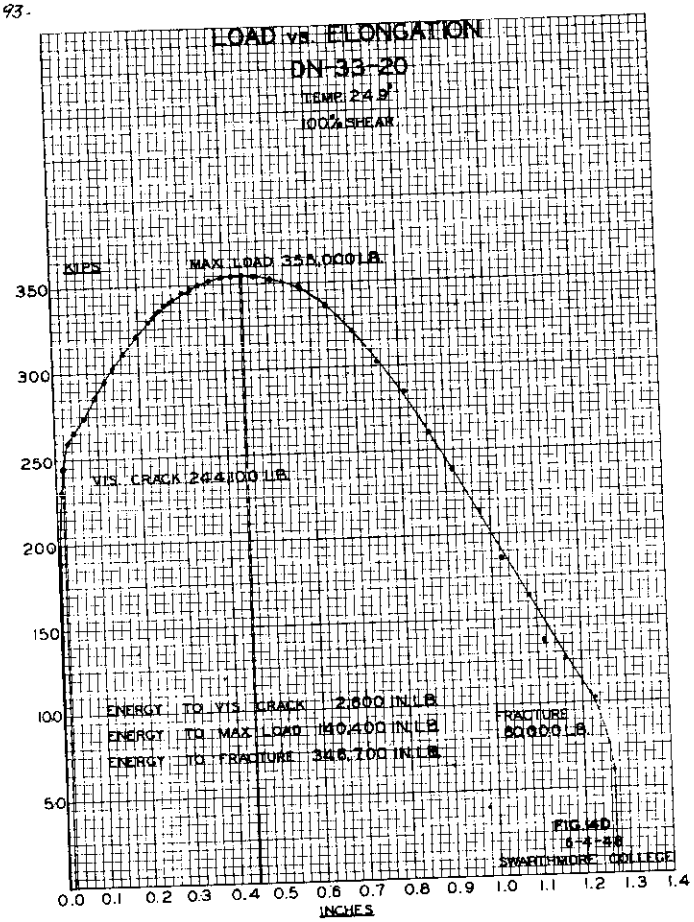

LOAD vs. ELONGATION
DN-33-18
TEMP. 15.0°
% SHEAR
KIPS
MAX. LOAD
FRACTURE 321,000 LB.
VIS. CRACK 245,700 LB.
ENERGY TO VIS. CRACK 4,500 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 44,200 IN.LB.
FIG. 9D
6-4-48
SWARTHMORE COLLEGE
INCHES

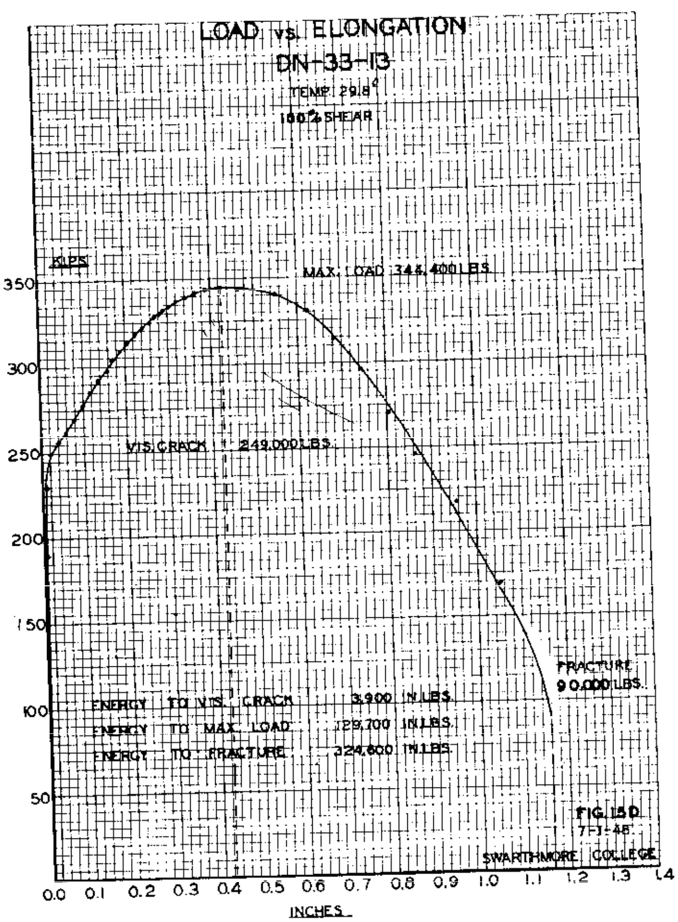

LOAD vs. ELONGATION
DN-33-16
TEMP. 18.0°
2 % SHEAR
KIPS
MAX. LOAD
FRACTURE 316,200 LBS.
VIS. CRACK 243,600 LBS.
ENERGY TO VIS. CRACK 3,700 IN.LBS.
ENERGY TO MAX. LOAD 59,500 IN.LBS.
ENERGY TO FRACTURE 59,500 IN.LBS.
FIG. 10 D
6-30-48
SWARTHMORE COLLEGE
INCHES

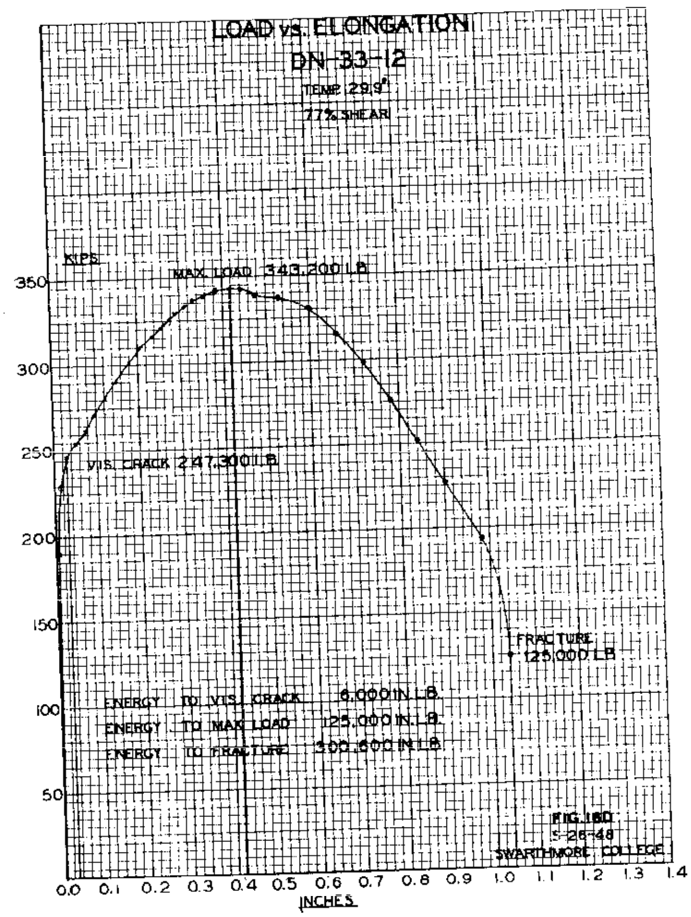

LOAD vs. ELONGATION
DN-33-3
TEMP. 19.6°
100% SHEAR
KIPS
MAX. LOAD 348,800 LB.
VIS. CRACK 245,700 LB.
ENERGY TO VIS. CRACK 4,500 IN.LB.
ENERGY TO MAX. LOAD 127,400 IN.LB.
ENERGY TO FRACTURE 310,800 IN.LB.
FRACTURE 30,000 LB.
FIG. 11 D
5-26-48
SWARTHMORE COLLEGE
INCHES

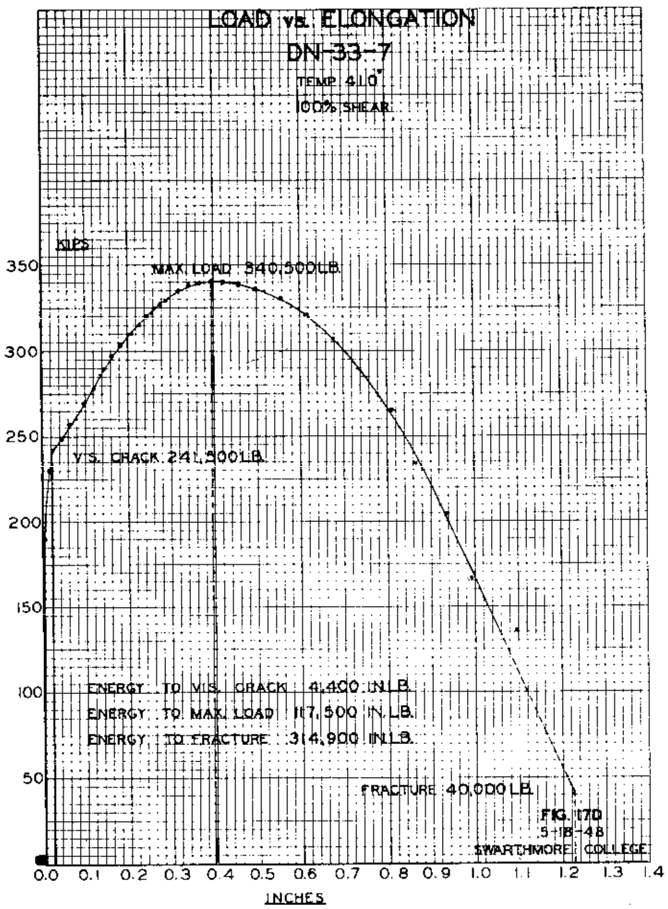

LOAD vs. ELONGATION
DN-33-11
TEMP. 19.8°
4% SHEAR
KIPS
MAX. LOAD
FRACTURE 338,000 LB.
VIS. CRACK 242,600 LB.
ENERGY TO VIS. CRACK 4,700 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 86,000 IN.LB.
FIG. 12 D
5-25-48
SWARTHMORE COLLEGE
INCHES

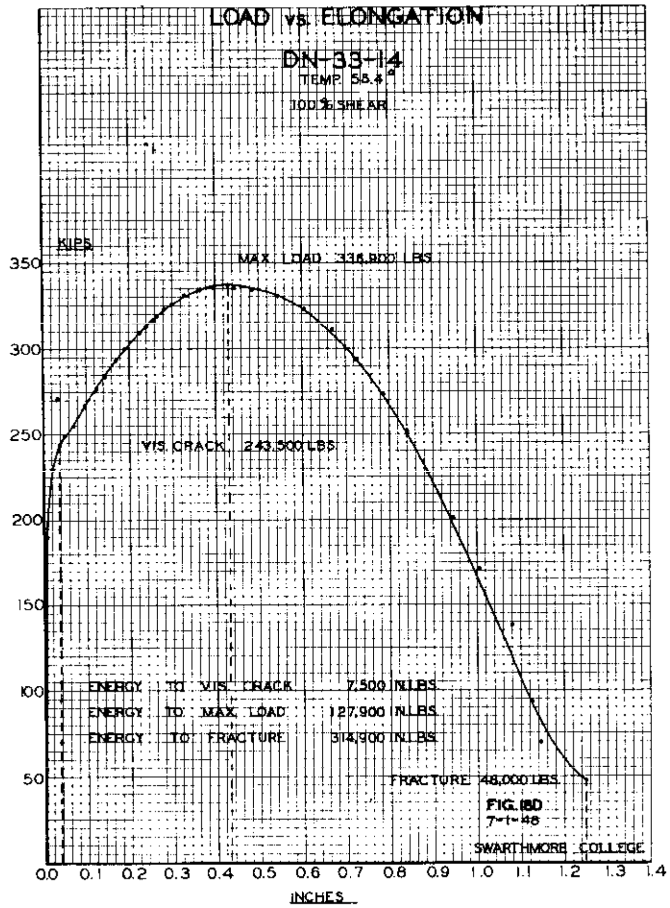

LOAD vs. ELONGATION
DN-33-17
TEMP. 24.8°
87% SHEAR
KIPS
MAX. LOAD 345,700 LB.
VIS. CRACK 259,500 LB.
ENERGY TO VIS. CRACK 6,500 IN.LB.
ENERGY TO MAX. LOAD 135,400 IN.LB.
ENERGY TO FRACTURE 311,600 IN.LB.
FRACTURE 78,000 LB.
FIG. 13D
5-3-48
SWARTHMORE COLLEGE
INCHES

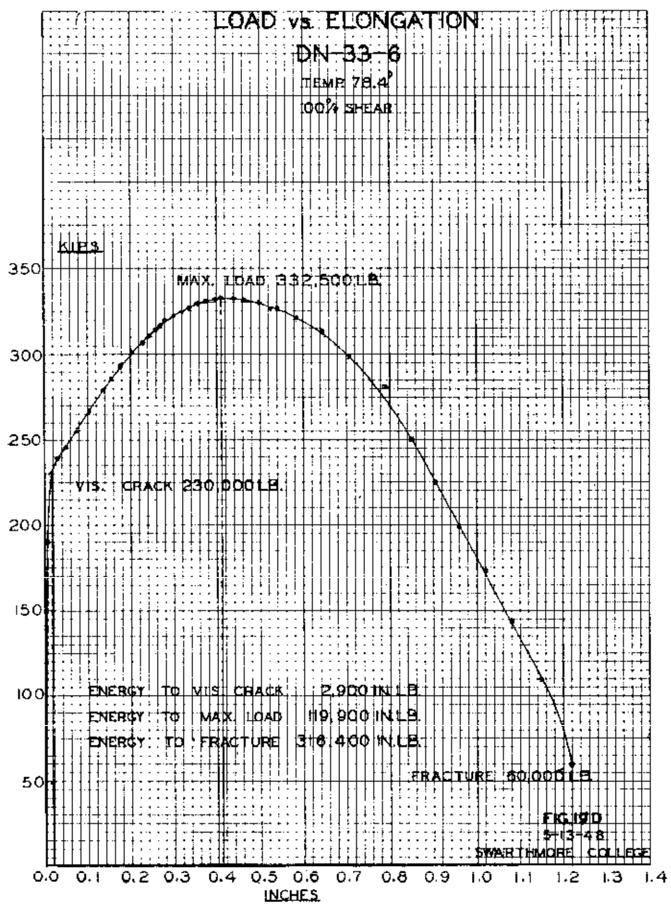

LOAD vs. ELONGATION
DN-33-20
TEMP. 24.9°
100% SHEAR
KIPS
MAX. LOAD 358,000 LB.
VIS. CRACK 244,100 LB.
ENERGY TO VIS. CRACK 2,600 IN.LB.
ENERGY TO MAX. LOAD 140,400 IN.LB.
ENERGY TO FRACTURE 346,700 IN.LB.
FRACTURE 80,000 LB.
FIG. 14D
6-4-48
SWARTHMORE COLLEGE
INCHES

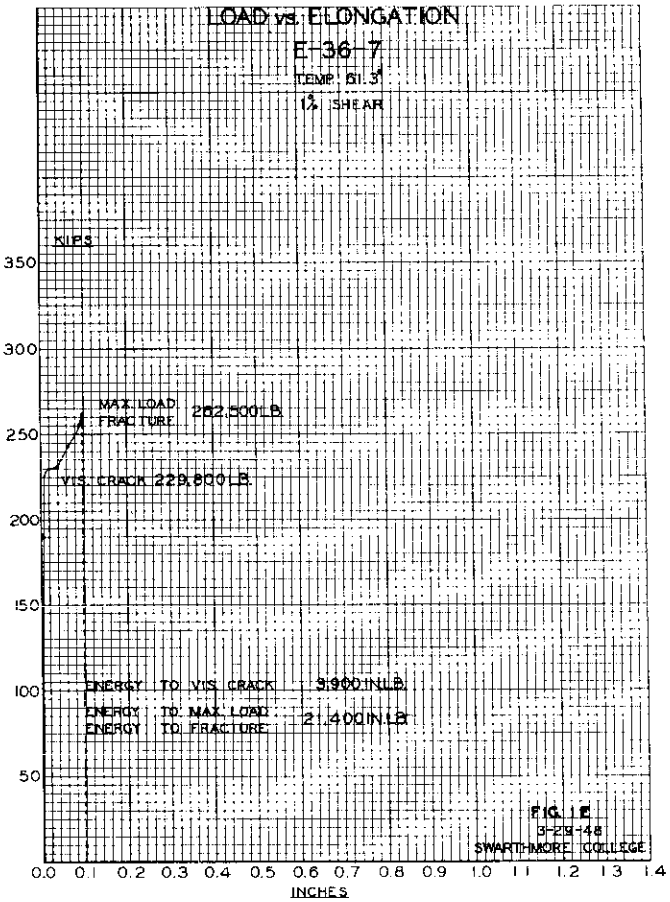

LOAD vs. ELONGATION
DN-33-13
TEMP. 29.8°
100% SHEAR
KIPS
MAX. LOAD 344,400 LBS.
VIS. CRACK 249,000 LBS.
ENERGY TO VIS. CRACK 3,900 IN.LBS.
ENERGY TO MAX. LOAD 129,700 IN.LBS.
ENERGY TO FRACTURE 324,600 IN.LBS.
FRACTURE 90,000 LBS.
FIG. 15D
7-1-48
SWARTHMORE COLLEGE
INCHES

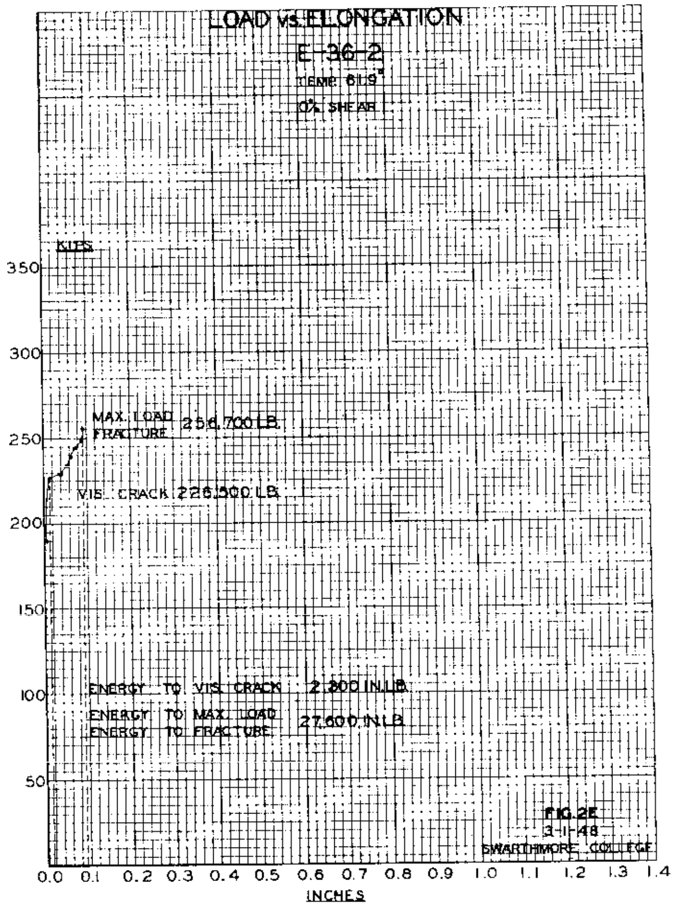

LOAD vs. ELONGATION
DN-33-12
TEMP. 29.9°
77% SHEAR
KIPS
MAX. LOAD 343,200 LB.
VIS. CRACK 247,300 LB.
ENERGY TO VIS. CRACK 6,000 IN.LB.
ENERGY TO MAX. LOAD 125,000 IN.LB.
ENERGY TO FRACTURE 300,600 IN.LB.
FRACTURE 125,000 LB.
FIG. 16D
5-26-48
SWARTHMORE COLLEGE
INCHES

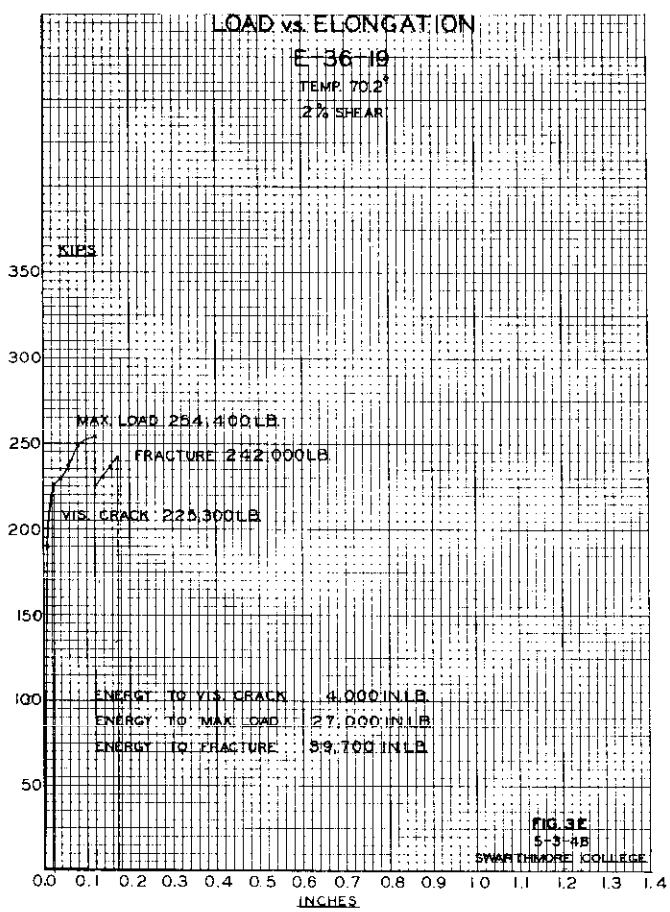

LOAD vs. ELONGATION
DN-33-7
TEMP 41.0°
100% SHEAR
KIPS
MAX LOAD 340,500 LB.
VIS. CRACK 241,500 LB.
ENERGY TO VIS. CRACK 4,400 IN.LB.
ENERGY TO MAX. LOAD 117,500 IN.LB.
ENERGY TO FRACTURE 314,900 IN.LB.
FRACTURE 40,000 LB.
FIG. 17D
5-18-48
SWARTHMORE COLLEGE
INCHES

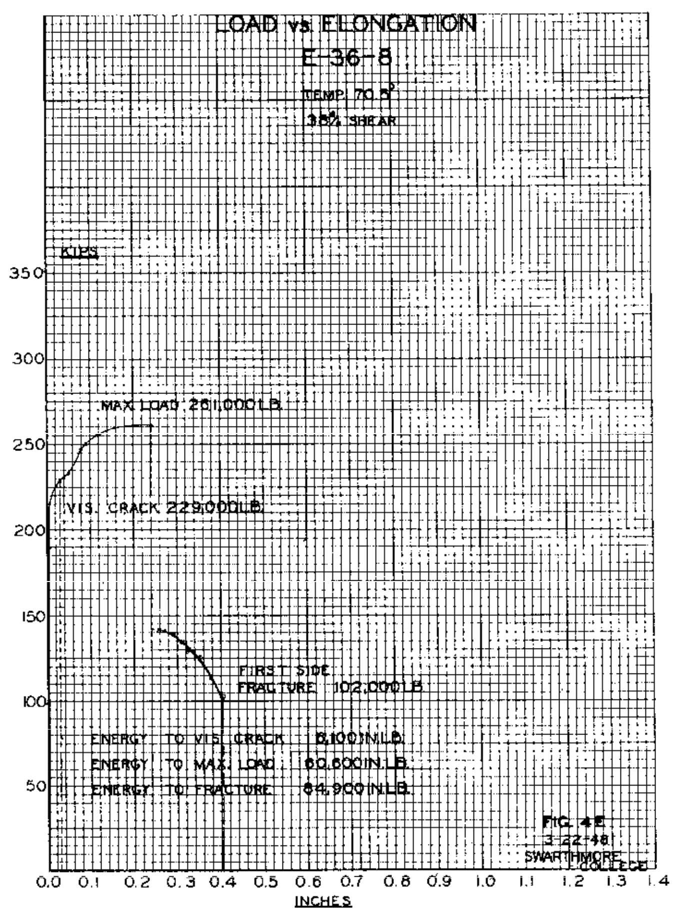

LOAD vs. ELONGATION
DN-33-14
TEMP 58.4°
100% SHEAR
KIPS
MAX. LOAD 336,900 LBS.
VIS. CRACK 243,500 LBS.
ENERGY TO VIS. CRACK 7,500 IN.LBS.
ENERGY TO MAX. LOAD 127,900 IN.LBS.
ENERGY TO FRACTURE 314,900 IN.LBS.
FRACTURE 48,000 LBS.
FIG. 18D
7-1-48
SWARTHMORE COLLEGE
INCHES

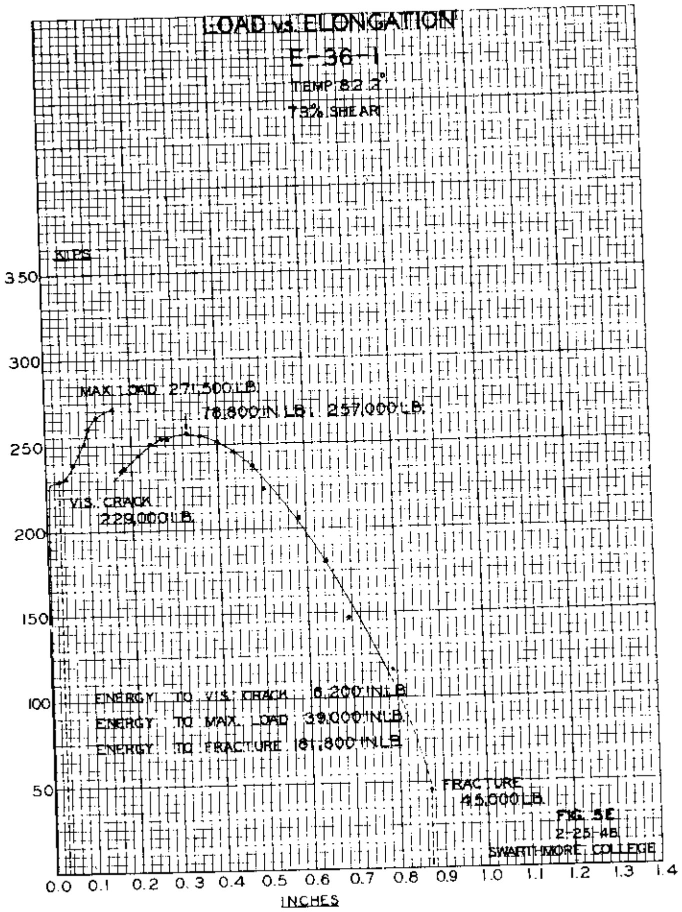

LOAD vs. ELONGATION
DN-33-6
TEMP 78.4°
100% SHEAR
KIPS
MAX. LOAD 332,500 LB.
VIS. CRACK 230,000 LB.
ENERGY TO VIS. CRACK 2,900 IN.LB.
ENERGY TO MAX. LOAD 119,900 IN.LB.
ENERGY TO FRACTURE 316,400 IN.LB.
FRACTURE 60,000 LB.
FIG. 19D
5-13-48
SWARTHMORE COLLEGE
INCHES

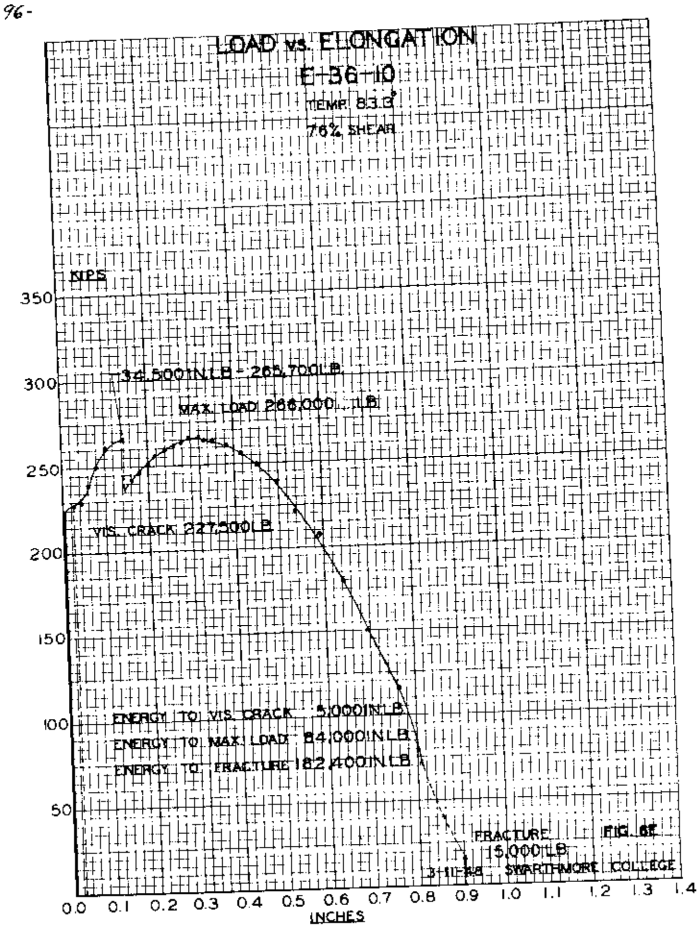

LOAD vs. ELONGATION
E-36-7
TEMP. 61.3°
1% SHEAR
KIPS
MAX. LOAD
FRACTURE 262,500 LB.
VIS. CRACK 229,800 LB.
ENERGY TO VIS. CRACK 3,900 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 21,400 IN.LB.
FIG. 1E
3-29-48
SWARTHMORE COLLEGE
INCHES

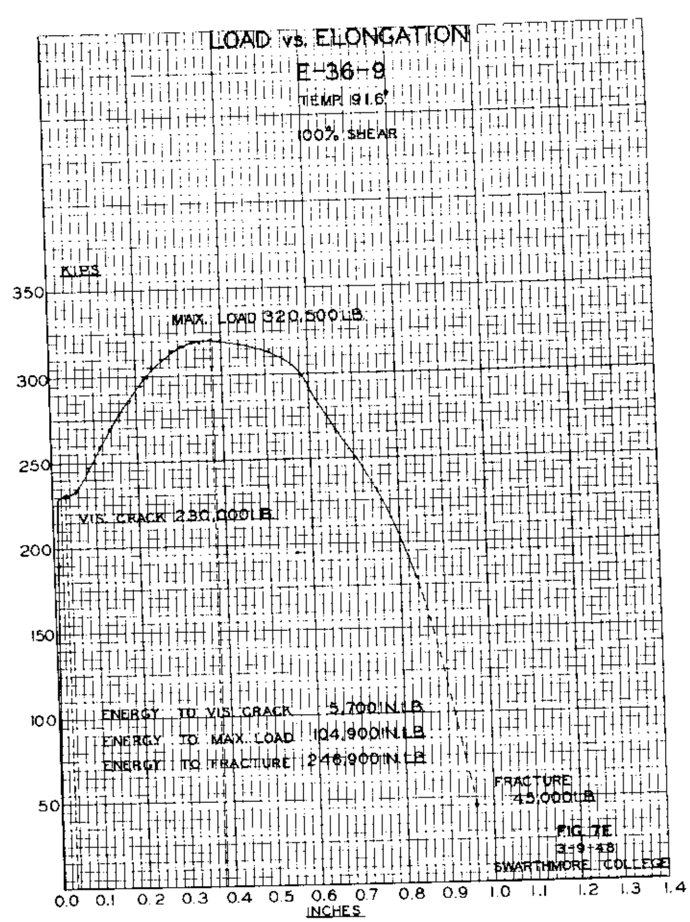

LOAD vs. ELONGATION
E-36-2
TEMP. 61.9°
0% SHEAR
KIPS
MAX. LOAD
FRACTURE 256,700 LB.
VIS. CRACK 226,500 LB.
ENERGY TO VIS. CRACK 2,800 IN.LB.
ENERGY TO MAX. LOAD
ENERGY TO FRACTURE 27,600 IN.LB.
FIG. 2E
3-1-48
SWARTHMORE COLLEGE
INCHES

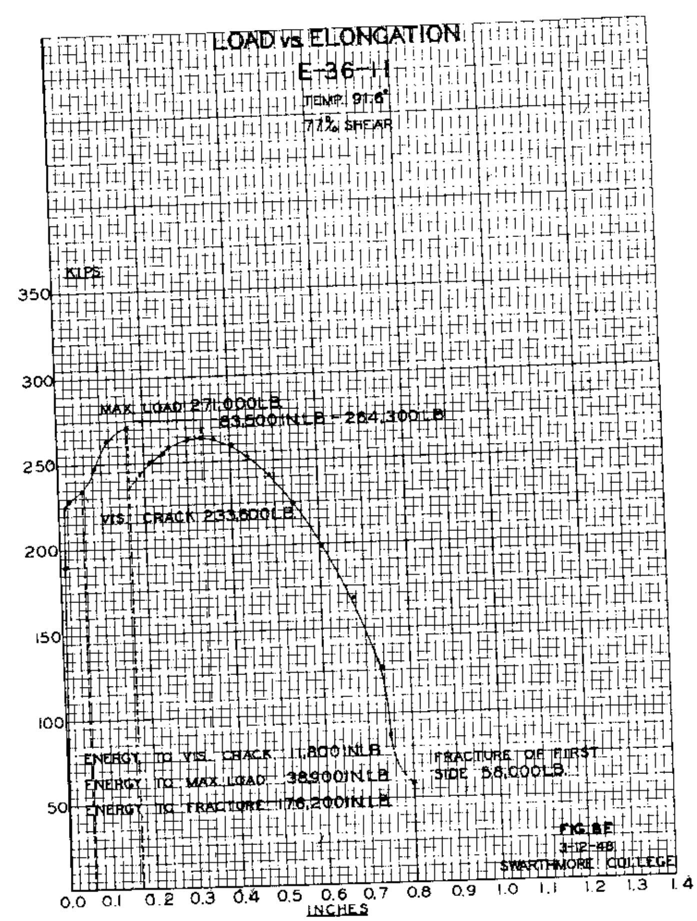

LOAD vs. ELONGATION
E-36-19
TEMP. 70.2°
2% SHEAR
KIPS
MAX. LOAD 254,400 LB.
FRACTURE 242,000 LB.
VIS. CRACK 225,300 LB.
ENERGY TO VIS. CRACK 4,000 IN.LB.
ENERGY TO MAX. LOAD 27,000 IN.LB.
ENERGY TO FRACTURE 39,700 IN.LB.
FIG. 3E
5-3-48
SWARTHMORE COLLEGE
INCHES

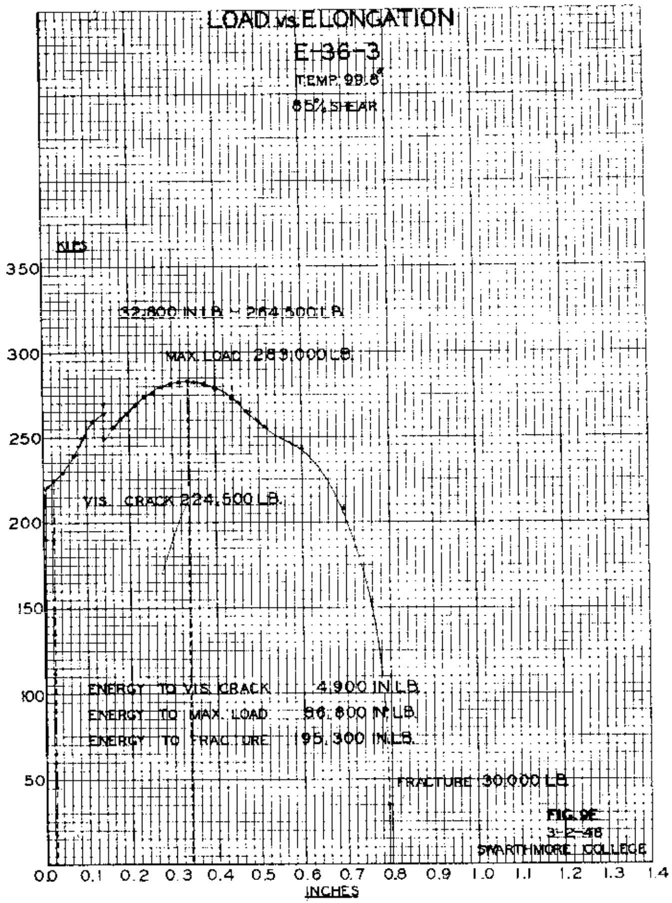

LOAD vs. ELONGATION
E-36-8
TEMP. 70.5°
38% SHEAR
KIPS
MAX. LOAD 261,000 LB.
VIS. CRACK 229,000 LB.
FIRST SIDE
FRACTURE 102,000 LB.
ENERGY TO VIS. CRACK 8,100 IN.LB.
ENERGY TO MAX. LOAD 60,600 IN.LB.
ENERGY TO FRACTURE 84,900 IN.LB.
FIG. 4E
3-22-48
SWARTHMORE COLLEGE
INCHES

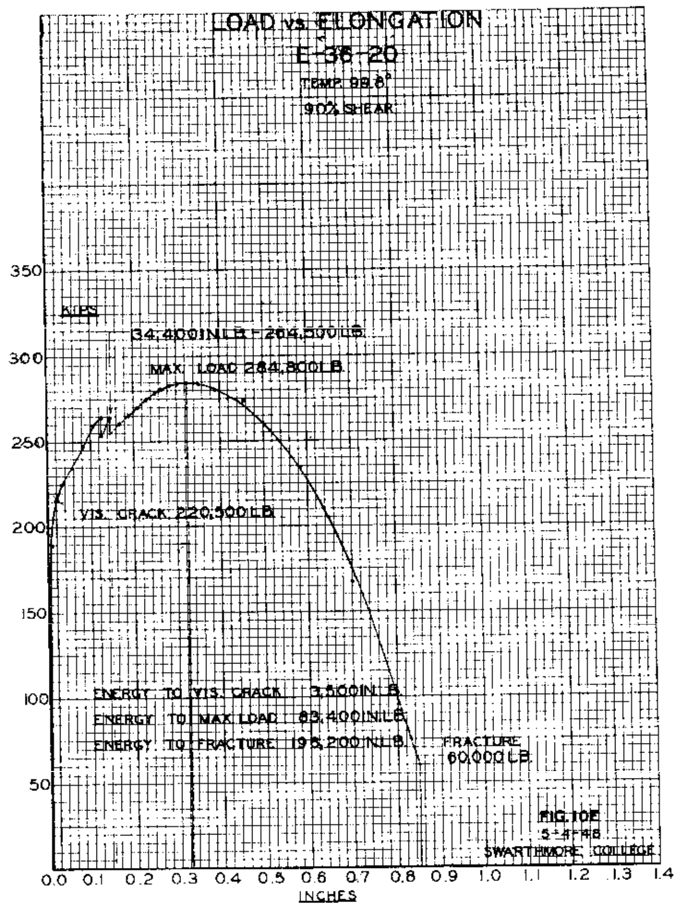

LOAD vs. ELONGATION
E-36-1
TEMP 82.2°
73% SHEAR
KIPS
MAX. LOAD 271,500 LB.
76,800 IN. LB. : 257,000 LB.
VIS. CRACK 229,000 LB.
ENERGY TO VIS. CRACK 6,200 IN. LB.
ENERGY TO MAX. LOAD 39,000 IN. LB.
ENERGY TO FRACTURE 161,800 IN. LB.
FRACTURE 45,000 LB.
FIG. 5E
2-25-48
SWARTHMORE COLLEGE
INCHES

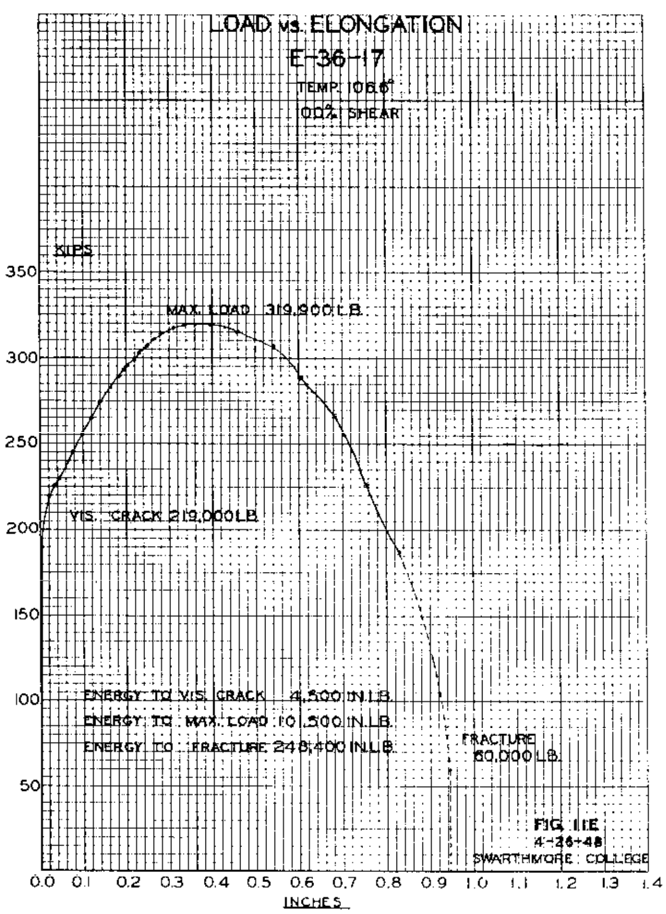

LOAD vs. ELONGATION
E-36-10
TEMP. 83.3°
76% SHEAR
KIPS
34,500 IN. LB. - 265,700 LB.
MAX. LOAD 266,000 LB.
VIS. CRACK 227,500 LB.
ENERGY TO VIS. CRACK 5,000 IN. LB.
ENERGY TO MAX. LOAD 84,000 IN. LB.
ENERGY TO FRACTURE 182,400 IN. LB.
FRACTURE 15,000 LB.
FIG. 6E
3-11-48 SWARTHMORE COLLEGE
INCHES

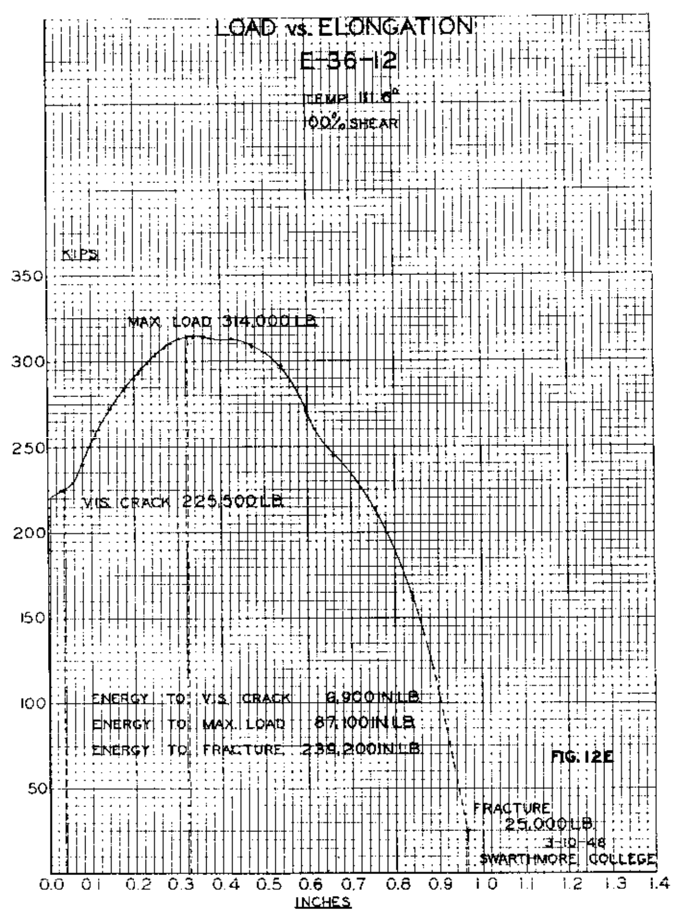

LOAD vs. ELONGATION
E-36-9
TEMP. 91.6°
100% SHEAR
KIPS
MAX. LOAD 320,500 LB.
VIS. CRACK 230,000 LB.
ENERGY TO VIS. CRACK 5,700 IN. LB.
ENERGY TO MAX. LOAD 104,900 IN. LB.
ENERGY TO FRACTURE 246,900 IN. LB.
FRACTURE 45,000 LB.
FIG. 7E
3-9-48
SWARTHMORE COLLEGE
INCHES

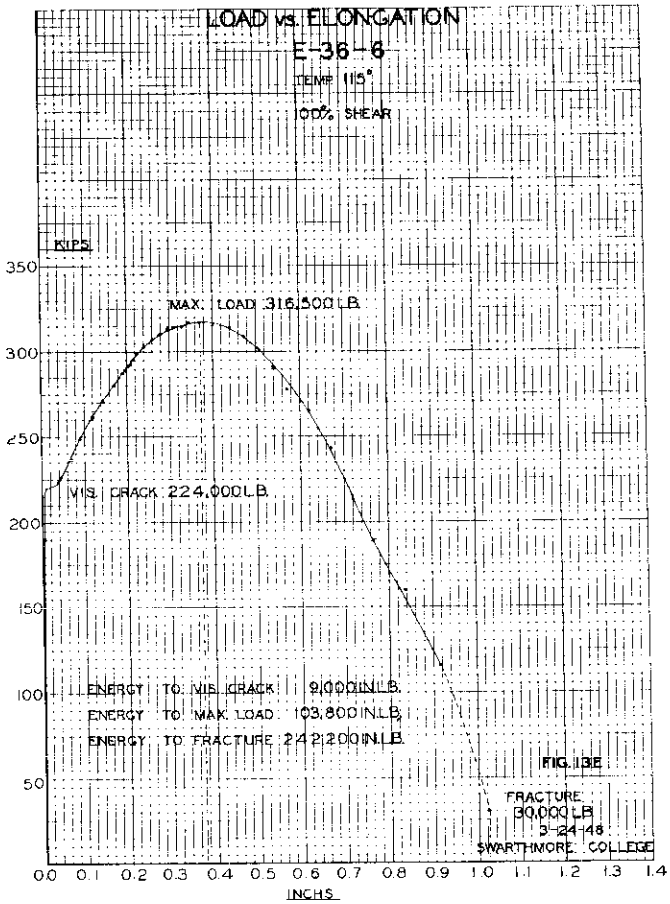

LOAD vs. ELONGATION
E-36-11
TEMP. 91.6°
77% SHEAR
KIPS
MAX. LOAD 271,000 LB.
83,500 IN. LB. - 264,300 LB.
VIS. CRACK 233,500 LB.
ENERGY TO VIS. CRACK 11,800 IN. LB.
ENERGY TO MAX. LOAD 38,900 IN. LB.
ENERGY TO FRACTURE 176,200 IN. LB.
FRACTURE OF FIRST SIDE 58,000 LB.
FIG. 8E
3-12-48
SWARTHMORE COLLEGE
INCHES

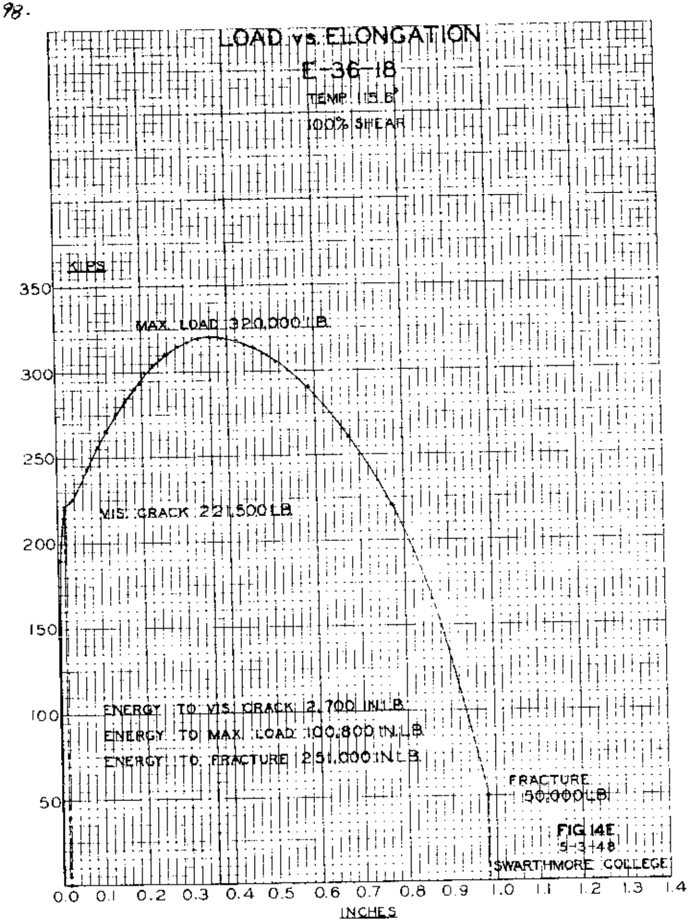

LOAD vs ELONGATION
E-36-3
TEMP. 99.8°
85% SHEAR
KIPS
32,800 IN LB - 264,500 LB
MAX LOAD 283,000 LB
VIS. CRACK 224,500 LB
ENERGY TO VIS. CRACK 4,900 IN LB
ENERGY TO MAX. LOAD 86,800 IN LB
ENERGY TO FRACTURE 195,300 IN LB
FRACTURE 30,000 LB
FIG. 9E
3-2-48
SWARTHMORE COLLEGE
INCHES

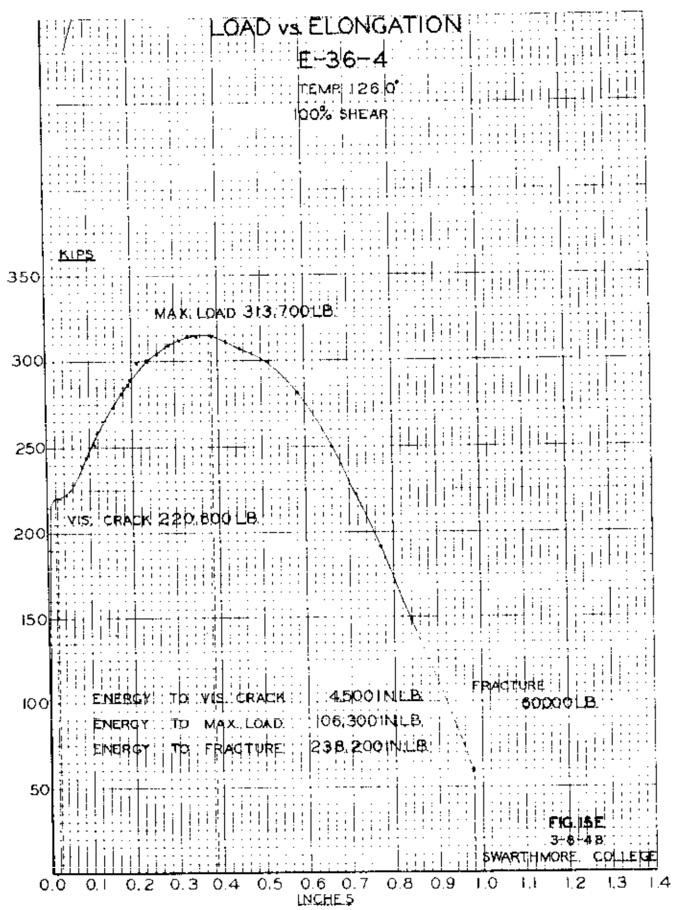

LOAD vs ELONGATION
E-36-20
TEMP. 99.8°
90% SHEAR
KIPS
34,400 IN LB - 264,500 LB
MAX LOAD 284,800 LB
VIS. CRACK 220,500 LB
ENERGY TO VIS. CRACK 3,500 IN LB
ENERGY TO MAX LOAD 83,400 IN LB
ENERGY TO FRACTURE 195,200 IN LB
FRACTURE 60,000 LB
FIG. 10E
5-4-48
SWARTHMORE COLLEGE
INCHES

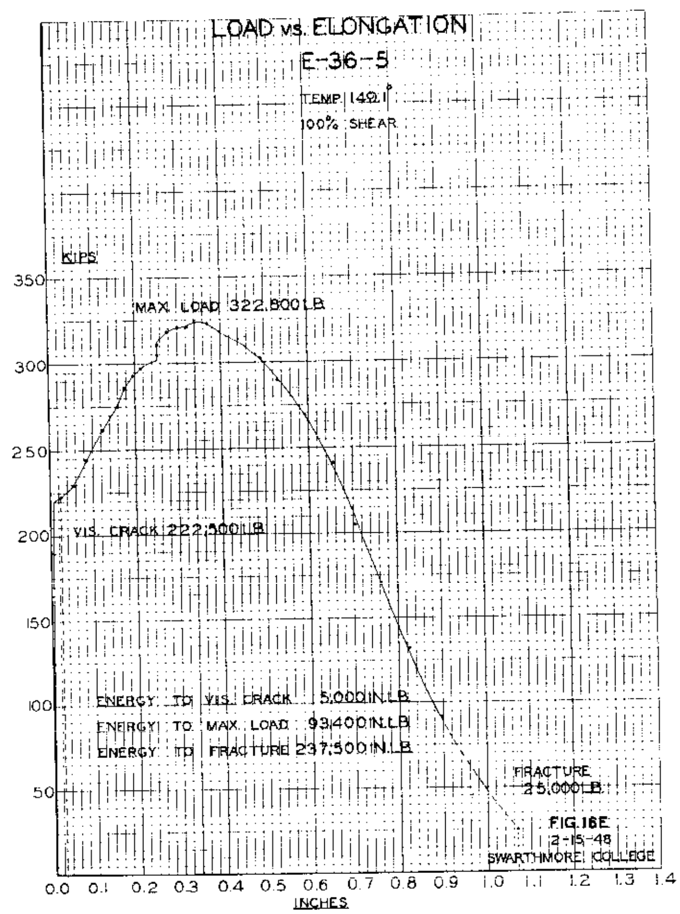

LOAD vs ELONGATION
E-36-17
TEMP. 106.6°
100% SHEAR
KIPS
MAX LOAD 319,900 LB
VIS. CRACK 219,000 LB
ENERGY TO VIS. CRACK 4,500 IN LB
ENERGY TO MAX. LOAD 101,500 IN LB
ENERGY TO FRACTURE 248,400 IN LB
FRACTURE 60,000 LB
FIG. 11E
4-26-48
SWARTHMORE COLLEGE
INCHES


LOAD vs ELONGATION
E-36-12
TEMP. 111.6°
100% SHEAR
KIPS
MAX LOAD 314,000 LB
VIS. CRACK 225,500 LB
ENERGY TO VIS. CRACK 6,900 IN LB
ENERGY TO MAX. LOAD 87,100 IN LB
ENERGY TO FRACTURE 239,200 IN LB
FIG. 12E
FRACTURE 25,000 LB
3-10-48
SWARTHMORE COLLEGE
INCHES


LOAD vs. ELONGATION
E-36-6
TEMP 115°
100% SHEAR
KIPS
MAX. LOAD 316,500 LB.
VIS. CRACK 224,000 LB.
ENERGY TO VIS. CRACK 9,000 IN.LB.
ENERGY TO MAX. LOAD 103,800 IN.LB.
ENERGY TO FRACTURE 242,200 IN.LB.
FIG. 13E
FRACTURE 30,000 LB.
3-24-48
SWARTHMORE COLLEGE
INCHS


LOAD vs. ELONGATION
E-36-18
TEMP 115.6°
100% SHEAR
KIPS
MAX. LOAD 320,000 LB.
VIS. CRACK 221,500 LB.
ENERGY TO VIS. CRACK 2,700 IN.LB.
ENERGY TO MAX. LOAD 100,800 IN.LB.
ENERGY TO FRACTURE 251,000 IN.LB.
FRACTURE 50,000 LB.
FIG. 14E
5-3-48
SWARTHMORE COLLEGE
INCHES


LOAD vs. ELONGATION
E-36-4
TEMP 126.0°
100% SHEAR
KIPS
MAX. LOAD 313,700 LB.
VIS. CRACK 220,800 LB.
ENERGY TO VIS. CRACK 4,500 IN.LB.
ENERGY TO MAX. LOAD 106,300 IN.LB.
ENERGY TO FRACTURE 238,200 IN.LB.
FRACTURE 60,000 LB.
FIG. 15E
3-8-48
SWARTHMORE COLLEGE
INCHES


LOAD vs. ELONGATION
E-36-5
TEMP 149.1°
100% SHEAR
KIPS
MAX. LOAD 322,800 LB.
VIS. CRACK 222,500 LB.
ENERGY TO VIS. CRACK 5,000 IN.LB.
ENERGY TO MAX. LOAD 93,400 IN.LB.
ENERGY TO FRACTURE 237,500 IN.LB.
FRACTURE 25,000 LB.
FIG. 16E
2-15-48
SWARTHMORE COLLEGE
INCHES