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DYNAMIC TENSILE TESTS OF PARACHUTE WEBBING

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ABSTRACT

Dynamic-load-stretch and stretch-energy data were obtained for two types of nylon and one type of cotton parachute webbing. These data were compared with similar data obtained from static tensile tests of the materials. The dynamic and static breaking strengths of the webbing were also obtained.

The nylon specimens showed a reduced strength, stretch, and capacity for energy absorption under dynamic loading as compared with static loading. The cotton specimens showed under dynamic loading about the same strength, reduced stretch, and increased energy absorption. The energy absorbed by the broken nylon specimens was more than three times that of the broken cotton specimens.

CONTENTS

I. INTRODUCTION

At the request of the Bureau of Aeronautics, Navy Department, the National Bureau of Standards undertook comparative tests on various types of parachute webbing. The load-stretch relationships and other mechanical properties of three types of webbing under dynamic tensile loading were investigated. The loads were to be applied by means of a 200-lb mass falling through a height sufficient to produce in the webbing a tensile force of 4,000 lb (an acceleration of the falling mass of 20 g).

High-speed tensile-test data for textile materials are comparatively rare; hence the results of these tests are of some general interest, even though the test specimens were specialized and the ranges of variables investigated were narrow. The method of obtaining the dynamic-load–stretch relationship is similar in principle to that used on metals by Clark and Dätwyler [1].[1]

II. SPECIMENS

The three types of 1¾-in.-wide parachute webbing tested were identified as rib-weave nylon, herringbone-weave nylon, and type *X* herringbone-weave cotton. The types of webbing are shown in figure 1. Each specimen consisted of a length of webbing held by a heavy D-ring (with cross bar) at the top and by two similar D-rings at the bottom, as shown in figure 2. The clear inside distance between D-rings was 36.0 in. in all cases. The test results given in this report apply to the complete specimen, including the D-rings.

III. DESCRIPTION OF TESTS

1. GENERAL

The test setup is shown in figure 2. The specimen was hung from a 1⅝-in.-diameter steel bar held in the fixed head of a testing machine. (The testing machine was used only as a support and for calibration purposes.) A steel weight pan was suspended from the lower D-rings by means of a connecting link. The combined mass of the weight pan and link was 13.7 lb.

The falling weight, which had a mass of 198.5 lb, consisted of a steel cylindrical annulus with a hole large enough to clear the rod, the specimen, and the connections. The weight was hung from the movable head of the testing machine by light sash cord. The movable head was positioned to give the desired height of drop, and the weight was released by cutting the cord.

2. MAXIMUM STRETCH, OVER-ALL SET, AND FREE-LENGTH SET

The maximum stretch of the specimen was obtained from the depression of the column of modeling clay directly under the weight pan. The length of the specimen under the load of the weight pan was considered the initial length (zero stretch).

The clear inside distance between D-rings was measured before (36.0 in.) and after the drop with the weight pan in place.

Before the drop, a 20-in. gage line was marked on the webbing with pins, and the gage line was measured after the drop with the weight pan in place.

3. LOAD

The connection between the upper end of the specimen and the lower end of the 1⅝-in. rod consisted of a connecting link and a ¾-in. eyebolt arranged as a dynamometer. Several inches of the shank of the eyebolt had been reduced to ⅝-in. diameter and four *SR–4* wire strain gages, type A7, were cemented to the reduced surface. Two of the gages were parallel to the axis of the shank and were connected in series, the other two, also in series, were at right angles to the axis.

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[1] Figures in brackets indicate the literature references at the end of this paper.

The two pairs of gages were connected as adjacent arms in an a-c Wheatstone bridge. The output of this (unbalanced) bridge was proportional to the tensile load on the eyebolt.

The voltage on the bridge was 10 volts, 1,000 cycles per second, produced by an electronic oscillator. The output of the bridge was amplified and the demodulated signal made available for recording on an oscillograph recorder that produced a photographic record of load versus time.

A load of 4,000 lb on the dynamometer produced a deflection on the record of about 0.65 in. Calibrations of the dynamometer by means of the testing machine were made several times daily while the tests were in progress. The time scale on the record was marked by lines about ⅛ in. apart, corresponding to time intervals of 0.01 sec. The duration of test from beginning of impact to maximum load was about 0.05 to 0.06 sec for the nylon and 0.03 to 0.04 sec for the cotton specimens.

The natural frequency of the dynamometer was, of course, very high compared to that of the specimen, and the natural frequency of the galvanometer coil was 430 cycles per second. Typical oscillograms are shown in figure 3.

4. LOAD-STRETCH RELATION

The forces acting on the combined mass, $M+m$, of the falling weight and weight pan are the weight, $(M+m)g$, acting downward (positive); the tension, $F=F(t)$, given on the oscillogram, and the initial load due to the weight pan, mg, acting upward. Hence the differential equation for the stretch, $s=s(t)$, is, by Newton's law,

$$(M+m)g-F-mg=(M+m)\frac{d^2s}{dt^2},$$

or

$$\frac{d^2s}{dt^2}=\frac{Mg}{M+m}-\frac{F}{M+m}. \qquad (1)$$

Here F is in absolute units (poundals). Since F is given as $F(t)$ on the oscillogram, eq 1 may be integrated numerically for $s(t)$. Elimination of t between $F=F(t)$ and $s=s(t)$ gives the load-stretch relationship.

If t is taken as zero at the beginning of impact, then the initial condition for s is $s=0$ when $t=0$. The velocity of the weight just before impact is $\sqrt{2gh}$, where h is the height of drop. Upon impact (assumed plastic), the common velocity of the weight and pan is reduced to

$$v_0=\frac{M}{M+m}\sqrt{2gh} \qquad (2)$$

in accordance with the principle of conservation of momentum. This is the initial condition on the velocity required for the integration.

The maximum stretch computed by this method may be compared with that given by the clay-column measurement.

5. ENERGY

The work done on the specimen, corresponding to various stretches, was obtained by evaluating numerically the integral $\int_0^s F ds$. The maximum work, $\int_0^{s_m} F ds$, where s_m is the maximum stretch, was compared with the "input energy," E. In cases where no failure occurred, the input energy was equal to the sum of the kinetic energy at the instant of impact and the potential energy lost during stretching.

$$E = \frac{(M+m)v_0^2}{2} + (M+m)gs_m$$

$$= \frac{M}{M+m} Mgh + (M+m)gs_m. \tag{3}$$

6. STATIC TESTS

For comparison, one specimen of each type of webbing, in all respects identical with the dynamic-test specimens, was tested at slow speed (4 in./min) in a horizontal testing machine. Load-stretch data to failure were obtained, and the stretch-energy relations were computed as for the dynamic tests.

IV. RESULTS AND DISCUSSION

1. LOAD-STRETCH RELATIONS

The results for the individual dynamic tests are given in tables 1, 2, and 3. Because the load corresponding to a given stretch shows no consistent variation with height of drop, the results were averaged for each type of webbing and compared with the results of the static tests. The load and stretch are reckoned as zero when the tension in the specimen is equal to the weight of the weight pan, about 14 lb.

TABLE 1.—*Load-stretch data for rib-weave nylon*

Stretch	Specimen number						Average dynamic	Static
	1	2	3	4	5	6		
	Load							
in.	*lb*	*lb*	*lb*	*lb*	*lb*	*lb*	*lb*	*lb*
0	0	0	0	0	0	0	0	0
1	220	160	240	130	220	200	190	80
2	440	350	460	280	430	410	390	220
3	660	590	680	470	700	610	620	420
4	880	810	910	660	1,020	810	850	590
5	1,100	1,080	1,150	850	1,340	1,010	1,090	800
6	1,360	1,390	1,400	1,070	1,700	1,240	1,360	1,080
7	1,670	1,770	1,680	1,370	2,030	1,530	1,670	1,390
8	2,000	2,130	2,000	1,740	2,380	1,890	2,020	1,750
9	2,380	2,520	2,370	2,170	2,780	2,310	2,420	2,190
10	2,850	2,880	2,770	2,630	3,210	2,750	2,850	2,690
11	3,340	3,250	3,220	3,020	3,740	3,190	3,290	3,310
12	3,680	3,640	3,610	3,390	4,260	3,620	3,700	4,000
13	-----	-----	3,940	3,940	-----	3,960	-------	4,800
14	-----	-----	-----	-----	-----	-----	-------	5,750

TABLE 2.—*Load-stretch data for herringbone-weave nylon*

Stretch	Specimen number										Average dynamic	Static
	7	8	9	10	11	12	13	14	15	16		
	Load											
in.	*lb*	*lb*	*lb*	*lb*	*lb*	*lb*	*lb*	*lb*	*lb*	*lb*	*lb*	*lb*
0	0	0	0	0	0	0	0	0	0	0	0	0
1	250	240	200	460	290	210	260	440	250	320	290	80
2	500	500	400	840	540	510	540	660	520	600	560	270
3	750	770	590	1, 110	750	780	810	880	790	840	810	480
4	1, 010	1, 050	800	1, 260	1, 020	1, 060	1, 110	1, 130	1, 130	1, 100	1, 070	740
5	1, 290	1, 370	1, 100	1, 570	1, 350	1, 380	1, 420	1, 390	1, 480	1, 390	1, 370	1, 040
6	1, 610	1, 720	1, 440	1, 910	1, 710	1, 730	1, 770	1, 700	1, 900	1, 730	1, 720	1, 370
7	2, 000	2, 120	1, 800	2, 300	2, 130	2, 080	2, 170	2, 100	2, 360	2, 150	2, 120	1, 760
8	2, 370	2, 590	2, 240	2, 640	2, 560	2, 500	2, 630	2, 580	2, 830	2, 680	2, 560	2, 230
9	2, 790	3, 100	2, 710	3, 150	3, 050	3, 100	3, 110	3, 100	3, 300	3, 220	3, 060	2, 770
10	3, 340	3, 620	3, 230	3, 980	3, 520	3, 720	3, 610	3, 650	3, 750	3, 710	3, 610	3, 440
11	3, 580	---	3, 770	---	3, 800	4, 120	3, 980	3, 890	---	---	---	4, 210
12	---	---	4, 250	---	---	---	---	---	---	---	---	5, 080

TABLE 3.—*Load-stretch data for herringbone-weave cotton*

Stretch	Specimen number						Average dynamic	Static
	17	18	19	20	21	22		
	Load							
in.	*lb*	*lb*	*lb*	*lb*	*lb*	*lb*	*lb*	*lb*
0. 0	0	0	0	0	0	0	0	0
. 5	60	170	40	160	80	160	110	30
1. 0	200	360	180	500	220	440	320	60
1. 5	400	590	460	1, 060	460	860	640	170
2. 0	660	870	1, 040	1, 810	940	1, 580	1, 150	370
2. 5	1, 010	1, 370	1, 600	2, 800	1, 710	2, 460	1, 820	770
3. 0	1, 670	2, 280	2, 360	3, 830	2, 700	3, 420	2, 710	1, 350
3. 5	2, 890	3, 260	3, 250	-----	3, 570	4, 030	3, 400	2, 190
4. 0	-----	-----	-----	-----	-----	-----	-----	3, 290

It will be seen from these tables that the dynamic-load values are greater than the static-load values for equal stretches, except for the rib-weave nylon webbing for stretches of 11 and 12 inches. The difference between the dynamic- and static-load stretch values is greater for the cotton webbing than for the nylon webbings.

2. STRETCH-WORK RELATIONS

The stretch-work results are given in tables 4, 5, and 6, which are arranged in the same way as tables 1, 2, and 3. For equal stretches, the average dynamic work values are greater than the static work values.

TABLE 4.—*Stretch-work data for rib-weave nylon*

Stretch	Specimen number						Average dynamic	Static
	1	2	3	4	5	6		
	Work							
in.	*ft-lb*	*ft-lb*	*ft-lb*	*ft-lb*	*ft-lb*	*ft-lb*	*ft-lb*	*ft-lb*
0	0	0	0	0	0	0	0	0
1	9	5	11	5	5	8	7	4
2	37	35	40	22	35	34	30	20
3	82	66	88	53	82	76	70	50
4	147	122	155	100	154	134	130	90
5	229	203	241	163	250	210	220	150
6	332	312	346	243	377	304	320	230
7	458	443	474	345	530	418	440	340
8	607	600	627	474	720	560	600	470
9	789	800	809	636	930	734	780	630
10	1, 010	1, 020	1, 020	836	1, 180	945	1, 000	840
11	1, 270	1, 280	1, 270	1, 070	1, 470	1, 200	1, 260	1, 080
12	1, 560	1, 560	1, 560	1, 340	1, 800	1, 480	1, 550	1, 400
13	-----	-----	1, 870	1, 640	-----	1, 790	-------	1, 760
14	-----	-----	-----	-----	-----	-----	-------	2, 190

TABLE 5.—*Stretch-work data for herringbone-weave nylon*

Stretch	Specimen number										Average dynamic	Static
	7	8	9	10	11	12	13	14	15	16		
	Work											
in.	*ft-lb*	*ft-lb*	*ft-lb*	*ft-lb*	*ft-lb*	*ft-lb*	*ft-lb*	*ft-lb*	*ft-lb*	*ft-lb*	*ft-lb*	*ft-lb*
0	0	0	0	0	0	0	0	0	0	0	0	0
1	11	10	9	20	13	10	11	22	13	14	10	4
2	42	40	35	75	48	36	44	67	48	53	50	20
3	93	94	77	156	102	88	100	132	99	113	110	50
4	166	169	135	253	175	167	180	215	175	194	180	100
5	261	270	215	370	273	268	285	319	283	298	280	180
6	382	399	320	516	401	400	417	448	428	428	410	280
7	532	559	455	691	562	560	580	606	607	590	570	410
8	714	756	624	897	756	750	780	801	812	790	770	580
9	929	989	831	1, 130	989	980	1, 020	1, 040	1, 070	1, 040	1, 000	780
10	1, 180	1, 270	1, 080	1, 430	1, 260	1, 270	1, 300	1, 320	1, 360	1, 330	1, 280	1, 040
11	1, 480	-----	1, 370	-----	-----	-----	1, 620	1, 630	-----	------	-----	1, 360
12	-----	-----	1, 710	-----	-----	-----	-----	-----	-----	------	-----	1, 750

TABLE 6.—*Stretch-work data for herringbone-weave cotton*

Stretch	Specimen number						Average dynamic	Static
	17	18	19	20	21	22		
	Work							
in.	*ft-lb*	*ft-lb*	*ft-lb*	*ft-lb*	*ft-lb*	*ft-lb*	*ft-lb*	*ft-lb*
0.0	0	0	0	0	0	0	0	0
.5	2	7	1	3	3	3	3	1
1.0	12	21	5	19	8	16	13	3
1.5	29	35	20	54	24	42	34	7
2.0	52	65	52	110	56	91	71	18
2.5	88	113	102	208	110	174	116	42
3.0	140	185	185	345	202	295	225	86
3.5	228	300	300	-----	336	455	324	160
4.0	-----	-----	-----	-----	-----	-----	-------	274

3. MAXIMUM VALUES

Table 7 gives the maximum load; the maximum stretch both measured (clay column) and computed (eq 1); the sets; the input energy (eq 3); and the maximum work (integration of load-stretch curve) for the dynamic-test specimens.

The maximum stretch computed by integration of eq 1 is consistently higher than the stretch measured by means of the clay column. This discrepancy is probably due to accumulation of systematic errors in the load-measuring equipment and gives an indication of the accuracy of the loads and stretches determined by the method described. However, the agreement between the input energy and the maximum work obtained by integration of the load-stretch relationship is excellent.

The set in the entire free length of the webbing is less than half the over-all set. This shows that slippage, as well as stretch, took place during the loading and emphasizes the fact that the specimen under test must be considered as the entire assembly, including the connections.

TABLE 7.—*Maximum values for specimens tested under dynamic loading*

Specimen number	Height of drop	Maximum load	Maximum stretch		Set		Input energy	Maximum work
			Measured	Computed	Over-all	20-in. free length		
	ft.	*lb.*	*in.*	*in.*	*in.*	*in.*	*ft-lb*	*ft-lb*
RIB-WEAVE NYLON								
1	9.0	3,830	12.3	13.1	4.7	1.2	1,890	1,900
2	9.0	3,880	12.2	13.0	4.8	1.3	1,880	1,870
3	9.5	3,950	12.2	13.4	4.7	1.1	1,980	1,980
4	9.5	4,130	13.4	14.0	5.0	1.2	2,000	1,970
5	9.5	4,300	12.6	12.4	4.6	1.1	1,980	1,940
6[a]	10.0	4,050	----	13.5	----	----	----	1,960
HERRINGBONE-WEAVE NYLON								
7	8.0	3,650	10.4	11.8	3.9	1.1	1,670	1,720
8	8.5	4,000	10.5	11.5	4.1	1.1	1,760	1,730
9	8.5	4,250	10.6	12.2	4.2	1.2	1,760	1,760
10	8.5	4,400	11.0	10.9	4.4	1.1	1,770	1,760
11	8.5	3,800	10.6	11.5	3.9	1.2	1,760	1,740
12	8.5	4,180	11.1	11.5	3.9	1.0	1,770	1,750
13	9.0	4,110	11.3	11.8	4.0	1.1	1,870	1,890
14	9.0	3,910	10.6	12.0	4.4	1.2	1,850	1,930
15[a]	9.0	4,060	----	10.8	----	----	----	1,630
16[a]	9.5	3,940	----	10.6	----	----	----	1,560
HERRINGBONE-WEAVE COTTON								
17	1.5	3,110	3.4	3.9	2.5	0.6	340	350
18	1.75	3,270	3.2	3.8	2.2	.5	380	380
19	2.0	3,520	3.2	3.9	2.2	.5	440	440
20	2.0	3,880	3.1	3.3	2.1	.5	430	420
21[a]	2.25	4,000	----	3.9	----	----	----	480
22[a]	2.5	4,060	----	3.5	----	----	----	460

[a] Webbing broke at upper D-ring.

The results show a considerable variability in the properties of the specimens. It should be remembered, however, that the specimens consisted of a length of webbing with D-rings at both ends, initially under a load of only 14 lb. Differences in the amount of slippage during test and variability in the properties of the webbing from specimen to specimen would tend to induce different results for similar specimens.

Table 8 gives the maximum load, stretch, and work for the dynamic-test specimens that failed and for the static-test specimens. The maximum stretch for the dynamic-test specimens was computed from eq 1.

TABLE 8.—*Maximum values for specimens that broke*

Specimen number	Height of drop	Maximum load	Maximum stretch	Maximum work
RIB-WEAVE NYLON				
	ft.	*lb*	*in.*	*ft-lb*
6	10.0	4,050	13.5	1,960
Static		5,770	14.1	2,250
HERRINGBONE-WEAVE NYLON				
15	9.0	4,060	10.8	1,630
16	9.5	3,940	10.6	1,560
Static		5,450	12.5	1,971
HERRINGBONE-WEAVE COTTON				
21	2.25	4,000	3.9	480
22	2.50	4,060	3.5	460
Static		4,090	4.4	388

All the failures occurred in the webbing at the connection to the single D-ring. The cross bar of the D-ring was deformed during the static tests but was undamaged by the dynamic tests.

The nylon specimens had a reduced strength, stretch, and capacity for energy absorption under dynamic loading as compared with static loading.

The cotton specimens had under dynamic loading about the same strength, reduced stretch, and increased energy absorption. This apparent anomaly is due to the fact that the difference between the dynamic- and static-load–stretch values were greater for the cotton webbing than for the nylon webbings.

From table 8 it is noted that the values of maximum load and maximum work for the nylon webbing specimens subjected to dynamic loading, and which were broken, were less than for the specimens subjected to static loading. This is contrary to the generally accepted idea that the strength of textile specimens increases as the rate of load application increases [2, 3]. The parts of the nylon specimens, after failure, were found to be fused and very warm at the fracture at the D-rings. It is probable that owing to the high rate of load application during the dynamic tests at the greatest height-of-drop values, heat was generated at such a rate that the temperature increased enough to cause a decrease in the strength of the nylon webbing. The values of maximum load and of maximum work given in table 7 for the nylon specimens which were broken are not as great as for other similar specimens also subjected to dynamic loading but not broken.

It is again probable that the temperature of the specimens not broken was less than for the broken specimens and consequently the strength and ability to absorb energy was greater for those not broken than for the specimens which were broken.

The breaking loads for the dynamic-test specimens were all very close to the 4,000-lb value that had originally been designated as the load to be attained. The strength of the herringbone-weave nylon specimen No. 16 was less than this value. It seems from these results that the strength of the nylon specimens, as determined by static tensile tests, cannot be safely used to predict the dynamic-load strengths. The energy absorbed by the broken nylon specimens was more than three times that of the broken cotton specimens.

V. REFERENCES

[1] D. S. Clark and G. Dätwyler, Stress-strain relations under tension impact loading, Proc. ASTM **38** II, 98 (1938).
[2] C. G. Lutts and D. Himmelfarb, The creep phenomenon in ropes and cords, Proc. ASTM **40,** 1251 (1940).
[3] Sanford B. Newman and Helen G. Wheeler, Impact strength of nylon and of sisal ropes, J. Research NBS **35,** 417 (1945) RP1679.

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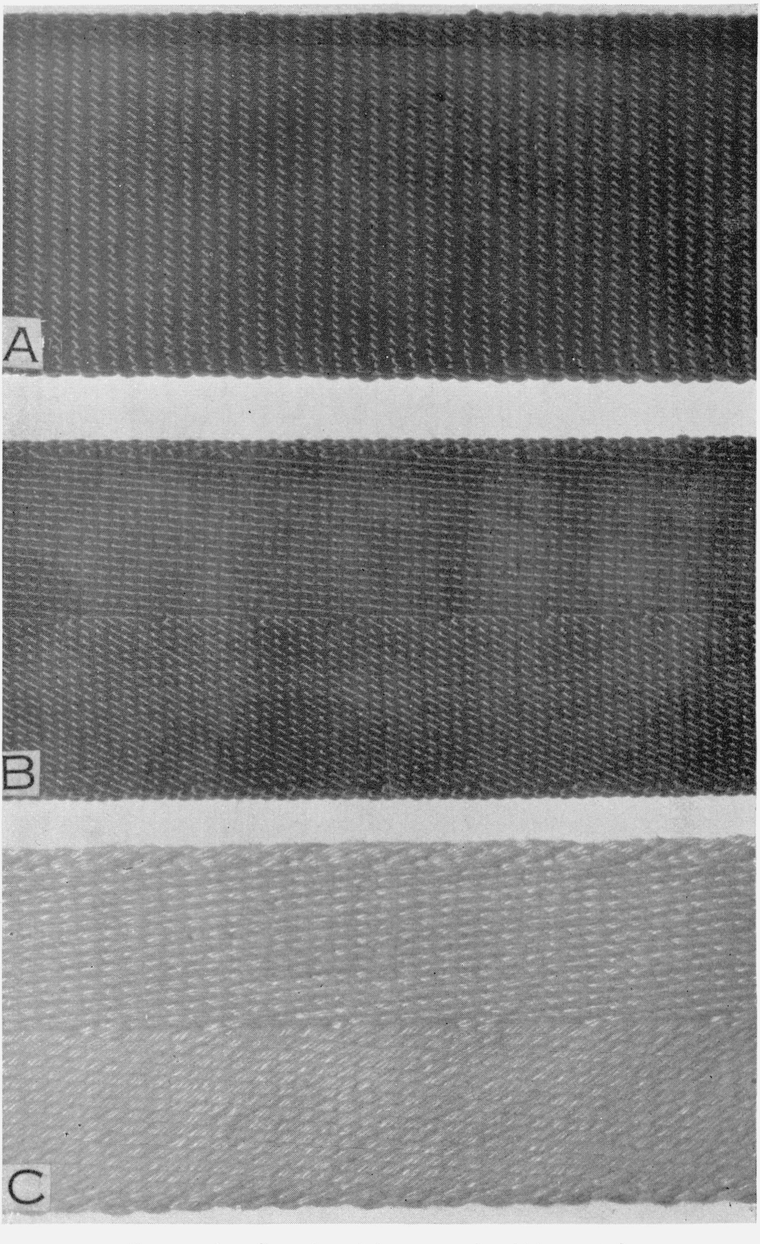

FIGURE 1.—*Samples of the types of webbing tested.*

A, rib-weave nylon; *B*, herringbone-weave nylon; *C*, type *X* herringbone-weave cotton.

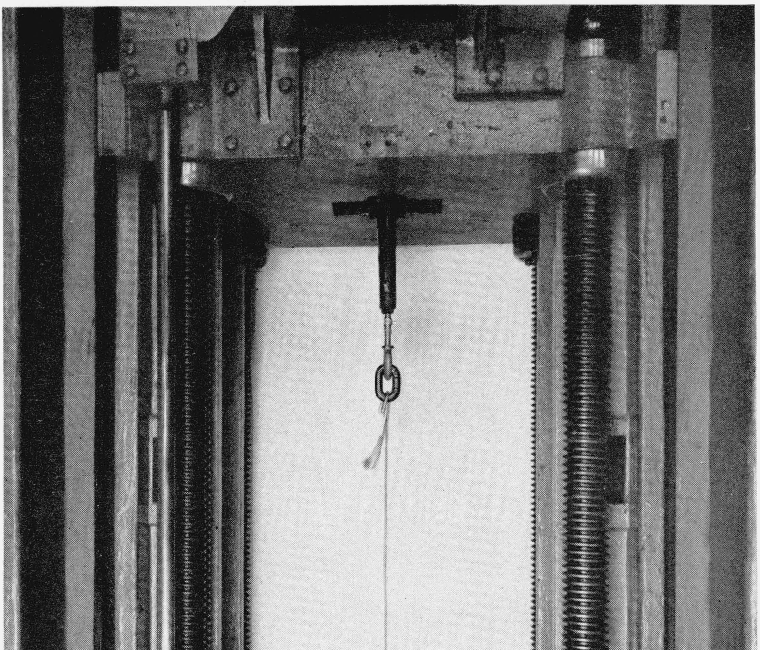

FIGURE 2.—*General view of test setup.*

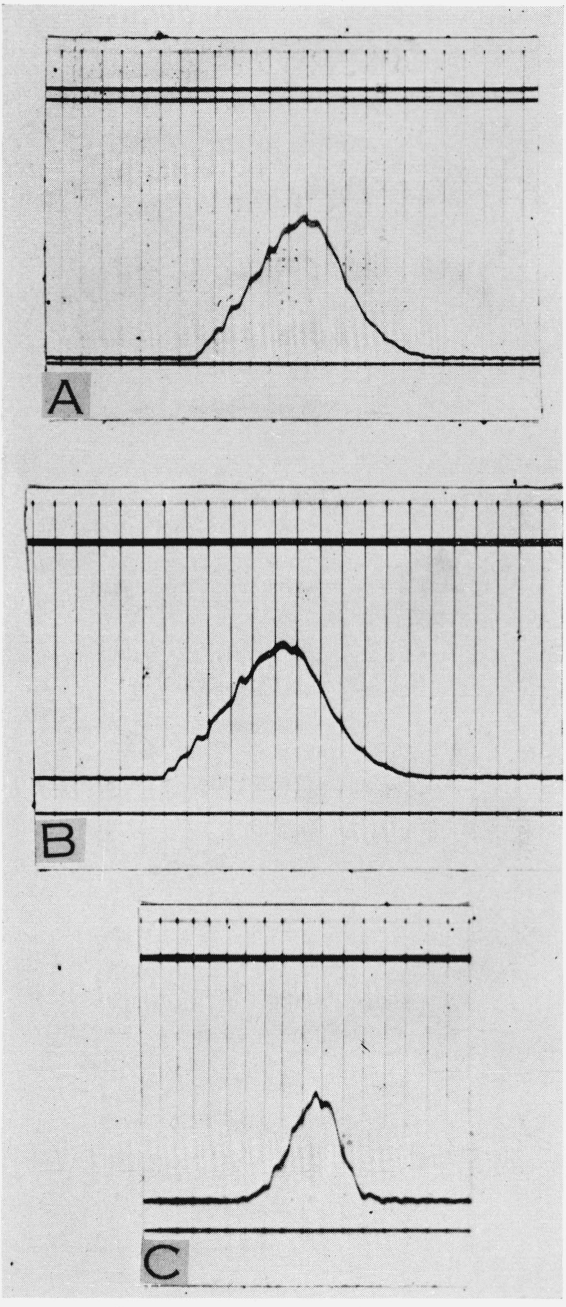

FIGURE 3.—*Typical oscillograms for rib-weave nylon, A, herringbone-weave nylon, B, and type X herringbone-weave cotton, C.*