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IMPACT STRENGTH OF NYLON AND OF SISAL ROPES

By Sanford B. Newman and Helen G. Wheeler

ABSTRACT

Static and impact tests were made on spliced specimens of 7/16-inch-diameter three-strand nylon rope and 9/16-inch-diameter, four-strand, sisal rope.

The stretch of the ropes under impact and static loading up to failure was measured, and from these data energy-stretch behavior was determined.

It was found that the energy required to cause failure under impact loading was greater than the energy required to cause failure under static loading. The stretch of the rope at failure was practically the same under impact and static loading.

The results of these tests indicate that energy values computed from static tests of these ropes give a safe estimate of the performance of the rope under impact loading.

CONTENTS

I. INTRODUCTION

Although it is customary to test the strength of rope in machines that apply the load at a slow rate, ropes are expected to withstand impact loads in important uses. Safety ropes used by structural workers, shipbuilders, and lumbermen, for example, are expected to absorb the shock if the workman falls. His life may depend upon the impact energy absorbed by the rope. Similarly, mountain climbers are dependent upon the impact strength of their ropes. The work reported in this paper was undertaken to supply accurate information as to the strength and limitations of ropes under consideration by the Office of the Quartermaster General for the use of mountain troops. The results are equally applicable to related uses of ropes.

Adequate data had previously been furnished by the Bureau as to the energy that can be absorbed by a rope, as computed from the load-stretch curves obtained from a specimen loaded at a comparatively slow rate of speed in a testing machine. It was realized that the energy-absorbing capacity of the rope might be substantially different under impact loading.

The most severe impact to which a climbing rope can be subjected would be applied by a man falling from a position directly above the point of attachment of the rope, with the rope fully extended, and dropping through a distance equal to twice the length of the rope. It was therefore suggested that nylon rope and sisal rope, representing fibers and sizes commonly in use, be tested to determine energy and stretch behavior under impact and static loading. The lengths of samples suggested for test were 5 ft and 10 ft; the impact load to be dropped through a distance equal to twice the length of the ropes. For the purposes of this investigation, failure was defined as the breaking of one or more strands at the maximum load sustained in a static test, or the breaking of one or more strands under the impact load applied in an impact test.

II. SPECIMENS

1. STATIC TESTS

Four 120-ft coils of 7/16-in.-diameter three-strand nylon climbing rope of type 300 bright nylon yarn and one 53-lb coil of 9/16-in.-diameter four-strand, sisal rope, supplied by the Office of the Quartermaster General, were used for these tests. The specimens were conditioned in an atmosphere of 65 ±2-percent relative humidity and 70° ±2° F for at least 72 hours preceding the tests.

Three spliced specimens of sisal rope and three spliced specimens of nylon rope were prepared for determination of breaking strength, load-stretch relationship, and stretch at failure under static loading. Each was a conventional breaking-strength specimen having an eye splice at each end and a free length of approximately 2 ft. The splices consisted of three full tucks and two tucks made with half the yarns in each strand. The over-all lengths and the free lengths of the sisal and the nylon specimens were measured under no load while they were in the testing machine ready for test. The lengths are given in table 1.

TABLE 1.—*Over-all length and free length of static specimens*

Specimen	Over-all length	Free length [a]
	in.	*in.*
Sisal 1-1a	48.7	21.9
Sisal 1-1b	48.6	22.9
Sisal 1-1c	48.4	22.6
Nylon 1-2a	48.3	24.4
Nylon 1-2b	48.5	24.1
Nylon 1-2c	48.4	23.9

[a] Defined as the distance between a point ½ in. in from the last tuck of 1 splice to a point ½ in. in from the last tuck of the other splice.

2. IMPACT TESTS

Fourteen spliced specimens of nylon rope and 15 spliced specimens of sisal rope from the same coils as were used for the static tests with 5-ft nominal over-all length were used for impact test. In addition, 12 spliced specimens of each kind of rope with 10-ft nominal over-all length were tested. These specimens also consisted of a free length with an eye splice at each end. The splices of the impact-test and static-test specimens were carefully made so as to be very nearly alike.

The specimen lengths were measured by determining the distance L shown in figure 1. The specimen was suspended from an eyebolt by means of snap links passed through one eye, and the weight pan was fastened to the other eye by means of other snap links. The weight pan and its connecting snap links weighed 14 lb. An appreciable amount of creep was exhibited by the nylon specimens, and their lengths were taken 5 minutes after the weight pan was attached. No creep was observed in the sisal specimens. The lengths of the four groups of specimens are given in table 2.

TABLE 2.—*Lengths of impact specimens*

[All specimens measured under a load of 14 lb.]

Specimens	Maximum	Minimum	Average
5-ft sisal:	*in.*	*in.*	*in.*
Over-all length	60.1	58.4	59.2
Free length	32.5	29.4	30.2
10-ft sisal:			
Over-all length	121.2	118.5	119.7
Free length	92.0	89.5	91.0
5-ft nylon:			
Over-all length	62.4	60.2	61.3
Free length	36.6	34.0	35.3
10-ft nylon:			
Over-all length	126.7	121.6	123.6
Free length	99.5	95.5	96.9

III. TESTING PROCEDURE

1. STATIC TESTS

The static-test specimens were loaded in a horizontal hydraulic testing machine of 100,000-lb capacity, the 20,000-lb scale range being used. The specimens were fastened to the heads of the testing machine by means of a 3-in.-diameter pin passed through the eye at each end. The speed of the moving head of the testing machine was 1 in./min during the tests. Each specimen was loaded until failure occurred.

To determine the load-stretch relationship, stretch readings under loads from zero to the maximum load were taken for the free length [1] and for each eye and splice of each specimen by means of a graduated scale held parallel to the specimen and with the end of the scale tangent to the pin through the eye at the set head of the testing machine. Stretch readings were taken at both ends of the free length and at the end of the specimen at the moving head of the testing machine.

[1] Defined as the distance between a point ½ in. in from the last tuck of 1 splice to a point ½ in. in from the last tuck of the other splice.

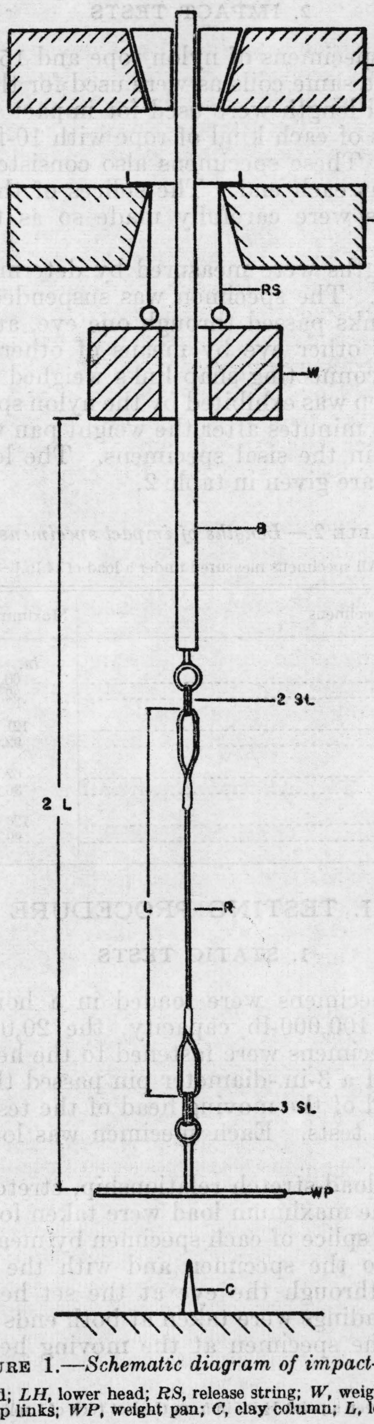

Figure 1.—*Schematic diagram of impact-test setup.*

Legend: *UH*, Upper head; *LH*, lower head; *RS*, release string; *W*, weight; *B*, bar; 2*SL*, two snap links; *R*, rope; 3*SL*, three snap links; *WP*, weight pan; *C*, clay column; *L*, length of specimen; 2*L*, twice the length of the specimen.

2. IMPACT TESTS

A large testing machine was found convenient for mounting and adjusting the fixtures used in the impact tests. Figure 1 shows schematically the fixtures used for applying impact loads to the spliced specimens. A 1⅝-in. steel bar (*B*) was gripped in the jaws of the upper head (*UH*) of the large testing machine and passed through the lower head (*LH*). An eyebolt screwed into the bar was attached to the specimen (*R*) by means of two snap links (2 *SL*) passed through one eye. The other eye of the specimen was attached to the eyebolt of the weight pan (*WP*) by means of three snap links. The weight (*W*) consisted of steel disks with a 4-in. hole through their centers. The disks were bolted together, passed over the bar, and suspended by means of a ¼-in. diameter sash-cord release string (*RS*), which was strung over two pins in the lower head.

The lower head was then raised or lowered until the distance (2*L*) from the bottom of the weight to the top of the weight pan, was adjusted to twice the length of the specimen. The weight was dropped by cutting the release string. Each specimen was subjected to one impact load.

The instantaneous clearance at impact between the weight pan and the floor was obtained from the clay column (*C*). The distance from the bottom of the weight pan to the floor was measured before test, and the height of the clay column was measured after the impact load had been applied. The difference between the two measurements is the stretch of the specimen under the impact load. The weight required to cause complete failure of the specimen or that needed to break one or more strands was determined. Where all of the strands of a specimen parted it was impossible to determine stretch under load.

IV. RESULTS

1. STATIC TESTS

From the load-stretch data obtained from the static tests of the specimens, the load-stretch relationships were calculated separately for each eye and splice length and for the free length of each specimen. The test results of the three sisal specimens and the three nylon specimens were averaged.

In figures 2 and 3 the stretch, in inches, of the eyes and splices of the sisal and the nylon static-test specimens have been plotted against load. The curves have been drawn through the average stretch values. The individual stretch-load curves for each eye and splice length were also drawn, and the area under each curve was determined by graphical integration. This area gives the energy absorbed by each eye and splice. The energy values in inch-pounds are presented in table 3.

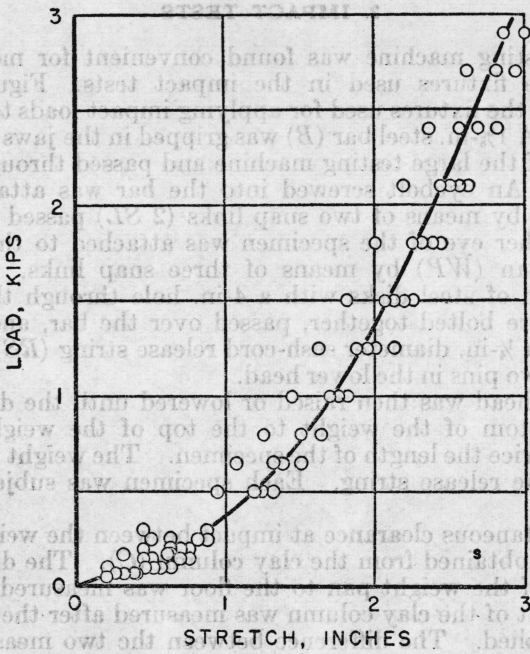

FIGURE 2.—*Load-stretch curve for eye and splice lengths of sisal static-test specimens*

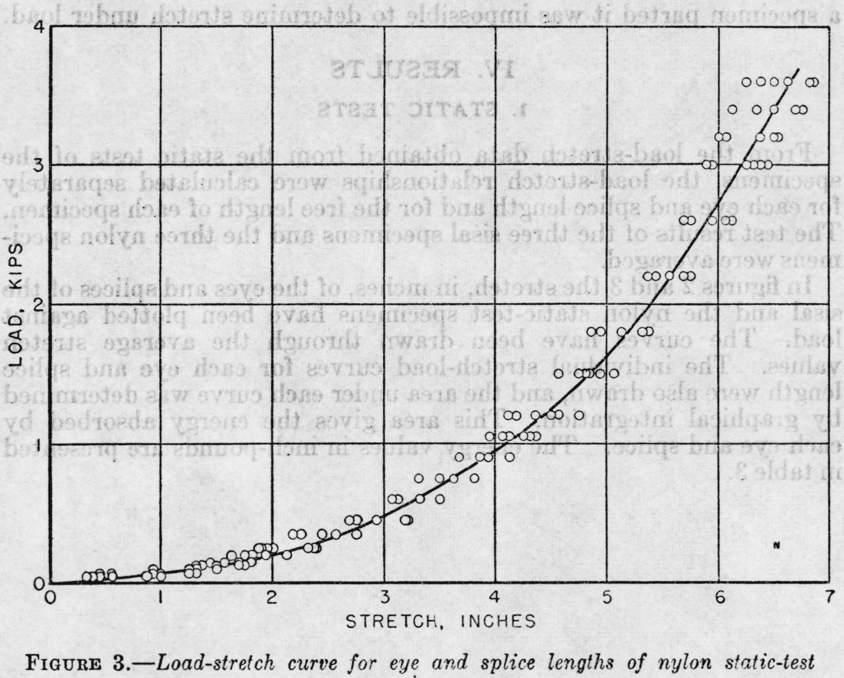

FIGURE 3.—*Load-stretch curve for eye and splice lengths of nylon static-test specimens.*

TABLE 3.—*Results of static tests*

[Speed of moving head of testing machine, 1 in./min.]

	Specimen 1-1a	Specimen 1-1b	Specimen 1-1c	Average	Specimen 1-2a	Specimen 1-2b	Specimen 1-2c	Average
	Sisal, 9/16 in. in diameter				Nylon, 7/16 in. in diameter			
Breaking load, lb	2,800	3,230	2,920	2,980	4,320	4,240	4,050	4,200
Failure	End of splice	End of splice	End of splice	----------	In the splice	In the splice	In the splice	----------
Elongation of free length at failure, percent	17.8	17.7	18.9	18.1	53.0	53.7	51.3	52.7
Static energy:								
Free length, in.-lb/in	161	193	191	182	616	583	566	588
One eye and splice, in.-lb	2,670	3,330	2,800	2,970	8,380	8,510	7,670	7,990
Other eye and splice, in.-lb	2,900	3,270	2,880		8,090	7,750	7,540	

In figures 4 and 5 the percentage of stretch of the free lengths of the sisal and the nylon static-test specimens have been plotted against load. The curves have been drawn through the average stretch values. The individual stretch-load curves for each free length were also drawn, and the area under each curve was determined by graphical integration. This area gives the energy absorbed by each unit length of free length of the specimen. The energy values in inch-pounds per inch are presented in table 3.

The average over-all lengths of the 5-ft impact specimens and of the 10-ft impact specimens of each kind of rope were determined, and static-load–stretch curves were drawn for specimens having these over-all lengths. It was assumed that the eye-and-splice part of the hypothetical and the static specimens would have the same load-stretch relationship, and that the free length part of the two kinds of specimens would have equal stretch per unit length. These load-stretch curves are given in figure 6.

By graphical integration of the static load-stretch curves for the average-length impact specimens shown in figure 6, the energy absorption for various amounts of stretch was obtained. This computed static-energy–stretch relationship is given by the lines in figures 7, 8, 9, and 10. The energy values corresponding to the stretch at failure of the first strand are the ordinates at the maximum stretch on these curves. The values given in table 4 are the computed static energies for specimens having the average length of the impact-test specimens when loaded to failure of the first strand.

TABLE 4.—*Computed total static energy required to break one strand of specimens having the average length of those used for the impact tests*

Nominal length and fiber	Energy
	ft-lb
5-ft sisal	980
10-ft sisal	1,860
5-ft nylon	3,190
10-ft nylon	6,490

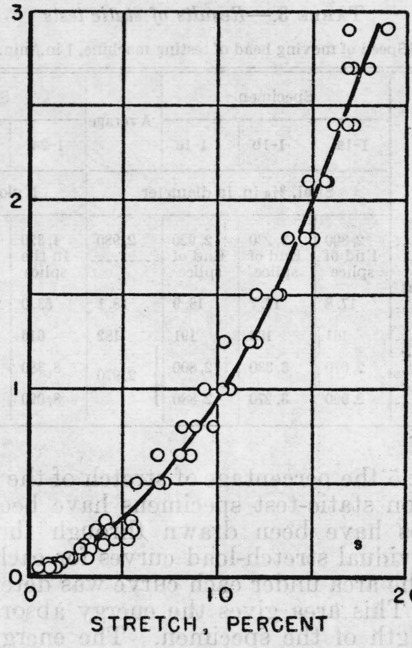

Figure 4.—*Load-stretch curve for free length of sisal static-test specimens.*

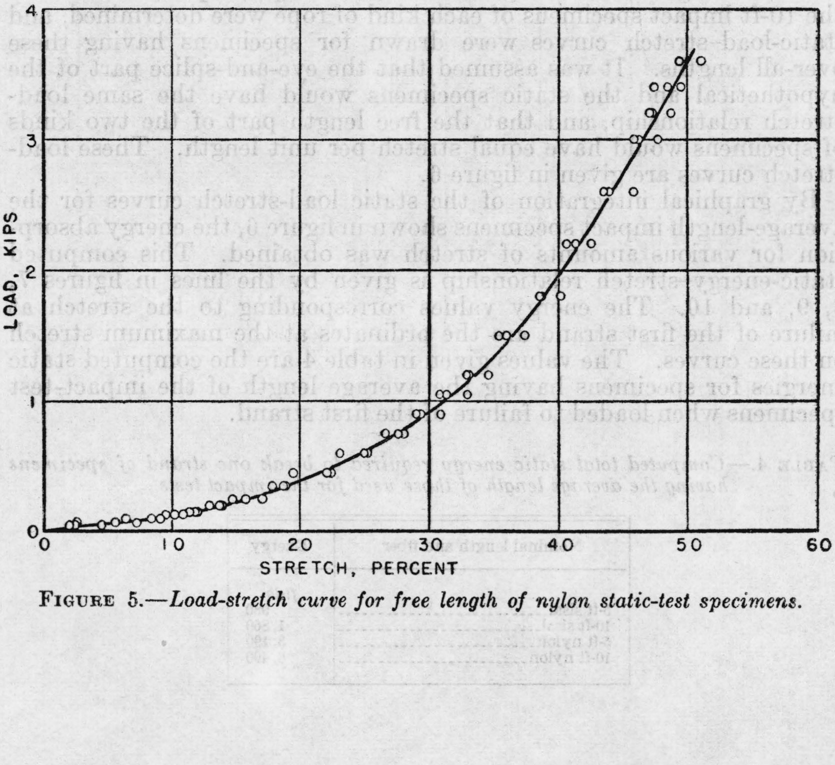

Figure 5.—*Load-stretch curve for free length of nylon static-test specimens.*

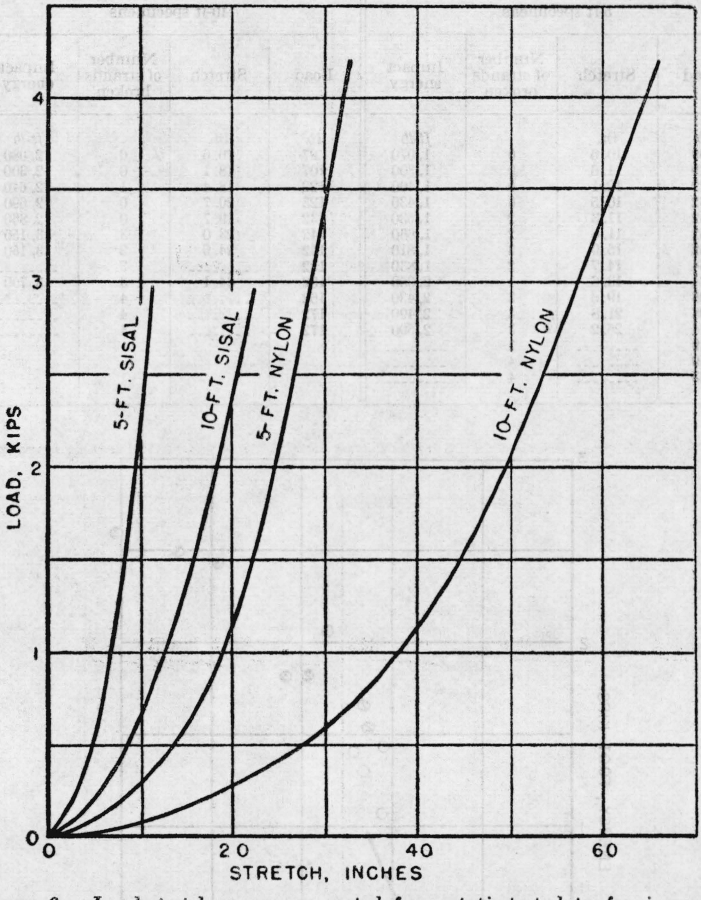

FIGURE 6.—*Load-stretch curves computed from static-test data for impact-test specimens*

2. IMPACT TESTS

The results of the impact tests are given in tables 5 and 6 and in figures 7, 8, 9, and 10.

TABLE 5.—*Results of impact tests of four-strand 9/16-in.-diameter sisal rope*

[Height of drop of load, twice the length of the specimen. Each specimen impacted once only]

5-ft specimens				10-ft specimens			
Load	Stretch	Number of strands broken	Impact energy	Load	Stretch	Number of strands broken	Impact energy
lb	*in.*		*ft-lb*	*lb*	*in.*		*ft-lb*
99	10.6	0	1,070	97	16.6	0	2,080
119	11.6	0	1,300	107	18.1	0	2,300
129	12.1	0	1,400	122	18.4	1	2,640
132	10.5	0	1,430	123	20.7	0	2,690
142	11.3	2	1,530	132	19.7	0	2,860
152	11.6	2	1,660	142	23.0	3	3,150
162	15.9	3	1,810	142	24.9	3	3,150
164	14.7	2	1,830	152	--------	3	--------
184	13.6	1	2,060	162	34.1	3	3,700
208	19.6	3	2,430	162	--------	4	--------
208	21.8	3	2,490	172	--------	4	--------
214	25.2	3	2,590	172	--------	4	--------
219	--------	3	--------				
219	--------	4	--------				
223	--------	4	--------				

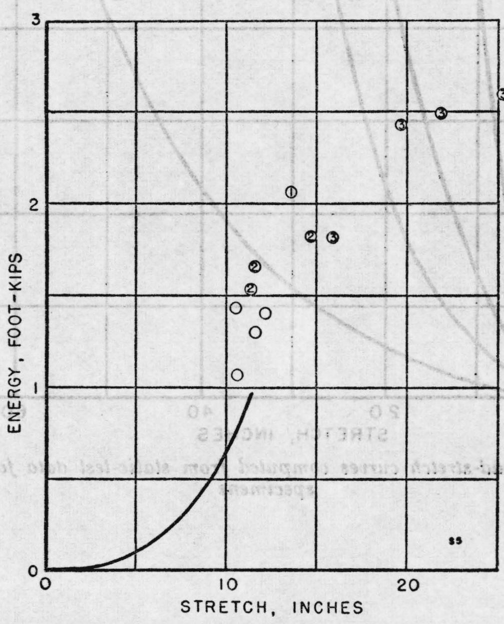

FIGURE 7.—*Energy-stretch relationships for 5-foot sisal specimens.*

The curve was computed from static data. The circles represent results of impact tests, and the numbers refer to number of broken strands.

TABLE 6.—*Results of impact tests of three-strand, 7/16-in. diameter, nylon rope*

[Height of drop of load, twice the length of the specimen. Each specimen impacted once only]

5-ft specimens				10-ft specimens			
Load	Stretch	Number of strands broken	Impact energy	Load	Stretch	Number of strands broken	Impact energy
lb	*in.*		*ft-lb*	*lb*	*in.*		*ft-lb*
254	28. 1	0	3, 230	268	55. 0	0	6, 740
268	27. 5	0	3, 340	278	55. 4	0	7, 010
274	29. 2	0	3, 510	288	56. 2	0	7, 250
278	27. 9	0	3, 500	298	58. 5	0	7, 590
278	--------	3	--------	298	57. 4	0	7, 620
288	28. 2	0	3, 620	298	--------	3	--------
294	29. 7	0	3, 770	308	58. 2	0	7, 840
298	28. 5	0	3, 730	328	62. 0	0	8, 550
308	28. 7	0	3, 870	328	61. 6	0	8, 570
309	29. 1	0	3, 940	328	--------	3	--------
319	39. 0	2	4, 370	338	--------	3	--------
319	--------	3	--------	338	--------	3	--------
319	--------	3	--------				
329	--------	3	--------				

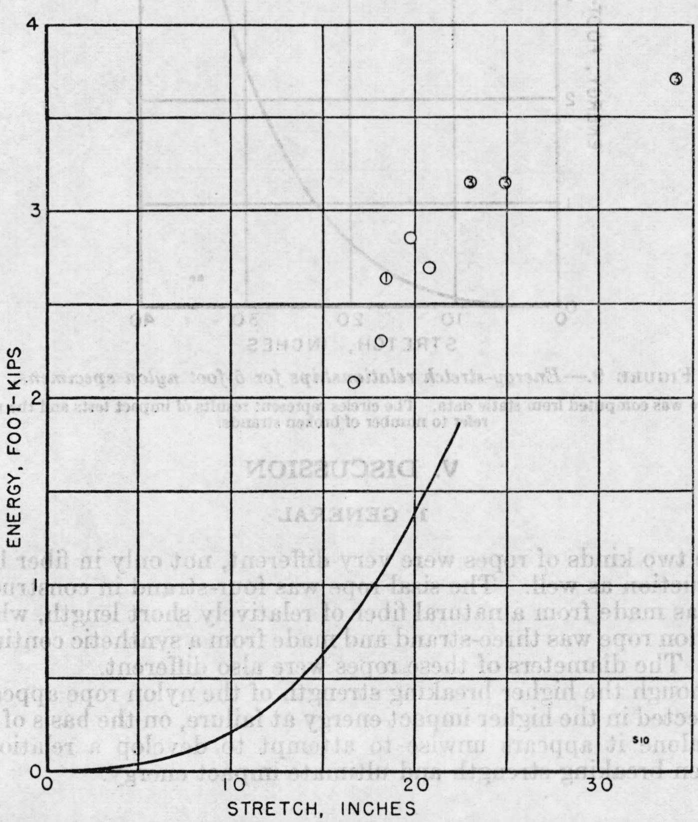

FIGURE 8.—*Energy-stretch relationships for 10-foot sisal specimens.*

The curve was computed from static data. The circles represent results of impact tests and the numbers refer to number of broken strands.

The impact energy absorbed by each specimen was computed by multiplying the weight by the total height of drop, which included the stretch of the specimen, and adding the stretch times the weight of the weight pan.

Stretch under impact load was plotted against the energy computed in each case and these are plotted as circles in figures 7, 8, 9, and 10. The numbers in the circles refer to the number of broken strands. Where no number appears in the circle, the specimen did not fail under the impact load.

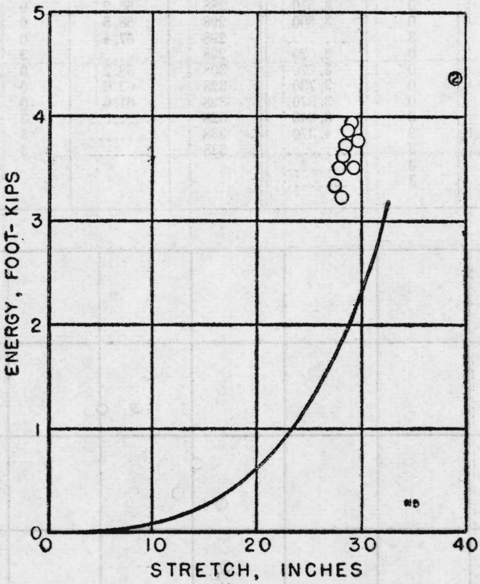

FIGURE 9.—*Energy-stretch relationships for 5-foot nylon specimens.*

The curve was computed from static data. The circles represent results of impact tests and the numbers refer to number of broken strands.

V. DISCUSSION

1. GENERAL

The two kinds of ropes were very different, not only in fiber but in construction as well. The sisal rope was four-strand in construction, and was made from a natural fiber of relatively short length, whereas the nylon rope was three-strand and made from a synthetic continuous fiber. The diameters of these ropes were also different.

Although the higher breaking strength of the nylon rope appears to be reflected in the higher impact energy at failure, on the basis of these tests alone it appears unwise to attempt to develop a relationship between breaking strength and ultimate impact energy.

2. STRETCH

Lutts and Himmelfarb [2] have found that when cotton and manila ropes are subjected to dead loads considerably below their normal breaking strengths they continue to stretch with time until limiting values are reached and the ropes fail. These limiting values were practically equal to the stretch at the breaking point as determined by static tests in a testing machine.

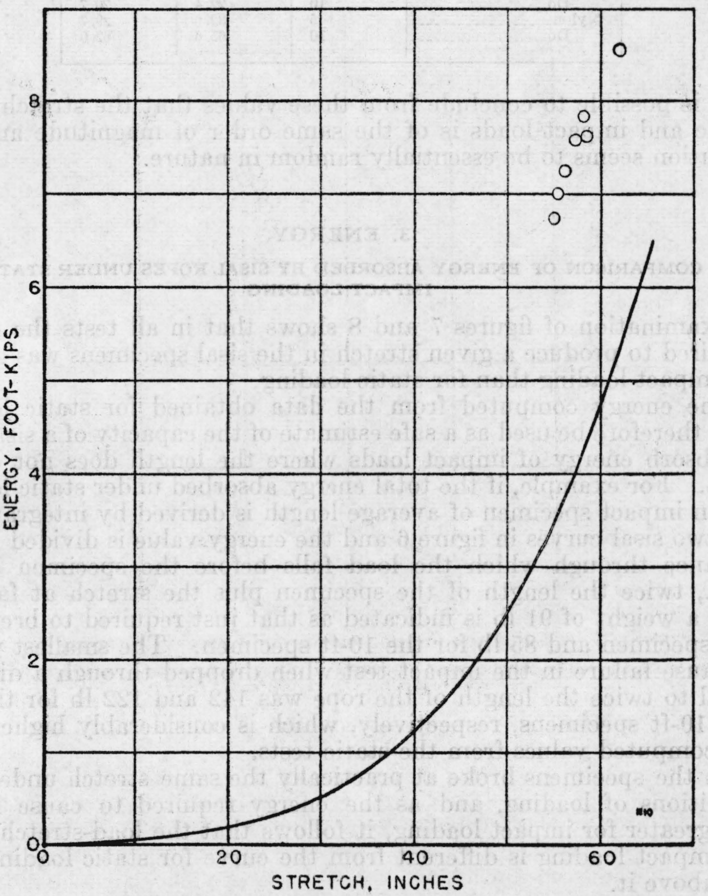

FIGURE 10.—*Energy-stretch relationships for 10-foot nylon specimens.*

The curve was computed from static data. The circles represent results of impact tests and the numbers refer to number of broken strands.

On the basis of these long-time tests they have concluded that the limiting range of stretch in a rope is a constant, regardless of the tension or load on the rope.

This conclusion is also in line with the present results of tests of sisal and of nylon ropes subjected to impact loads. Table 7 gives a comparison of the stretch of the static and the impact specimens.

[2] Carlton G. Lutts and David Himmelfarb, The Creep phenomenon in ropes and cords, Proc. Am. Soc. Testing Materials, pt. I, **40**, 1251 (1940).

TABLE 7.—*Stretch of static and of impact specimens*

Fiber	Nominal length of specimens	Computed average stretch at maximum static load	Maximum stretch of a specimen which did not break under impact load
	ft	*in.*	*in.*
Sisal	5	11.4	12.1
Do	10	22.4	20.7
Nylon	5	32.6	29.7
Do	10	65.6	62.0

It is possible to conclude from these values that the stretch under static and impact loads is of the same order of magnitude and any variation seems to be essentially random in nature.

3. ENERGY

(a) COMPARISON OF ENERGY ABSORBED BY SISAL ROPES UNDER STATIC AND IMPACT LOADING

Examination of figures 7 and 8 shows that in all tests the energy required to produce a given stretch in the sisal specimens was greater for impact loading than for static loading.

The energy computed from the data obtained for static loading may therefore be used as a safe estimate of the capacity of a sisal rope to absorb energy of impact loads where the length does not exceed 10 ft. For example, if the total energy absorbed under static loading by an impact specimen of average length is derived by integration of the two sisal curves in figure 6 and the energy value is divided by the distance through which the load falls before the specimen breaks (i. e., twice the length of the specimen plus the stretch at failure), then a weight of 91 lb is indicated as that just required to break the 5-ft specimen and 85 lb for the 10-ft specimen. The smallest weight to cause failure in the impact test when dropped through a distance equal to twice the length of the rope was 142 and 122 lb for the 5-ft and 10-ft specimens, respectively, which is considerably higher than the computed values from the static tests.

As the specimens broke at practically the same stretch under both conditions of loading, and as the energy required to cause failure was greater for impact loading, it follows that the load-stretch curve for impact loading is different from the curve for static loading and lies above it.

(b) COMPARISON OF ENERGY ABSORBED BY NYLON ROPES UNDER STATIC AND IMPACT LOADING

Figures 9 and 10 show that the energy required to produce a given stretch in the nylon specimens was greater for impact loading then for static loading. Therefore, the energy computed from static-test load-stretch data may also be used to obtain a safe estimate of the impact-energy capacity of a nylon rope of the length used in these tests.

If the energy absorbed under static loading by an impact specimen of average length is derived by integration of the two nylon curves in figure 6, and this energy value is divided by the distance through which the load falls before the specimen breaks (i. e., twice the length of the specimen plus the stretch at failure), a weight of 247 lb is indicated as that just required to break the 5-ft specimen and 249 lb for the 10-ft specimen. Both of these values are below the weights determined experimentally, namely, 278 and 298 lb for the 5-ft and the 10-ft impact specimens, respectively.

As the nylon specimens also broke at practically the same stretch under both conditions of loading, and as the energy required to cause failure was greater for impact loading, it follows that the load-stretch curve for impact loading is different from the curve for static loading and lies above it.

4. EFFECT OF ROPE LENGTH

For the two lengths of specimens tested with impact loads, there was no significant difference in energy per unit length to cause failure attributable to rope length in either the nylon or sisal specimens.

WASHINGTON, July 20, 1945.