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Baseline Tensile Testing at the Wire Rope Research Laboratory

By William M. McKewan and Anthony J. Miscoe

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	lbf-ft/kip	pound (force) foot per kip
ft/min	foot per minute	m	meter
gpm	gallon per minute	min	minute
hp	horsepower	mm	millimeter
in	inch	pct	percent
in/min	inch per minute	pct in/in	percent inch per inch
kip/in^2	kip per square inch	psi	pound (force) per square inch
lb	pound	s	second
lbf-ft	pound (force) foot		

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BASELINE TENSILE TESTING AT THE WIRE ROPE LABORATORY

By William M. McKewan[1] and Anthony J. Miscoe[2]

ABSTRACT

The U.S. Bureau of Mines has established a wire rope research laboratory to examine the factors that affect the life of wire rope. Ropes of sizes ranging from 3/4 to 2 in. in diameter and from 2 to 35 ft in length were tested to determine their breaking strength, elongation, and torque. This was done to characterize the test equipment on ropes used in mine hoisting systems.

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INTRODUCTION

The U.S. Bureau of Mines hoisting systems development project is an effort to improve the safety and efficiency of mine hoisting systems. A major part of this effort involves the study of the degradation of wire rope during its service life. Some 500 hoists are used in the United States, and in most of them, the cages for personnel and the skips for product are raised and lowered by a single wire rope. Cages may hold as many as 100 people, and shafts are as deep as 7,000 ft.

Skips have fallen in this country, with accidents to nearby personnel and damage to the hoisting system. The accidents resulting from retrieving the rope, repairing, and putting the shaft back into service are significant. No cages have fallen in the United States, but the probability of such occurrences will escalate in the future because mining deeper reserves will require longer ropes and higher hoisting speeds. Lower safety factors will be used since regulations state that the safety factor can be reduced from 7 to 4 as shaft depth increases from 0 to 4,000 ft and more. The fact that cages have fallen in foreign countries confirms that this research is not only desirable but necessary.

While the technology of fabricating wire ropes has achieved a high degree of sophistication, the quantitative understanding of the degradation of the rope during service is at a very low level. A wire rope is really a mechanical system having a very complex geometry. It is actually a multilayer spring with internal damping. When a loaded wire rope is bent around a sheave to change its direction, the mechanics become even more complicated since transverse forces are introduced. In addition to the internal wear caused by the wires sliding on each other, external wear is caused by rubbing and sliding in the sheave. Adding to the problem are the dynamics of ropes up to a mile long and ropes traveling at speeds up to 2,850 ft/min, accelerating and decelerating with attached loads on imperfectly aligned guides. Also to be considered are the mine shaft environmental conditions of abrasive dirt and acid or alkaline moisture. Consequently, mine-hoist ropes endure great punishment. Analysis of the effects of these factors on the deterioration of a wire rope therefore requires an extensive research program and data generation with high precision.

The Wire Rope Research Laboratory (WRRL) was established by the Bureau to examine the factors that affect wire rope strength, and ultimately, its useful life. At present, hoist ropes in mines are inspected both visually and by nondestructive sensors. A judgment is made, based on the observations and experience of the observer, as to whether the rope meets the retirement criteria of the U.S. Mine Safety and Health Administration (MSHA) (*1*)[3] and should be retired from service. At some mines, ropes are retired after a certain period of time has occurred or a given amount of tonnage has been lifted. The purpose of the WRRL is to provide accurate data to determine the effects of variables on the reduction of the strength of wire rope during its service life so that judgment becomes less of a factor.

The best way to measure the deterioration of strength in a wire rope is to measure its ultimate or breaking strength, but this obviously cannot be done while the rope is in service. At the WRRL, ropes will be deteriorated by a bending fatigue machine of unique design, containing three sheaves that will exercise a 1,000-ft length of rope to produce nine different levels of fatigue at a predetermined tensile load and travel speed. Visual inspection and nondestructive testing (NDT) profiles will be made periodically as the rope is cycled. After some time, broken wires and other indications of wear will determine that the rope be removed. Sections of special interest will be cut out, then further subdivided for detailed examination. The examination will consist of four analyses (in addition to the NDT profile): wire-by-wire examination for correlation with the NDT profiles, single-wire torsion tests, metallographic examination, and tensile strength measurements.

The primary objectives of the baseline testing program covered in this report were to determine (1) the operating characteristics of the tensile machine, (2) the precision of data produced by the tensile machine, and (3) the properties of the wire rope samples used during tensile testing.

EQUIPMENT DESCRIPTION

Although the tensile machine was designed primarily for tensile strength tests on wire rope specimens in support of bending fatigue research, it also has the versatility to test fatigue under cyclic axial force. The main application of this tensile machine will be to measure breaking strengths, elongations, and torques of new ropes for comparison with measurements made after the ropes have been degraded on the bending fatigue machine. These measurements will provide quantitative data to establish the effects of service conditions on the life of wire ropes. New and used ropes from mine hoists, obtained through cooperative agreements with mining companies, will also be tested to assess the effects of real-life use. The machine is shown in figure 1. System specifications are listed in table 1.

[3]Italic numbers in parentheses refer to items in the list of references at the end of this report.

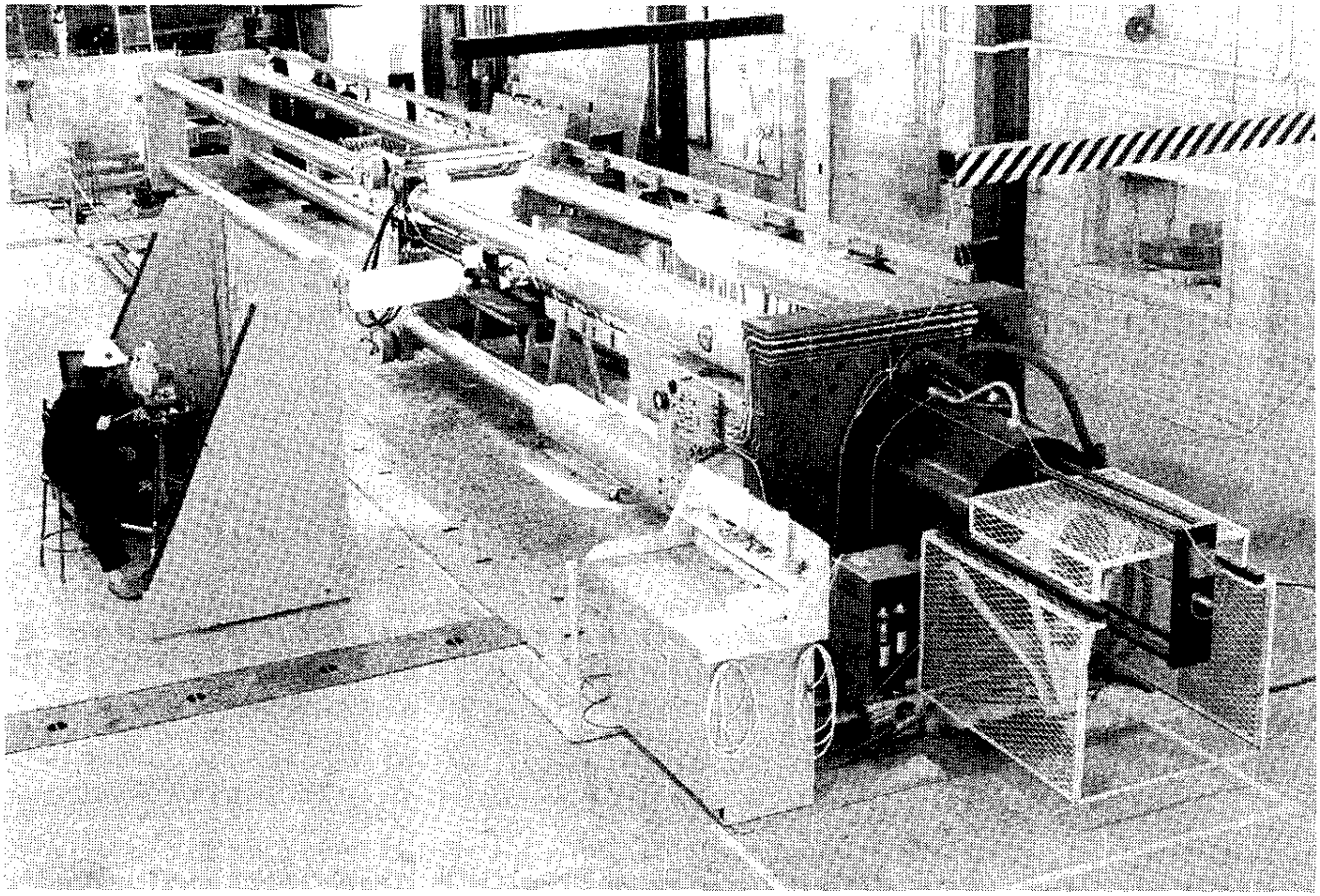

Figure 1.–Tensile and axial fatigue testing machine.

Table 1.–Tensile and axial fatigue testing machine specifications

Description		*Specification*
Maximum rope tension	lb	800,000
Maximum rope diameter	in	2-1/2
Specimen length	ft	2-33
Maximum actuator speed	in/min	16
Hydraulic system:		
Flow rate	gpm	70
Pressure	psi	3,000
Drive motor	hp	125

The machine is essentially a hydraulically actuated tensile testing machine in a horizontal position rather than the usual vertical position to reduce vertical height requirements and for ease of access. It is composed of three elements operating in conjunction: the load frame, the electrical console, and hydraulic power supply. The load frame contains the hydraulic crosshead locks. The locks sustain full rated load in either direction with zero slippage and zero backlash. Safety containers for the specimen are provided for operator protection during testing.

Functionally, the test machine is a closed-loop servohydraulic system in which high-pressure hydraulic fluid under the precise control of a servovalve is provided to the hydraulic actuator, which applies the load to the specimen. To accomplish this, the system controller accepts externally generated electrical control and feedback signals from the transducer. These signals are compared to detect any error, and the resulting signal is used to control the servovalve. Several operating variables can be selected as control parameters by choosing the appropriate transducer for the feedback signal. The controllable parameters are displacement of the actuator, load applied to the specimen, and torque generated by the wire rope specimen as an axial load is applied.

The electronic control console contains all the necessary components for servocontrol, hydraulic power control, signal conditioning, test parameter readout, and interlock functions. It also contains a digital computer and the necessary interfaces to record, manipulate, and plot the testing data.

The factors examined in the baseline series were

1. The precision of the data generated by the system for ultimate strength, elongation, and torque.

2. The effectiveness of resin sockets to withstand rope ultimate-strength loads and comparison of resin sockets with zinc (spelter) sockets.

3. The effect of actuator speed on generated data.

4. The effect of sample length on generated data.

5. Variation of generated data along the length on a single reel of rope.

EXPERIMENTAL DESIGN

There are a number of factors that can be determined during the tensile testing of wire rope. Some are measured directly, such as breaking load, and some are calculated, such as modulus of elasticity. Before a test is conducted, certain physical measurements are made on the rope. These are (1) gauge length, the rope length between the sockets, (2) rope diameter, and (3) lay length. From the diameter and the rope construction, the metallic area can be calculated.

During the course of the program the operational characteristics of the machine were determined. The measurements made during testing were (1) the displacement of the actuator rod, or the stroke, (2) the load applied to the specimen, and (3) the torque generated by the specimen as an axial load is applied. The sensors for these measurements were calibrated by the machine manufacturer.

Bureau researchers wanted to gain as much information as possible from the testing, both about the tensile machine and about the different samples of rope. It was known in advance that the manufacturer's catalog does not provide any detailed information about a rope. Manufacturers are required only to meet a minimum strength, nothing else; they are not required to give data on the actual breaking strength, the elongation, the chemical composition, or the microscopic structure of the rope. Therefore, the experimental work was designed to gain maximum data from as few tests as possible.

Originally, 10 tests were scheduled for each rope series. The characteristics of the ropes chosen for each series are shown in table 2. Samples were cut to the following lengths: 5, 10, 15, 20, and 35 ft. Two samples were taken of each. The 10 samples were cut from the reel in random order. From a procedure of this nature, the precision of the testing could be calculated. In addition, the effects of sample size on the results and the uniformity of the rope on the reel could be determined. Later, it was decided to add 2-ft samples to the test program to increase the range of the data and to substitute 30-ft samples for the 35-ft samples to allow for the larger elongations.

Table 2.–Characteristics of wire ropes used in tests

(All ropes were fiber core, improved plow steel, set in socket with epoxy resin, and tested at 1-in/min stroke rate, unless otherwise noted)

Rope	Diam, in	Description	Strength,[1] kips	Samples tested
A	1	6 × 25 filler wire, 6-in right regular lay	83.6	10
B	1-1/2	6 × 19 Seale, 10-in right Lang lay	184.0	12
C	1-1/4	6 × 25 filler wire, 8-in right Lang lay	129.2	10
D	3/4	6 × 19 Seale, 5.25-in right Lang lay	47.6	10
E	1-7/8	6 × 25 filler wire, 12.75-in right Lang lay	310.0	11
F	2	6 × 25 filler wire, 13.125-in right regular lay	320.0	13
G[2,3]	1-1/4	6 × 25 filler wire, 8-in right regular lay	129.2	9
H[3]	1-1/2	6 × 19 Seale, 10-in right Lang lay	184.0	5

[1]Catalog.
[2]Tested at stroke rates of 0.0625, 0.125, 1, 8, and 16 in/min.
[3]Zinc-filled socket.

EXPERIMENTAL PROCEDURE

Enough rope was cut to allow for the amount that would be in the sockets. The ends were seized, broomed, and cleaned. The brooms were cleaned in a vented tank of trichloroethane and then washed with steam and detergent to remove any residual matter. The brooms were then closed, inserted into the sockets and set in an epoxy resin. With this procedure, there was no problem with the brooms pulling out of the sockets. After curing for about an hour, the samples were ready for testing. One series of samples was made commercially with zinc-filled sockets, using rope from a reel that had been previously tested, to compare the results obtained with zinc and epoxy sockets.

The samples were placed in the tensile machine, and the testing was begun. Initially a prestretch load of about 5 to 10 kips was placed on the rope, and the stroke was set at zero. This procedure led to an S-shaped curve during the elastic portion of the test, because of the construction stretch that exists in new rope. During the second series of samples, a prestretch load equal to 20 pct of the breaking strength was placed on the sample for 10 min or until the rope stopped elongating. This load was then removed, and the test was conducted as before. This procedure eliminated construction stretch and the S-shaped curves. The 20-pct prestretch load was used for all of the remaining tests. Construction stretch and the S-curves are discussed later in this report.

The following measurements were made during the testing as a function of time: (1) load in kips, (2) stroke in inches, (3) torque in kip-inches. From these measurements the other factors can be calculated, such as stress, strain, and elongation.

The "Wire Rope Users Manual" (*2*) gives certain specifications for determining breaking strengths of wire ropes:

> The breaking strength is the ultimate load registered on a wire rope sample during a tension test.... All discussion of strength is predicated on the assumption of there being a gradually applied load that will not exceed one inch per minute.... A minimum acceptance strength, 2-1/2% lower than the published nominal breaking strengths, was established as the industry tolerance.... The sample's length must not be less than 3 ft (0.91 m) between sockets for ropes with diameters of from 1/8 inch (3.2 mm) through 3 inches (77 mm); on ropes with larger (over 3 inches) diameters, the clear length must be a least 20 times the rope diameter. The test is considered valid only if failure occurs 2 inches (51 mm) or more from either of the sockets, or from the holding mechanism.

The "Wire Rope Users Manual" specifications were followed for most of the testing. The exceptions were (1) a few 2-ft samples were tested to aid in the determination of modulus of elasticity, and (2) a series of tests were run over a range of stroke rates to determine the effect of this variable.

EXPERIMENTAL RESULTS

TYPICAL RESULTS

There were eight series of rope samples run during the baseline testing. Of these samples, only the 80 samples that broke more than the standard two in from the sockets were used for the determination of breaking strength. However, samples that broke near the sockets could be used for calculation of modulus of elasticity and yield because these data are accumulated prior to the breaking point and are independent of behavior in the plastic region near the breaking point.

The data from two tests are shown in tables 3 and 4. The stroke in inches is shown to be a function of time in seconds since the stroke was set at 1 in/min. This can be seen easily by comparing the stroke data with the time at 60-s intervals. The load in kips and the torque in kip-inches were measured by the machine at the designated time intervals. The torque in pound (force) feet was calculated from the torque in kip-inches. The elongation in inches was determined from the stroke, using a compliance factor determined by the machine configuration and the socket diameter. This factor multiplied by the load is subtracted from the stroke to give the elongation. The compliance factor takes care of any tension or compression in the machine parts, the grips, and the sockets. This is a significant correction as can be seen by comparing stroke with elongation. The stress in kips per square inch is calculated by dividing the load by the rope metallic area. The strain in percent inch per inch is calculated by dividing the elongation by the rope gauge length in inches and multiplying by 100.

From the data in tables 3 and 4, the curves in figures 2 and 3, respectively, were plotted. From every run made during the baseline testing, a table was generated and three curves were plotted.

Table 3.–Typical baseline test on wire rope D

Time, s	Stress, kip/in^2	Strain, pct in/in	Torque, lbf-ft	Load, kips	Elongation, in	Stroke, in
1.5	13.490	0.021	24.2	2.992	0.025	0.027
12.0	26.100	.167	47.6	5.789	.198	.203
24.0	44.382	.333	83.4	9.844	.397	.405
36.0	63.981	.497	121.1	14.191	.592	.603
48.0	82.926	.658	156.0	18.393	.784	.799
60.0	102.858	.826	194.4	22.814	.984	1.002
72.0	122.624	.990	229.3	27.198	1.179	1.201
84.0	140.906	1.154	262.3	31.253	1.374	1.399
96.0	157.534	1.317	293.3	34.941	1.568	1.596
108.0	171.740	1.480	319.6	38.092	1.763	1.793
120.0	183.693	1.651	340.9	40.743	1.967	1.999
132.0	193.602	1.817	358.3	42.941	2.164	2.198
144.0	201.533	1.982	372.5	44.700	2.361	2.396
156.0	208.030	2.146	385.0	46.141	2.556	2.593
168.0	213.206	2.313	391.6	47.289	2.756	2.793
180.0	217.556	2.481	399.3	48.254	2.956	2.994
192.0	220.694	2.646	402.8	48.950	3.152	3.191
204.0	223.665	2.815	407.6	49.609	3.354	3.393
216.0	226.032	2.979	409.7	50.134	3.549	3.589
228.0	227.687	3.145	411.9	50.501	3.747	3.787
240.0	229.504	3.313	414.8	50.904	3.947	3.987
252.0	230.771	3.482	417.5	51.185	4.147	4.188
264.0	232.146	3.651	416.3	51.490	4.349	4.390
276.0	232.809	3.814	416.3	51.637	4.543	4.584
288.0	233.855	3.983	416.0	51.869	4.745	4.786
300.0	234.238	4.148	415.0	51.954	4.941	4.982
312.0	234.842	4.319	415.8	52.088	5.145	5.186
324.0	235.063	4.483	413.8	52.137	5.341	5.382
325.5	235.176	4.507	413.8	52.162	5.369	5.410
327.0	235.063	4.527	414.0	52.137	5.393	5.434

From the plots of load versus elongation on figures 2*A* and 3*A* and the data from the tables, the breaking strength and the breaking elongation can be determined. The breaking strength is defined as the maximum load that the rope attains. The breaking elongation is defined as the maximum elongation that the rope attains, which occurs when the rope breaks. The maximum load does not necessarily occur at the maximum elongation, as is shown in table 3.

Figures 2B and 3B show plots of stress versus strain. The elastic region is the initial straight-line portion of the plot where stress is proportional to strain. The plastic region is the final part of the plot where the stress is no longer proportional to strain. The slope of the straight-line portion of a stress-strain curve is defined as the modulus of elasticity. It is equal to the stress divided by the strain and is in units of pounds per square inch. Because the stress-strain plots for many metals and for wire rope do not show a well-defined transition from elastic to plastic behavior, it is customary to define the yield stress by drawing a line parallel to the slope of the stress-strain plot and displaced 0.2 pct of the gauge length to the right. This line will intersect the curve in the plastic region. This point of intersection is defined as the yield stress. *The strain at that point is the yield strain.*

Figures 2*C* and 3*C* show plots of torque versus load. As can be seen from the figures, torque is proportional to load almost to fracture. The slope of the torque-versus-load plot is called the Torque K. It has the units of pound (force) feet per kip.

Table 4.-Typical baseline test on wire rope B

Time, s	Stress, kip/in^2	Strain, pct in/in	Torque, lbf-ft	Load, kips	Elongation, in	Stroke, in
1.5	13.051	0.041	188.3	11.578	0.024	0.031
6.0	25.607	.158	386.8	22.716	.092	.106
12.0	42.293	.315	647.6	37.518	.182	.206
18.0	55.289	.475	839.7	49.047	.275	.306
24.0	68.781	.635	1,045.8	61.016	.367	.406
30.0	83.099	.793	1,254.4	73.718	.459	.506
36.0	98.188	.946	1,478.3	87.103	.548	.603
42.0	112.892	1.108	1,694.6	100.147	.641	.705
48.0	126.713	1.262	1,895.6	112.408	.731	.802
54.0	139.875	1.421	2,088.9	124.084	.822	.901
60.0	152.155	1.588	2,267.0	134.978	.919	1.005
66.0	162.838	1.751	2,418.4	144.455	1.013	1.105
72.0	173.026	1.914	2,564.8	153.493	1.108	1.205
78.0	181.892	2.078	2,691.9	161.358	1.203	1.305
84.0	189.823	2.236	2,795.0	168.393	1.294	1.401
90.0	196.596	2.407	2,891.7	174.402	1.393	1.504
96.0	202.708	2.574	2,973.1	179.824	1.490	1.604
102.0	207.885	2.737	3,036.8	184.416	1.584	1.701
108.0	212.621	2.908	3,100.3	188.618	1.683	1.803
114.0	216.476	3.074	3,143.6	192.037	1.779	1.901
120.0	219.724	3.240	3,183.0	194.919	1.875	1.999
126.0	222.809	3.415	3,218.7	197.655	1.976	2.102
132.0	225.397	3.587	3,242.8	199.951	2.076	2.203
138.0	227.655	3.752	3,261.9	201.954	2.172	2.300
144.0	229.472	3.922	3,278.4	203.566	2.270	2.399
150.0	231.124	4.096	3,289.9	205.032	2.371	2.501
156.0	232.390	4.271	3,298.8	206.155	2.472	2.603
162.0	233.657	4.443	3,307.7	207.279	2.571	2.703
168.0	234.703	4.615	3,309.0	208.207	2.671	2.803
174.0	235.364	4.780	3,305.2	208.793	2.766	2.899
180.0	236.026	4.952	3,302.6	209.380	2.866	2.999
186.0	236.686	5.124	3,303.8	209.966	2.966	3.099
192.0	236.961	5.298	3,296.3	210.210	3.067	3.200
198.0	237.457	5.469	3,292.4	210.650	3.165	3.299
204.0	237.457	5.640	3,281.0	210.650	3.264	3.398
207.0	237.732	5.726	3,277.2	210.894	3.314	3.448

SUMMARY OF NORMAL BREAKS

A normal break is defined as a break that occurs 2 in or more from the socket. Only data obtained with normal breaks were accepted for the measurement of breaking strength. The summaries of data for the eight series of rope tests are shown in tables 5 to 12. Also shown in the summary tables are the means, the standard deviations, and the percentage that the standard deviations are of the means. In table 13 the means, standard deviations, and the percent standard deviations of all of the ropes are shown for the breaking strength (load), the modulus of elasticity, the breaking stress, the yield stress, and the torque constant. It is apparent from examining the percent standard deviation columns that the precision is good for the measurement of load and torque. It is also apparent that any measurement involving elongation, such as modulus of elasticity, has poor precision, considering all of the data from a series. The measurement of stroke, elongation, and modulus of elasticity are discussed later.

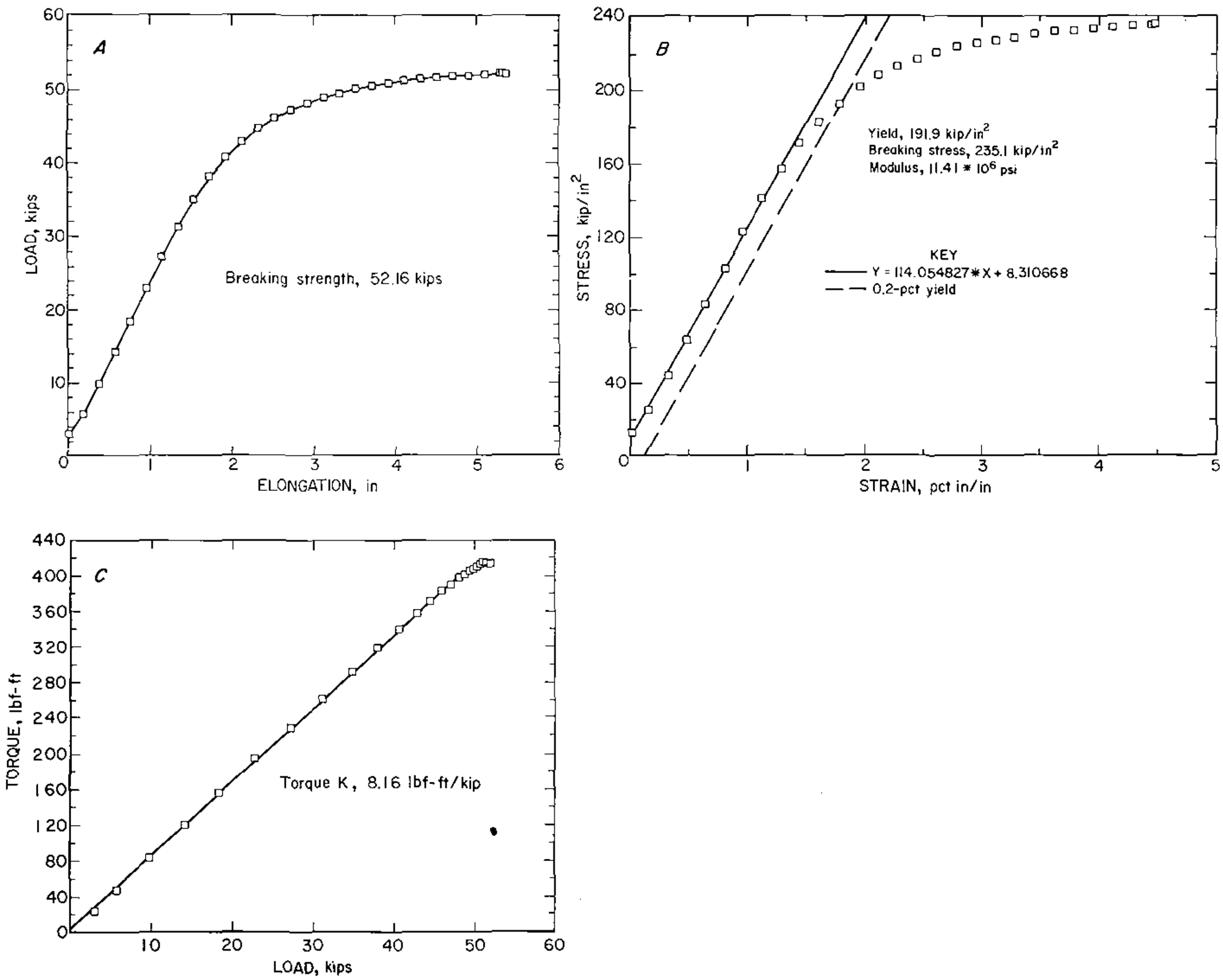

Figure 2.–Typical test data, rope D.

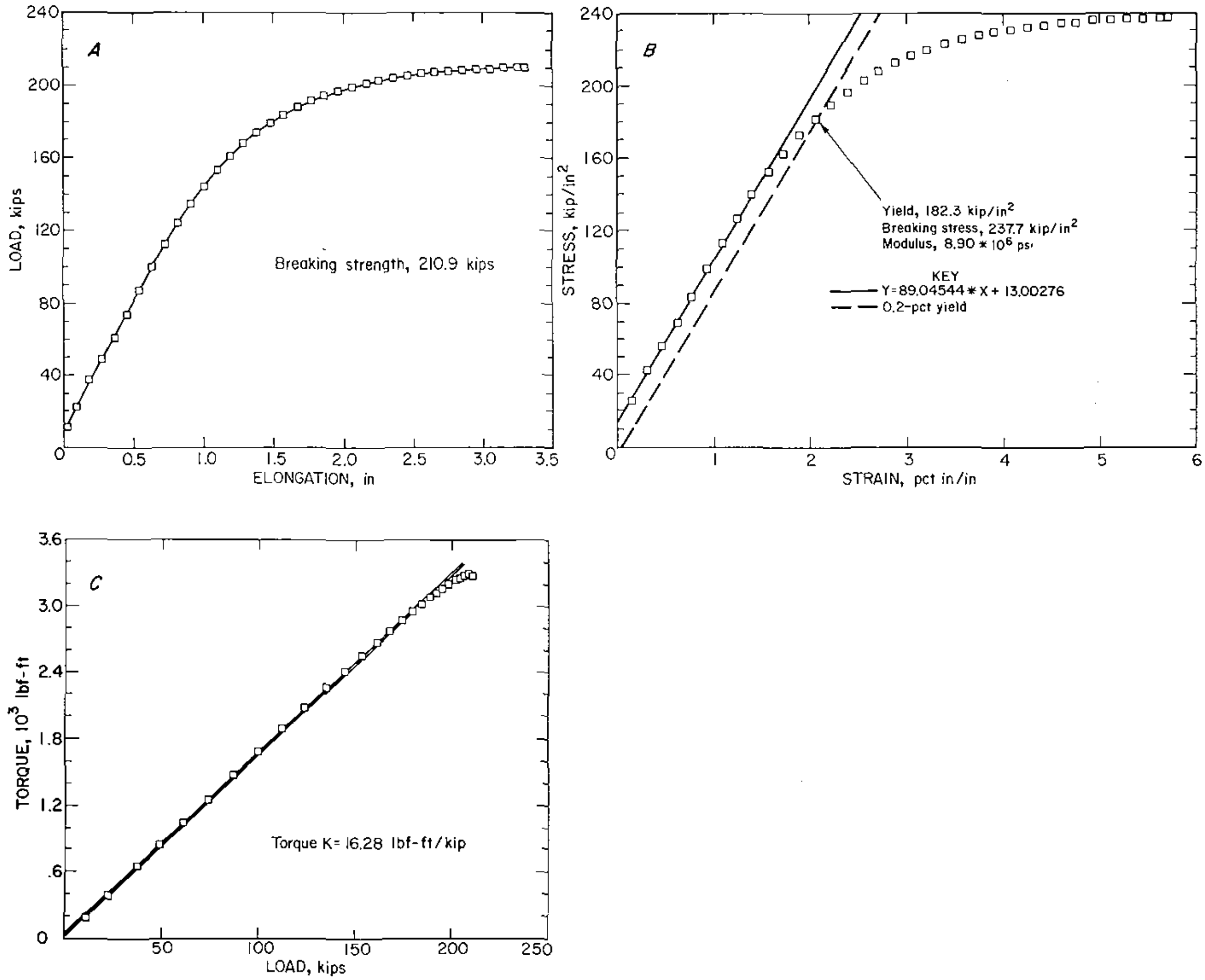

Figure 3.–Typical test data, rope B.

Table 5.–Summary of test series on rope A

Sample length, ft	Modulus of elasticity, 10^6 psi	Break				Yield		Torque K, lbf-ft/kip	Reel position, ft
		Load, kips	Elonga-tion, in	Stress, kip/in^2	Strain, pct in/in	Stress, kip/in^2	Strain, pct in/in		
5.01	8.48	92.06	2.78	228.00	4.62	188.00	2.41	7.69	2.9
5.07	9.29	92.38	2.61	228.80	4.28	183.70	2.03	8.14	251.0
10.00	9.50	92.04	5.04	288.00	4.20	183.90	2.03	8.26	116.8
10.13	8.89	91.09	5.07	225.60	4.18	191.90	2.44	8.22	226.5
14.96	9.43	89.50	6.84	221.70	3.81	185.20	2.30	7.92	13.7
15.21	9.49	91.09	7.76	225.60	4.21	186.90	2.27	8.23	240.0
20.03	9.77	91.16	9.82	225.80	4.09	182.30	1.93	8.46	264.4
20.27	9.59	91.04	9.76	225.50	4.01	187.30	2.19	8.47	132.7
35.21	9.87	90.06	16.48	223.10	3.90	185.50	2.14	8.26	203.0
35.32	9.90	90.96	16.93	225.30	3.99	183.90	1.96	8.34	39.7
Mean	9.42	91.14	NAp	225.74	4.13	185.86	2.17	8.20	NAp
SD	.44	.89	NAp	2.19	.23	2.78	.18	.24	NAp
SD . . pct	4.72	0.97	NAp	0.97	5.52	1.50	8.41	2.91	NAp

NAp Not applicable. SD Standard deviation.

Table 6.–Summary of test series on rope B

Sample length, ft	Modulus of elasticity, 10^6 psi	Break				Yield		Torque K, lbf-ft/kip	Reel position, ft
		Load, kips	Elonga-tion, in	Stress, kip/in^2	Strain, pct in/in	Stress, kip/in^2	Strain, pct in/in		
4.81	7.84	210.60	3.68	237.30	6.37	188.30	2.85	16.27	54.58
4.82	8.90	210.90	3.31	237.70	2.28	182.30	2.10	16.28	244.54
4.82	8.63	210.60	3.42	237.30	5.91	185.30	2.22	16.28	250.37
5.06	8.11	207.80	3.34	234.30	5.50	185.10	2.79	16.31	154.56
9.64	10.51	207.80	5.49	234.30	4.75	185.70	2.20	16.61	183.72
10.02	10.35	209.10	6.76	235.70	5.62	184.70	2.24	16.39	98.74
14.64	10.95	208.20	9.93	234.70	5.66	182.00	2.06	16.52	212.88
14.71	11.00	207.70	8.74	234.20	4.95	185.30	2.10	16.54	43.75
19.60	11.04	207.70	12.56	234.10	5.34	183.10	2.06	16.56	231.21
20.17	11.33	208.20	12.00	234.70	4.96	185.10	2.06	16.53	167.89
34.88	11.76	207.40	19.06	233.80	4.55	182.90	1.69	16.60	231.21
35.00	12.07	207.70	19.49	234.20	4.63	183.50	1.74	16.46	17.92
Mean	10.21	208.64	NAp	235.19	5.04	184.44	2.18	16.45	NAp
SD	1.46	1.31	NAp	1.43	1.03	1.77	.35	.13	NAp
SD . . pct	14.27	0.63	NAp	0.61	20.43	0.96	15.90	0.81	NAp

NAp Not applicable. SD Standard deviation.

Table 7.–Summary of test series on rope C

Sample length, ft	Modulus of elasticity, 10^6 psi	Break				Yield		Torque K, lbf-ft/kip	Reel position, ft
		Load, kips	Elonga-tion, in	Stress, kip/in^2	Strain, pct in/in	Stress, kip/in^2	Strain, pct in/in		
4.76	9.34	160.38	2.69	254.30	4.72	212.60	2.32	14.07	101.6
4.98	9.65	159.65	2.76	253.10	4.61	207.90	2.23	13.92	38.6
9.69	10.70	158.79	4.46	251.70	3.84	214.20	2.09	14.04	145.6
9.98	10.94	158.33	4.56	251.00	3.86	213.60	2.05	14.05	172.1
14.90	12.71	158.45	6.75	251.20	3.78	210.40	1.74	14.21	158.9
14.98	11.74	158.48	6.39	251.24	3.55	211.90	1.93	14.35	70.1
19.80	11.97	158.09	8.79	250.60	3.70	211.40	1.88	14.18	193.6
19.94	11.02	158.38	9.39	251.10	4.09	214.20	2.04	14.26	88.4
35.36	12.49	157.45	15.39	249.60	3.63	209.50	1.80	14.20	334.9
35.39	12.48	157.74	15.79	250.10	3.72	209.50	1.79	14.11	299.1
Mean	11.30	158.57	NAp	251.39	3.95	211.52	1.99	14.14	NAp
SD	1.18	.87	NAp	1.39	.40	2.17	.19	.13	NAp
SD . . pct	10.46	0.55	NAp	0.55	10.25	1.03	9.74	0.88	NAp

NAp Not applicable. SD Standard deviation.

Table 8.-Summary of test series on rope D

Sample length, ft	Modulus of elasticity, 10^6 psi	Break Load, kips	Break Elongation, in	Break Stress, kip/in²	Break Strain, pct in/in	Yield Stress, kip/in²	Yield Strain, pct in/in	Torque K, lbf-ft/kip	Reel position, ft
1.88	9.22	52.60	1.29	237.20	5.72	184.20	2.20	8.16	172.6
4.85	10.82	52.37	2.95	236.10	5.07	189.30	1.95	8.39	176.9
5.09	10.98	52.20	3.22	235.30	5.26	186.40	1.88	8.25	182.7
9.81	11.45	51.66	4.54	232.90	3.86	192.60	1.80	8.14	136.2
9.93	11.41	52.16	5.39	235.20	4.53	191.90	1.81	8.16	67.9
15.02	11.77	52.17	8.58	235.20	4.76	191.60	1.75	8.32	23.7
19.96	11.89	52.02	10.46	234.50	4.37	192.00	1.72	8.28	152.1
20.00	11.77	52.21	11.35	235.40	4.73	193.60	1.81	8.14	294.4
29.93	12.40	51.69	15.62	233.00	4.35	188.90	1.68	8.40	47.1
30.16	12.02	51.83	16.08	233.70	4.44	191.60	1.73	8.26	268.6
Mean	11.37	52.09	NAp	234.85	4.71	190.21	1.83	8.25	NAp
SD	.89	.30	NAp	1.35	.53	2.99	.15	.10	NAp
SD . . pct	7.84	0.57	NAp	0.58	11.26	1.57	8.26	1.20	NAp

NAp Not applicable. SD Standard deviation.

Table 9.-Summary of test series on rope E

Sample length, ft	Modulus of elasticity, 10^6 psi	Break Load, kips	Break Elongation, in	Break Stress, kip/in²	Break Strain, pct in/in	Yield Stress, kip/in²	Yield Strain, pct in/in	Torque K, lbf-ft/kip	Reel position, ft
1.96	6.34	338.80	1.34	238.80	5.72	193.30	2.98	19.13	147.5
2.00	6.83	338.60	1.42	238.60	5.92	185.30	2.61	19.53	117.5
4.88	9.25	331.70	2.74	233.70	4.68	181.20	2.10	20.01	3.0
4.91	9.72	334.00	2.80	235.30	4.76	175.50	1.92	19.90	173.0
9.87	10.76	329.00	5.16	231.80	4.33	180.40	1.82	20.44	124.5
9.93	10.49	330.70	5.08	233.00	4.29	185.10	1.90	20.30	73.5
14.90	10.99	329.90	7.96	232.40	4.54	179.60	1.81	20.51	108.0
14.97	11.77	327.60	7.74	230.80	4.31	177.40	1.65	20.31	138.5
19.82	12.62	328.90	10.25	231.80	4.31	175.50	1.56	20.65	89.5
20.01	12.34	326.80	10.10	230.30	4.21	173.20	1.56	20.71	159.5
29.96	12.59	328.30	14.78	231.30	4.11	177.40	1.58	20.54	21.5
Mean	10.34	331.30	NAp	233.44	4.65	180.35	1.95	20.18	NAp
SD	2.16	4.16	NAp	2.95	.61	5.76	.46	.50	NAp
SD . . pct	20.93	1.26	NAp	1.26	13.13	3.19	23.40	2.46	NAp

NAp Not applicable. SD Standard deviation.

Table 10.-Summary of test series on rope F

Sample length, ft	Modulus of elasticity, 10^6 psi	Break Load, kips	Break Elongation, in	Break Stress, kip/in²	Break Strain, pct in/in	Yield Stress, kip/in²	Yield Strain, pct in/in	Torque K, lbf-ft/kip	Reel position, ft
1.94	5.66	352.40	1.40	218.20	6.02	165.70	3.02	13.73	209.97
2.17	5.93	345.50	1.77	213.90	6.10	167.90	2.79	14.31	38.25
2.18	5.17	348.90	1.96	216.10	6.79	160.80	2.69	13.77	35.08
5.20	8.46	347.70	3.34	215.30	5.05	164.20	2.10	14.20	42.92
5.38	9.34	347.00	3.39	214.90	4.97	157.30	1.82	14.35	3.08
9.91	10.04	345.20	5.16	213.80	4.34	162.50	1.80	14.39	217.07
10.27	9.15	346.70	5.94	214.70	4.82	167.10	1.99	14.13	11.75
14.92	10.31	347.80	8.55	215.40	4.78	163.20	1.80	14.23	230.65
15.34	10.03	348.90	8.79	216.60	4.78	166.60	1.87	14.01	120.09
19.94	10.41	343.40	11.09	212.60	4.63	164.70	1.72	14.40	249.24
20.28	10.52	346.30	11.19	214.40	4.60	164.30	1.73	14.18	120.09
30.13	10.81	343.70	16.08	212.90	4.44	162.90	1.66	14.28	162.42
30.23	11.21	344.60	16.68	213.40	4.60	159.40	1.59	14.47	93.92
Mean	9.00	346.85	NAp	214.78	5.07	163.58	2.04	14.19	NAp
SD	2.08	2.53	NAp	1.57	.75	3.07	.47	.23	NAp
SD . . pct	23.12	0.73	NAp	0.73	14.77	1.88	23.15	1.62	NAp

NAp Not applicable. SD Standard deviation.

Table 11.–Effect of stroke rate, rope G test series

Stroke, in/min	Sample length, ft	Modulus of elasticity, Mpsi	Break: Load, Kips	Break: Elonga-tion, in	Break: Stress, kip/in²	Break: Strain, pct in/in	Yield: Stress, kip/in²	Yield: Strain, pct in/in	Torque K, lbf-ft/kip
0.0625	15.08	12.16	137.93	4.40	218.70	2.43	189.60	1.67	9.53
	15.05	12.17	135.93	4.17	215.50	2.31	191.20	1.68	9.56
0.1250	15.10	12.20	137.96	4.32	218.70	2.38	191.90	1.68	9.33
	15.07	12.49	133.98	3.91	212.40	2.16	190.10	1.64	9.49
1.0000	15.07	12.56	136.98	4.02	217.00	2.22	192.80	1.64	9.36
	15.07	12.57	136.54	4.00	216.50	2.21	193.30	1.64	9.58
8.0000	15.08	12.83	139.38	4.13	221.00	2.28	195.20	1.63	9.59
16.0000	15.08	13.08	136.10	3.68	215.80	2.03	192.90	1.59	9.52
	15.06	13.19	137.37	3.72	217.80	2.06	194.30	1.58	9.51
Mean	NAp	12.58	136.91	4.04	217.04	2.23	192.37	1.64	9.50
SD	NAp	.38	1.53	.25	2.44	.13	1.85	.04	.09
SD . . . . . pct . .	NAp	3.05	6.09	1.12	1.12	6.05	0.96	2.19	0.97

NAp Not applicable. SD Standard deviation.

Table 12.–Test series on zinc-filled sockets, rope H

Sample length, ft	Modulus of elasticity, 10^6 psi	Break: Load, kips	Break: Elonga-tion, in	Break: Stress, kip/in²	Break: Strain, pct in/in	Yield: Stress, kip/in²	Yield: Strain, pct in/in	Torque K, lbf-ft/kip	Reel position, ft
5.08	8.59	210.20	3.60	237.00	5.90	186.80	2.27	16.42	NAp
10.11	10.90	207.80	5.83	234.20	4.80	183.30	1.81	16.52	NAp
20.12	11.30	208.10	11.92	234.60	4.94	184.90	1.80	16.55	NAp
20.15	11.89	205.70	10.50	231.90	4.34	182.60	1.66	16.50	NAp
30.21	12.07	206.40	17.81	232.60	4.91	182.50	1.64	16.73	NAp
Mean	10.95	207.64	NAp	234.06	4.98	184.02	1.84	16.54	NAp
SD	1.40	1.74	NAp	1.98	.57	1.83	.25	.11	NAp
SD . . pct . .	12.78	0.84	NAp	0.85	11.43	0.99	13.88	0.69	NAp

NAp Not applicable. SD Standard deviation.

Table 13.–Baseline tensile test summary

Rope series	Diam, in	Breaking load: Mean, kips	Breaking load: SD, kips	Breaking load: SD, pct	Modulus of elasticity: Mean, 10^6 psi	Modulus of elasticity: SD, 10^6 psi	Modulus of elasticity: SD, pct	Breaking stress: Mean, kip/in²	Breaking stress: SD, kip/in²	Breaking stress: SD, pct	Yield stress: Mean, kip/in²	Yield stress: SD, kip/in²	Yield stress: SD, pct	Torque K: Mean, lbf-ft kip	Torque K: SD, lbf-ft/kip	Torque K: SD, pct
A . .	1	91.14	0.89	0.97	9.42	0.44	4.72	225.74	2.19	0.97	185.86	2.78	1.50	8.20	0.24	2.91
B . .	1-1/2	208.64	1.31	.63	10.21	1.46	14.27	235.19	1.43	.61	184.44	1.77	.96	16.45	.13	.81
C . .	1-1.4	158.57	.87	.55	11.30	1.18	10.46	251.39	1.39	.55	211.52	2.17	1.03	14.14	.13	.81
D . .	3/4	52.09	.30	.57	11.37	.89	7.84	234.85	1.35	.58	190.21	2.99	1.57	8.25	.10	1.20
E . .	1-7/8	331.30	4.16	1.26	10.34	2.16	20.93	233.44	2.95	1.26	180.35	5.76	3.19	20.18	.50	2.46
F . .	2	346.85	2.53	.73	9.00	2.08	23.12	214.78	1.57	.73	163.58	3.07	1.88	14.19	.23	1.62
G . .	1-1/4	136.91	1.53	1.12	12.58	.38	3.05	217.04	2.44	1.12	192.37	1.85	.96	9.50	.09	.97
H . .	1-1/2	207.64	1.74	.84	10.95	1.40	12.78	234.06	1.98	.85	184.02	1.83	.99	16.54	.11	.69

SD Standard deviation.

CONSTRUCTION STRETCH

Wire rope stretches under load. This stretch comes from two sources, elastic and constructional. The elastic stretch is reversible, and the rope recovers to its original length when the load is removed. The construction stretch is not reversible. Construction stretch occurs in new rope and happens when a load is first applied. The wires and strands are first seated, then act in a constricting manner to compress the core permanently. Construction stretch is more pronounced in fiber-core ropes than in wire-rope-core or strand-core ropes.

When a tensile test is made on a rope, and the construction stretch has not been removed, it adds to the elongation on the rope during the initial loading. This will give an S-shaped stress-strain curve, with sometimes only a small central linear portion. An example is shown in figure 4*A*. All of the rope A series and part of the rope B series were run in this manner, resulting in S-shaped curves.

During the rope B series, it was decided to attempt to remove the construction stretch prior to the test. It was observed from examining the stress-strain curves that the linear portion began after the rope was loaded to about 20 pct of the breaking strength. Consequently, the ropes were loaded to 20 pct of the breaking strength and held for 10 min or until they stopped stretching. Then the load was removed, and the test was made under normal procedures. The results are shown in figure 4*B*.

This stress-strain plot does not have an S-curve and is linear from the beginning. For comparison, the curves from figures 4*A* and 4*B* are plotted together in figure 5. All subsequent tests were made following this procedure for removing construction stretch. None of the following tests showed the S curves.

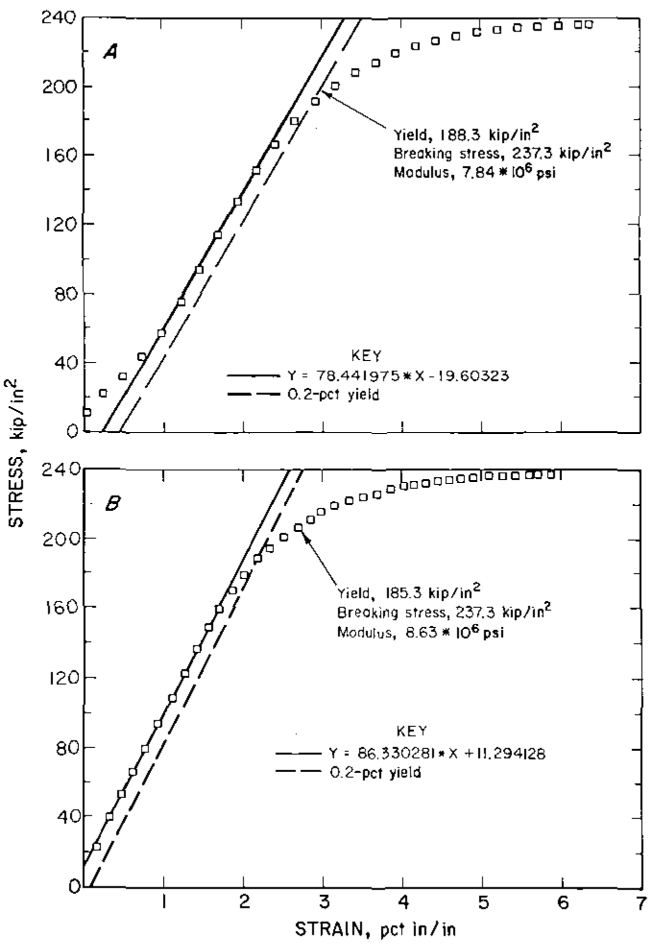

Figure 4.–Stress versus strain, rope B. ***A*, 4.813-ft sample; *B*, 4.818-ft sample.**

BREAKING LOAD VERSUS GAUGE LENGTH

Breaking load was plotted against gauge length to determine the effect of sample length on breaking load (fig. 6). The plots show a definite effect of length on breaking strength. The shorter samples have higher breaking strengths than the longer samples. There seems to be little effect on samples of 15 ft and longer. However, the 2-ft samples have much higher strength. Even the 5- and 10-ft samples show higher strength. This is true for the 3/4-in-diameter samples as well as the 2-in-diameter samples. The reason for this phenomenon is not known. However, it can be hypothesized that shorter ropes with rigidly attached sockets form a more rigid structure in the test machine, thus exhibiting higher "system strength."

BREAKING LOAD VERSUS REEL POSITION

The samples were cut from the reel in a random order to determine whether any variations in properties existed along the length of the rope. When the variables were plotted against reel position, there was no correlation shown between any factor and the position on the reel. The most important variable in this respect is the breaking strength. Figure 7 shows two plots of breaking strength against reel position, for ropes B and D. As can be seen, there is no correlation. The results are the same for the other samples.

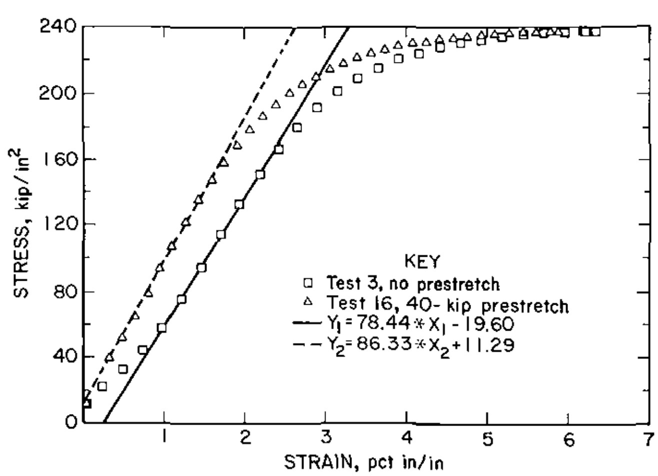

Figure 5.–Effect of prestretching on rope samples, rope B.

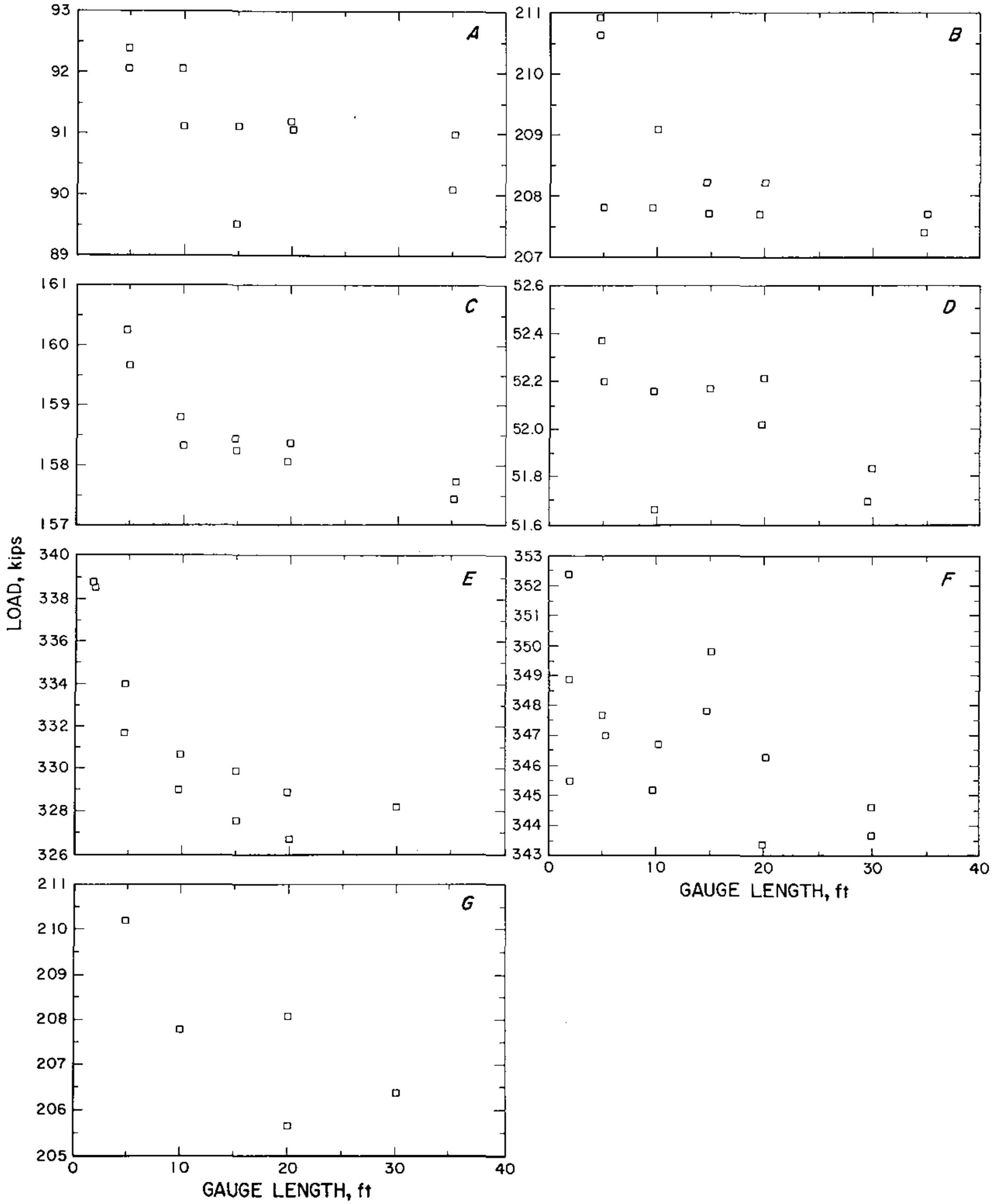

Figure 6.–Breaking load versus sample length. *A*, **Rope A;** *B*, **rope B;** *C*, **rope C;** *D*, **rope D;** *E*, **rope E; F, rope F;** *G*, **rope H.**

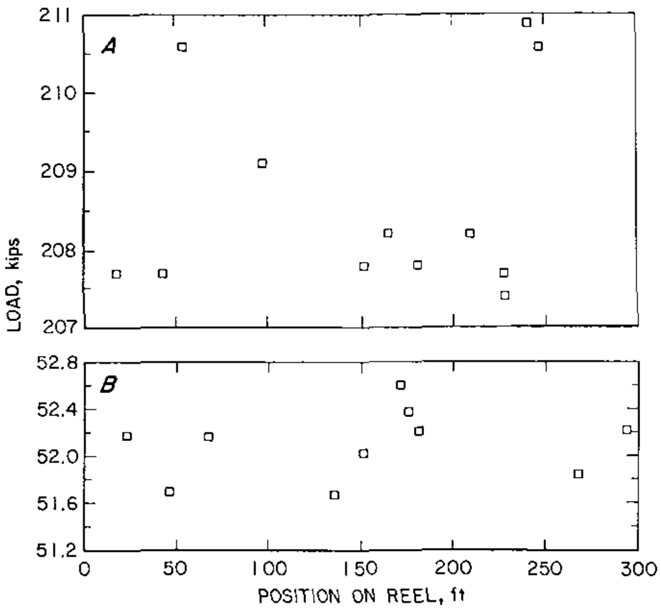

Figure 7.–Effect of sample position on reel. *A*, **Rope B;** *B*, **rope D.**

EFFECTS OF STROKE RATE ON RESULTS

The "Wire Rope Users Manual" states that for a strength test to be valid there must be a "gradually applied load that will not exceed a stroke rate of 1 in/min." All of the baseline tests to determine physical factors were run at a stroke rate of 1 in/min regardless of the size of the sample.

It was desired to see if strain rate had any effect on the results. At a stroke rate of 1 in/min, it is obvious that the strain rate of a 2-ft sample will be 15 times the strain rate of a 30-ft sample. For a 2-ft sample to have the same strain rate as a 30-ft sample at a stroke rate of 1 in/min, the stroke rate for the 2-ft sample would have to be 1/15 in/min. For a 30-ft sample to have the same strain rate as a 2-ft sample at a stroke rate of 1 in/min, the stroke rate for the 30-ft sample would have to be 15 in/min. To determine the effects of varying strain rates on the samples, a series of samples with zinc sockets were made up, all of 15 ft in length. The stroke rates tested were 0.0625, 0.125, 1, 8, and 16 in/min. These stroke rates cover the variations in strain rate discussed above. The results are shown in table 11 and in figure 8. Figure 8*A* shows that the breaking elongation is lessened as the stroke rate is increased. Figure 8*B* shows that the modulus of elasticity is increased slightly as the stroke rate is increased. This, of course, correlates with the decreased elongation as the stroke rate is increased. As can be seen in figure 8*C*, there is no effect on breaking strength from the variation in stroke rate over the ranges shown. The correlation coefficient for breaking strength versus stroke rate has the value of 0.279, which indicates no correlation for this relationship.

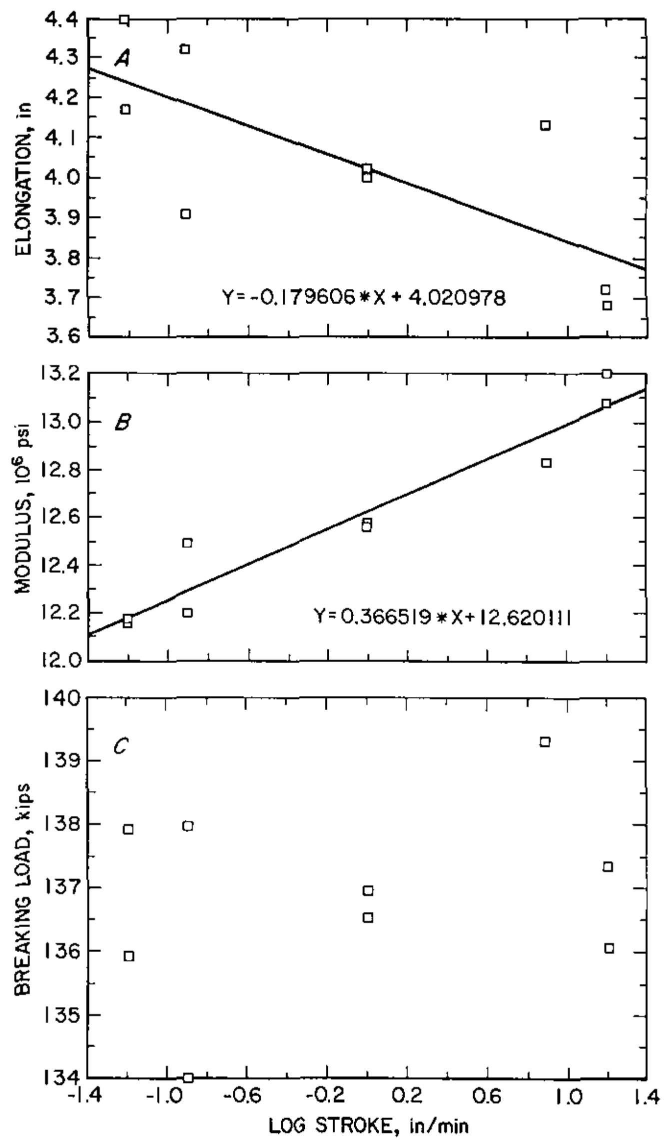

Figure 8.–Effect of log stroke rate, rope G. *A*, **Elongation;** *B*, **modulus;** *C*, **breaking load.**

EFFECT OF GAUGE LENGTH ON MODULUS OF ELASTICITY

When the data tables (tables 5-12) are examined, it becomes apparent that the columns involving strain measurements have high errors compared with the columns involving load or torque measurements. The modulus of elasticity, the breaking strain, and the yield strain all show these high errors. And yet, when samples of the same length are compared, the values are shown to be close to each other. Plots of modulus of elasticity, breaking strain, and yield strain against gauge length all show correlation, although not necessarily linear correlation. Figure 9 shows plots of modulus of elasticity versus gauge length for the various test ropes. These plots show

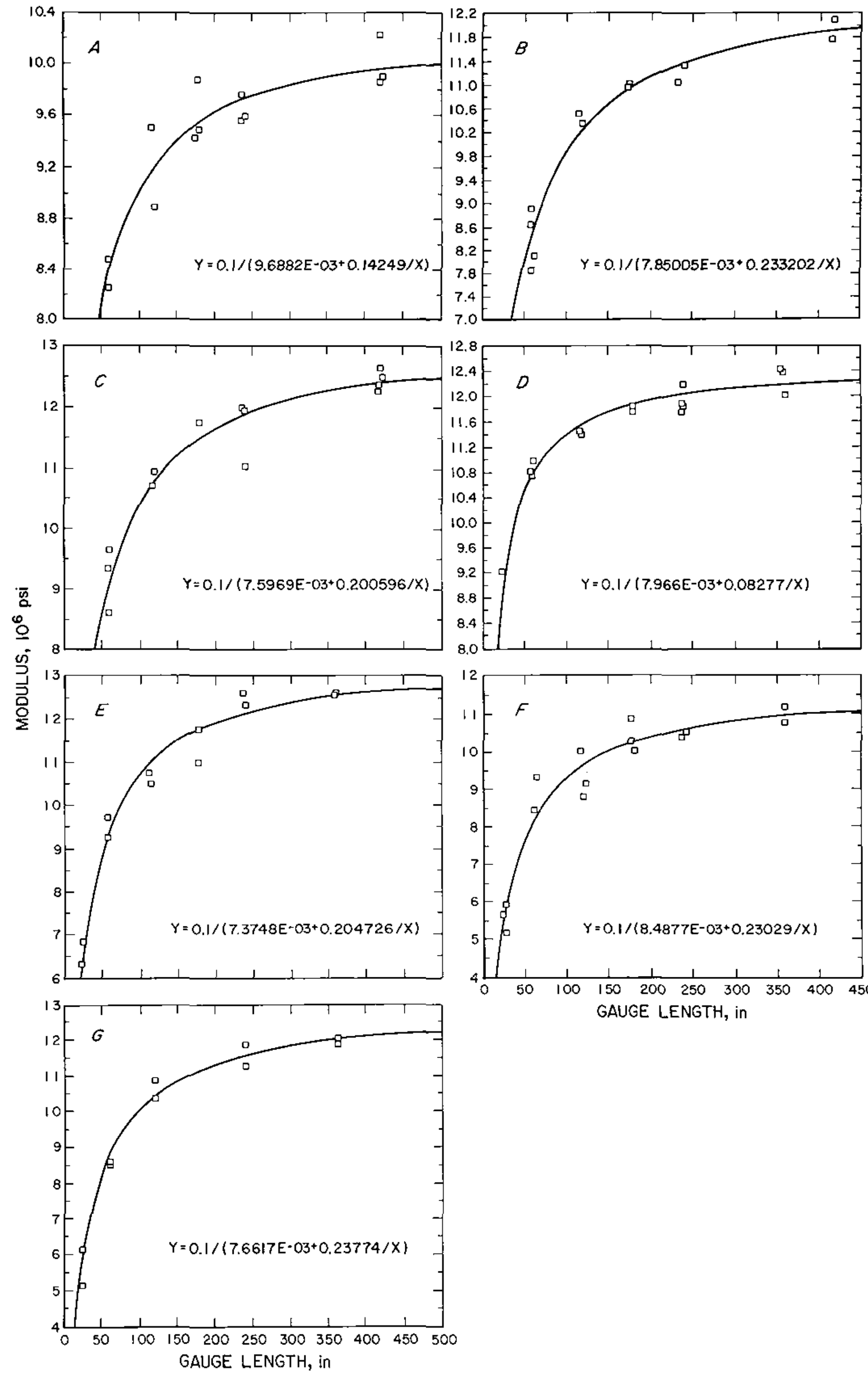

Figure 9.–Modulus versus gauge length for various ropes. *A*, **Rope A;** *B*, **rope B;** *C*, **rope C;** *D*, **rope D; E. rope E;** *F*, **rope F;** *G*, **rope H.**

that the modulus of elasticity is lowest for the 2-ft samples and highest for the 30- and 35-ft samples, initially increasing rapidly in value with gauge length, then leveling off at the higher gauge lengths.

The tensile machine does not measure gauge length directly. During the initial calibration of the machine, very precise measurements were made of the elongation and compression of the machine components over the full range of load capability. These components included the columns, heads, grips, pins, and sockets. The deflection data are contained in the data logging program. The program subtracts from the movement of the actuator the appropriate deflection at the sensed load for all of the involved components. The different grips and sockets for each rope size are included individually in the program. After pretest stretching, the load is removed, the gauge length is measured manually, and the actuator position is set to zero. Consequently, a very accurate and reproducible measurement is made of the change in distance between the socket ends during a run, which is nominally the gauge length for a solid sample. In the case of a socketed wire rope, the wire is not fastened rigidly to the socket end. The rope is broomed and cast with epoxy or zinc in the cone of the socket. Thus, the compressibility of the material in the socket becomes a variable.

If an assumption is made that the broomed end of the rope can stretch and move to some degree out of the socket, then an explanation can be made for the high errors of the elongation measurements. There is some physical justification for this assumption. Markers placed on the socket ends with a pointer on the rope showed some movement of the rope end out of the socket when a load was applied. The rope end moved back into the socket when the load was removed. Further, the epoxy resin has a very low modulus of compression. Zinc has a higher modulus of compression, but it is still much lower than that of the high-carbon steel of which the wires are made.

Consider the following. The broomed end in each socket moves out of the socket by an amount proportional to the load. Because the tensile machine measures the distance between the socket ends, it determines the sum of the lengths that each broom pulls out plus the elongation of the original length of rope measured between the sockets (the gauge length). The amounts that the broomed ends move out are independent of the gauge length of the sample. Consequently, the percentage error becomes less as the gauge length increases.

It is possible to calculate this error if elongation at a constant load is plotted against gauge length for different sample lengths. For a solid rod, elongation would be directly proportional to gauge length within the elastic range. For a wire rope, elongation should still be directly proportional to gauge length, but with an intercept on the y-axis (elongation). The intercept represents the error caused by the broom pullout. This error is directly proportional to load while within the elastic region of the stress-strain plot.

The values for elongation at a constant load cannot be taken directly from the data tables. If the *B* plots in figures 2 and 3 are examined, it can be seen that the slopes for the stress-strain curves do not go through the origin of the coordinates, because of the preload put on the sample and the subsequent zeroing of the stroke. This can be allowed for by taking the slope of each stress-strain plot and mathematically forcing it through the origin. The slope of the stress-strain curve is the modulus of elasticity and is given in column 2 of the data tables (tables 5-11).

Then,

$$\text{modulus} = \text{stress/strain}, \quad (1)$$

$$\text{strain} = \text{stress/modulus}, \quad (2)$$

$$\text{strain} = \text{elongation/gauge}, \quad (3)$$

and $$\text{elongation} = \text{strain} \times \text{gauge}. \quad (4)$$

Thus, it is possible to calculate elongation at a given strain, knowing the modulus of elasticity. These calculations are shown for a given stress of 100,000 psi in tables 14-20. The given stress of 100,000 psi is approximately at the midpoint of the elastic region of the stress-strain plot. As is demonstrated in the tables, strain is calculated from the modulus and the given stress using equation 2. Then, elongation is calculated from the strain and gauge using equation 4.

Table 14.–Effect of sample length on modulus and elongation at 100,000-psi stress for rope A

Sample length, ft	Modulus of elasticity, 10^6 psi: Actual	Calculated	Difference	Difference, squared	Strain, in/in	Elongation, in
4.90	8.26	8.257	-0.003	0.00001	0.01211	0.712
5.01	8.48	8.293	-.187	.0349	.01179	.709
10.00 ...	9.50	9.195	-.305	.0931	.01053	1.263
10.13 ...	8.89	9.208	.318	.1010	.01125	1.367
14.96 ...	9.43	9.540	.110	.0122	.01060	1.904
15.14 ...	9.89	9.549	-.341	.1164	.01011	1.837
15.21 ...	9.49	9.552	.062	.0039	.01054	1.923
20.00 ...	9.57	9.726	.156	.0243	.01045	2.508
20.03 ...	9.77	9.727	-.043	.0019	.01024	2.460
20.27 ...	9.59	9.733	.143	.0205	.01043	2.536
35.08 ...	10.22	9.973	-.247	.0608	.00978	4.119
35.21 ...	9.87	9.975	.105	.0109	.01013	4.281
35.32 ...	9.90	9.976	.076	.0057	.01010	4.281
Mean ..	9.45	NAp	NAp	NAp	NAp	NAp
SS	NAp	NAp	NAp	.4856	NAp	NAp
Variation	NAp	NAp	NAp	.0405	NAp	NAp
SD	.58	NAp	NAp	.2012	NAp	NAp
SD .. pct ..	6.09	NAp	NAp	2.1286	NAp	NAp

NAp Not applicable.
SD Standard deviation.
SS Sum of squares.

NOTE.–Modulus of elasticity = 0.1/(9.68819E-03 + 0.142489/X).

Table 15.–Effect of sample length on modulus and elongation at 100,000-psi stress for rope B

Sample length, ft	Modulus of elasticity, 10^6 psi: Actual	Calculated	Difference	Difference, squared	Strain, in/in	Elongation, in
4.81	7.84	8.410	0.570	0.3252	0.01276	0.736
4.82	8.90	8.416	-.484	.2341	.01124	.650
4.82	8.63	8.416	-.214	.0457	.01159	.670
5.06	8.11	8.554	.444	.1970	.01233	.749
9.64	10.51	10.136	-.374	.1400	.00951	1.101
10.02 . . .	10.35	10.215	-.135	.0182	.00966	1.162
14.64 . . .	10.95	10.896	-.054	.0029	.00913	1.604
14.71 . . .	11.00	10.904	-.096	.0093	.00909	1.605
19.60 . . .	11.04	11.310	.270	.0730	.00906	2.130
20.17 . . .	11.33	11.346	.016	.0003	.00883	2.136
34.88 . . .	11.76	11.895	.135	.0181	.00850	3.559
35.00 . . .	12.07	11.897	-.173	.0298	.00829	3.480
Mean . .	10.21	NAp	NAp	NAp	NAp	NAp
SS	NAp	NAp	NAp	1.0936	NAp	NAp
Variation	NAp	NAp	NAp	.0994	NAp	NAp
SD	1.46	NAp	NAp	.3153	NAp	NAp
SD . . pct . .	14.27	NAp	NAp	3.0889	NAp	NAp

NAp Not applicable.
SD Standard deviation.
SS Sum of squares.

NOTE.–Modulus of elasticity = 0.1/(9.68819E-03 + 0.142489/X).

Table 16.–Effect of sample length on modulus and elongation at 100,000-psi stress for rope C

Sample length, ft	Modulus of elasticity, 10^6 psi: Actual	Calculated	Difference	Difference, squared	Strain, in/in	Elongation, in
4.76	9.34	9.002	-0.338	0.1143	0.01071	0.612
4.84	8.61	9.049	.439	.1929	.01161	.675
4.98	9.65	9.129	-.521	.2710	.01036	.619
9.69	10.70	10.727	.027	.0007	.00935	1.087
9.98	10.94	10.785	-.155	.0239	.00914	1.095
14.98 . . .	11.74	11.477	-.263	.0690	.00852	1.531
19.80 . . .	11.97	11.847	-.123	.0152	.00835	1.985
19.94 . . .	11.02	11.855	.835	.6973	.00907	2.171
19.98 . . .	11.95	11.857	-.093	.0086	.00837	2.006
34.81 . . .	12.26	12.381	.121	.0146	.00816	3.407
34.83 . . .	12.25	12.381	.131	.0172	.00816	3.412
34.95 . . .	12.36	12.384	.024	.0006	.00809	3.393
35.07 . . .	12.64	12.386	-.254	.0645	.00791	3.329
35.36 . . .	12.49	12.392	-.098	.0096	.00801	3.397
35.39 . . .	12.48	12.393	-.087	.0076	.00801	3.403
Mean . .	11.36	NAp	NAp	NAp	NAp	NAp
SS	NAp	NAp	NAp	1.5069	NAp	NAp
Variation	NAp	NAp	NAp	.1076	NAp	NAp
SD	1.28	NAp	NAp	.3281	NAp	NAp
SD . . pct . .	11.27	NAp	NAp	2.8880	NAp	NAp

NAp Not applicable.
SD Standard deviation.
SS Sum of squares.

NOTE.–Modulus of elasticity = 0.1/(9.68819E-03 + 0.142489/X).

Table 17.–Effect of sample length on modulus and elongation at 100,000-psi stress for rope D

Sample length, ft	Modulus of elasticity, 10^6 psi: Actual	Calculated	Difference	Difference, squared	Strain, in/in	Elongation, in
1.88	9.22	8.595	-0.625	0.3910	0.01085	0.245
4.85	10.82	10.652	-.168	.0284	.00924	.538
4.86	10.82	10.655	-.165	.0272	.00924	.539
4.91	10.75	10.671	-.079	.0062	.00930	.548
5.09	10.98	10.728	-.252	.0634	.00911	.556
9.81	11.45	11.535	.085	.0073	.00873	1.028
9.93	11.41	11.546	.136	.0186	.00876	1.044
15.01 . . .	11.84	11.869	.029	.0008	.00845	1.521
15.02 . . .	11.77	11.869	.099	.0098	.00850	1.531
19.96 . . .	11.89	12.031	.141	.0200	.00841	2.014
20.00 . . .	11.77	12.032	.262	.0688	.00850	2.039
20.07 . . .	12.19	12.034	-.156	.0243	.00820	1.976
20.09 . . .	11.86	12.035	.175	.0305	.00843	2.033
29.88 . . .	12.43	12.200	-.230	.0530	.00805	2.885
29.93 . . .	12.40	12.200	-.200	.0399	.00806	2.896
30.16 . . .	12.02	12.203	.183	.0335	.00832	3.011
Mean . .	11.48	NAp	NAp	NAp	NAp	NAp
SS	NAp	NAp	NAp	.8226	NAp	NAp
Variation	NAp	NAp	NAp	.0548	NAp	NAp
SD	.81	NAp	NAp	.2342	NAp	NAp
SD . . pct . .	7.09	NAp	NAp	2.0406	NAp	NAp

NAp Not applicable.
SD Standard deviation.
SS Sum of squares.

NOTE.–Modulus of elasticity = 0.1/(9.68819E-03 + 0.142489/X).

Table 18.–Effect of sample length on modulus and elongation at 100,000-psi stress for rope E

Sample length, ft	Modulus of elasticity, 10^6 psi: Actual	Calculated	Difference	Difference, squared	Strain, in/in	Elongation, in
1.96	6.34	6.219	-0.121	0.0146	0.01577	0.371
2.00	6.83	6.287	-.543	.2945	.01464	.351
4.88	9.25	9.199	-.051	.0026	.01081	.633
4.91	9.72	9.217	-.503	.2529	.01029	.606
9.87	10.76	10.985	.225	.0506	.00929	1.101
9.93	10.49	10.998	.508	.2577	.00953	1.136
14.90 . . .	10.99	11.737	.747	.5586	.00910	1.627
14.97 . . .	11.77	11.745	-.025	.0006	.00850	1.526
19.82 . . .	12.62	12.142	-.478	.2281	.00792	1.885
20.01 . . .	12.34	12.155	-.185	.0344	.00810	1.946
29.85 . . .	12.57	12.584	.014	.0002	.00796	2.850
29.96 . . .	12.59	12.588	-.002	5E-06	.00794	2.856
Mean . .	10.52	NAp	NAp	NAp	NAp	NAp
SS	NAp	NAp	NAp	1.6948	NAp	NAp
Variation	NAp	NAp	NAp	.1541	NAp	NAp
SD	2.16	NAp	NAp	.3925	NAp	NAp
SD . . pct . .	20.54	NAp	NAp	3.7303	NAp	NAp

NAp Not applicable.
SD Standard deviation.
SS Sum of squares.

NOTE.–Modulus of elasticity = 0.1/(9.68819E-03 + 0.142489/X).

Table 19.–Effect of sample length on modulus and elongation at 100,000-psi stress for rope F

Sample length, ft	Modulus of elasticity, 10^6 psi: Actual	Calculated	Difference	Difference, squared	Strain, in/in	Elongation, in
1.94	5.66	5.441	-0.219	0.0481	0.01767	0.411
2.17	5.93	5.770	-.160	.0256	.01686	.439
2.18	5.17	5.783	.613	.3763	.01934	.506
5.20	8.46	8.211	-.249	.0618	.01182	.738
5.38	9.34	8.295	-1.045	.0910	.01071	.691
9.91	10.04	9.593	-.447	.1998	.00996	1.184
10.18 ...	8.81	9.641	.831	.6898	.01135	1.387
10.27 ...	9.15	9.656	.506	.2560	.01093	1.347
14.80 ...	10.89	10.220	-.670	.4484	.00918	1.631
14.92 ...	10.31	10.231	-.079	.0062	.00970	1.737
15.34 ...	10.03	10.268	.238	.0568	.00997	1.835
19.94 ...	10.41	10.582	.172	.0295	.00961	2.299
20.28 ...	10.52	12.600	.080	.0064	.00951	2.313
30.13 ...	10.81	12.959	.149	.0223	.00925	3.345
30.23 ...	11.21	12.962	-.248	.0616	.00892	3.236
Mean ..	9.12	NAp	NAp	NAp	NAp	NAp
SS	NAp	NAp	NAp	3.3796	NAp	NAp
Variation	NAp	NAp	NAp	.2414	NAp	NAp
SD	1.99	NAp	NAp	.4913	NAp	NAp
SD .. pct ..	21.82	NAp	NAp	5.3897	NAp	NAp

NAp Not applicable.
SD Standard deviation.
SS Sum of squares.

NOTE.–Modulus of elasticity = 0.1/(9.68819E-03 + 0.142489/X).

Table 20.–Effect of sample length on modulus and elongation at 100,000-psi stress for rope H

Sample length, ft	Modulus of elasticity, 10^6 psi: Actual	Calculated	Difference	Difference, squared	Strain, in/in	Elongation, in
2.06	6.12	5.787	-0.333	0.1106	0.01634	0.404
2.06	5.15	5.787	.637	.4062	.01942	.480
5.06	8.55	8.638	.088	.0077	.01170	.710
5.08	8.59	8.649	.059	.0035	.01164	.710
10.10 ...	10.38	10.391	.011	.0001	.00963	1.168
10.11 ...	10.90	10.394	-.506	.2564	.00917	1.113
20.12 ...	11.30	11.566	.266	.0705	.00885	2.137
20.15 ...	11.89	11.568	-.322	.1040	.00841	2.034
30.16 ...	11.90	12.021	.121	.0147	.00840	3.041
30.21 ...	12.07	12.023	-.047	.0022	.00829	3.003
Mean ..	9.69	NAp	NAp	NAp	NAp	NAp
SS	NAp	NAp	NAp	.9761	NAp	NAp
Variation	NAp	NAp	NAp	.1085	NAp	NAp
SD	2.49	NAp	NAp	.3293	NAp	NAp
SD .. pct ..	25.71	NAp	NAp	3.4004	NAp	NAp

NAp Not applicable.
SD Standard deviation.
SS Sum of squares.

NOTE.–Modulus of elasticity = 0.1/(9.68819E-03 + 0.142489/X).

Plots of elongation versus gauge for the test ropes are shown in figure 10. As predicted, elongation is a linear function of gauge length with an intercept off the origin. The intercept is the sum of the amounts of the pullout of each broomed end at a stress of 100,000 psi. In plot *A*, which shows a plot for the rope A series samples, the equation of the slope is given as

$$Y = 9.68819E\text{-}03 * X + 0.142489, \qquad (5)$$

where Y = elongation, in,

and X = gauge length, in.

If the elongation (Y) is divided by the gauge length (X), the strain (S) is calculated as per equation 3.

Equation 5 becomes

$$S = 9.68819E\text{-}03 + 0.142489/X, \qquad (6)$$

where S = strain, in/in.

If the stress is divided by the strain (S), the modulus of elasticity (Mod) is calculated as per equation 1. Equation 6 becomes

$$Mod = 100{,}000/(9.68819E\text{-}03 + 0.142489/X), \qquad (7)$$

where Mod = modulus of elasticity, psi.

If equation 7 is divided by 1,000,000, the modulus of elasticity is converted from pounds per square inch to million pounds per square inch. Equation 7 then becomes

$$Mod = 0.1/(9.68819E\text{-}03 + 0.142489/X). \qquad (8)$$

Plots of modulus of elasticity in million pounds per square inch versus gauge length in inches are given in figure 9 for all of the baseline test series. Also shown in the plots are the equations for the modulus of elasticity developed as in equation 8. The curves shown were not determined by curve fitting. These curves are derived from the elongation data for each series of tests and calculated as shown above in equations 5 through 8.

The linearity of the elongation-versus-gauge-length plots and the positive intercepts prove the hypothesis that there is a constant error in elongation measurement that is proportional to load and independent of gauge length. The fit of the data points to the calculated equations for modulus of elasticity on figure 9 is further proof of the hypothesis.

The modulus of elasticity for rope A can be calculated using equation 8 and the gauge length data shown in table 14. The calculated values can be compared with the experimental values. The standard deviation for regression of the experimental data about the calculated curve is shown at the bottom of column 5 of table 14. This is much lower than the standard deviation for the experimental data (column 2), without considering the effects of gauge length. The same is true for the other series (tables 15-20).

One way to determine strain accurately would be to mechanically mount an elongation measuring device such as the one developed by Versuchsgrube Tremonia (*3*). This procedure is generally undesirable because it would

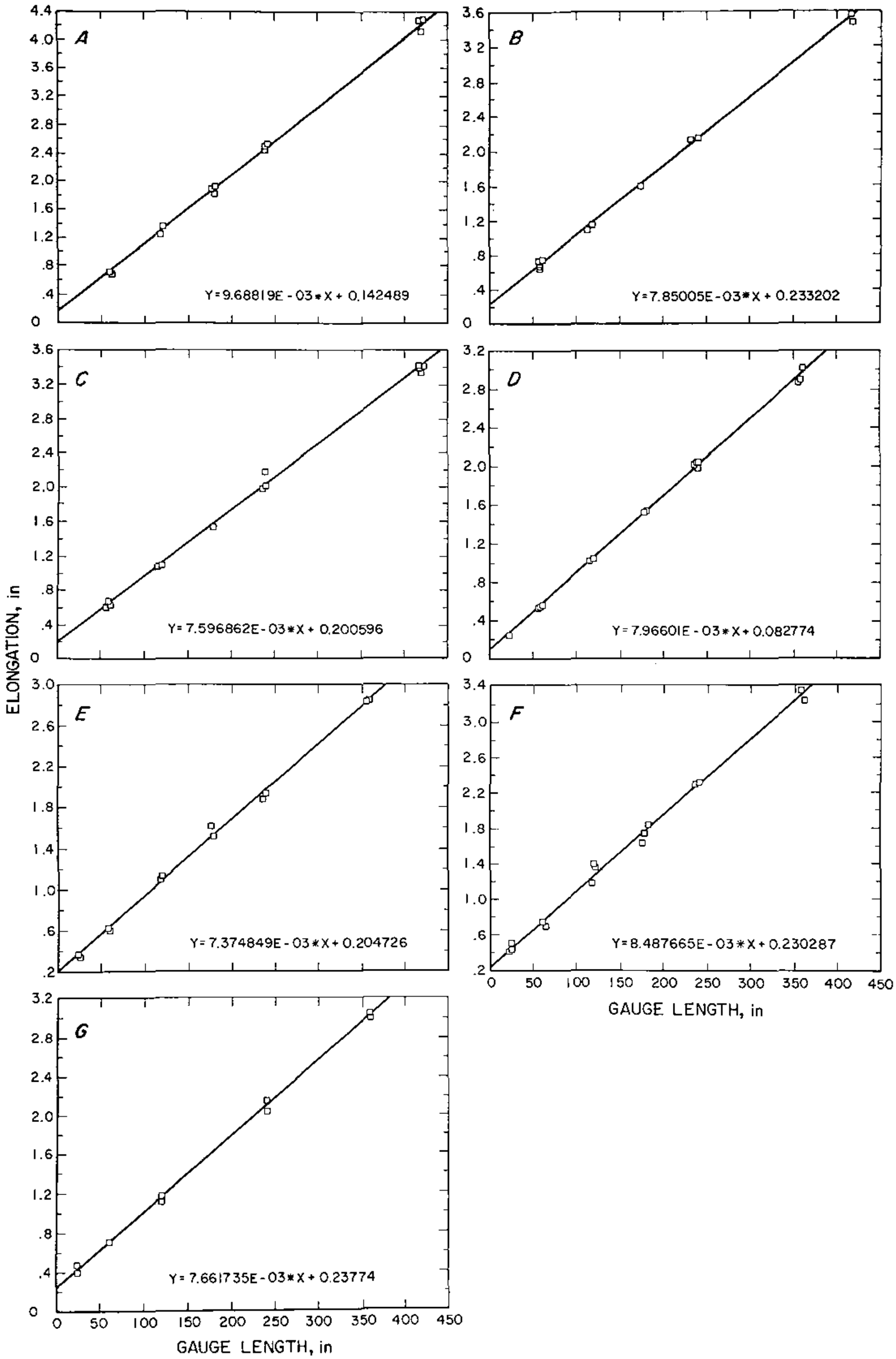

Figure 10.–Elongation versus gauge length at 100,000-psi stress for various ropes. ***A*****, Rope A;** ***B*****, rope B;** ***C*****, rope C;** ***D*****, rope D;** ***E*****, rope E;** ***F*****, rope F;** ***G*****, rope H.**

be necessary to stop the test before yield is reached, remove the load, open the protection boxes, dismount the device, close the boxes, then reload. All these steps would be time consuming and could affect the later test results. Other possibilities would be to develop a precise optical ranging system or a system with disposable components.

The elongation corrections at a stress of 100,000 psi are shown in table 21 for all of the rope series tested. Also shown in the table are the rope diameters, the rope cross-sectional metallic areas, and the loads on the ropes at 100,000 psi stress. In figure 11, the elongation correction in inches is plotted against the load in kips. The load in kips was calculated from the rope metallic area and the stress of 100,000 psi. The plot shows that the elongation correction is essentially constant for the ropes from 1-1/4- to 2-in diameter. Further, a straight line covers the ropes from 3/4- to 1-1/4-in diameter. However, considerably more work would have to be done before any real correlation could be proven. It appears likely that the elongation correction for each rope diameter and construction would have to be done by testing. The elongation correction factor could then be placed in the computer program, and the effects of varying gauge length would be eliminated.

Table 21.–Elongation correction versus rope diameter at 100,000-psi stress

Diam, in	Area, in^2	Load, kips	Correction, in	Sample
3/4	0.222	22.2	0.083	D
1	.404	40.4	.143	A
1-1/4 ...	.631	63.1	.201	C
1-1/2 ...	.887	88.7	.233	B
1-1/2 ...	.887	88.7	.238	H
1-7/8 ...	1.419	141.9	.205	E
2	1.615	161.5	.230	F

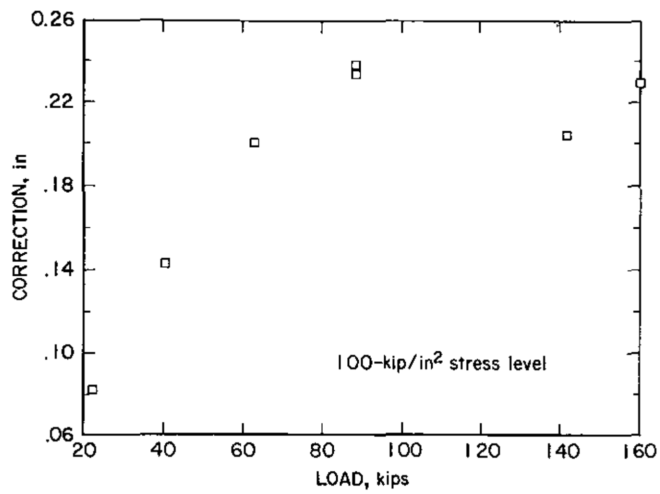

Figure 11.–Elongation correction for stretch of socket filler versus load.

COMPARISON OF ZINC AND EPOXY SOCKETING

The modulus of elasticity for epoxy is approximately 500,000 psi, while that for zinc is about 12,000,000 psi. The question was whether zinc-socketed ropes would behave differently than epoxy-resin-socketed ropes. It must be remembered that the material in the socket is not epoxy or zinc alone but a composite of high-carbon steel wires plus a zinc or an epoxy filler.

A set of 10 ropes was made with zinc-socketed ends. The lengths were 2, 5, 10, 20, and 30 ft, with two samples each. The rope used for the tests was the same 1-1/2-in-diameter rope that was used for the rope B series so that the results could be compared directly. The data for the zinc series are shown in table 12. These data can be compared with the rope B series shown in table 6. The results are remarkably similar. The breaking strength versus gauge length is shown in figure 12. The plot shows no

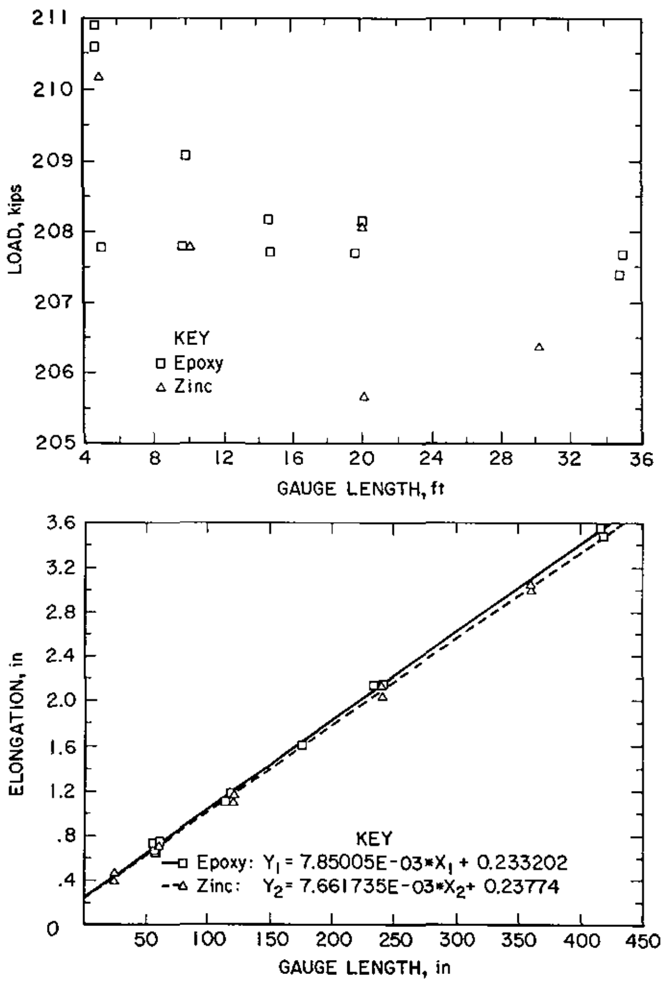

Figure 12.–Breaking strength and elongation versus gauge length for epoxy and zinc terminations.

significant difference between the zinc and epoxy terminations. This is verified by the means and standard deviations in tables 6 and 12. A plot of elongation versus gauge length for both series is also shown in figure 12. Neither the correction factors nor the slopes in the plots of elongation versus gauge length are statistically different. Finally, plots of modulus versus gauge length for both zinc and epoxy resin are shown in figure 13. Again, the data points and the independently determined equations for the modulus as a function of gauge length are very close to each other. The conclusion is that there is no significant difference in the behavior of the zinc and the epoxy resin socketed ropes for breaking strength tests. Both the zinc sockets and the epoxy resin sockets developed 100 pct of the normal breaking strength of the ropes. During the testing for all of the rope series, the resin-socketed terminations developed 100 pct of the normal breaking strength of the ropes.

The U.S. Code of Federal Regulations (*1*) states that for wire rope load end attachments

> (a) Wire rope shall be attached to the load by a method that develops at least 80 pct of the nominal strength of the rope.
>
> (b) Except for terminations where use of other materials is a design feature, zinc (spelter) shall be used for socketing wire ropes.

The wording in the regulations is identical for metal and nonmetal open pit mines; sand, gravel, and crushed stone operations; metal and nonmetal underground mines; underground coal mines; surface coal mines; and surface work areas of underground coal mines.

In Great Britain, the Safety in Mines Research Establishment, after extensive testing, found that resin

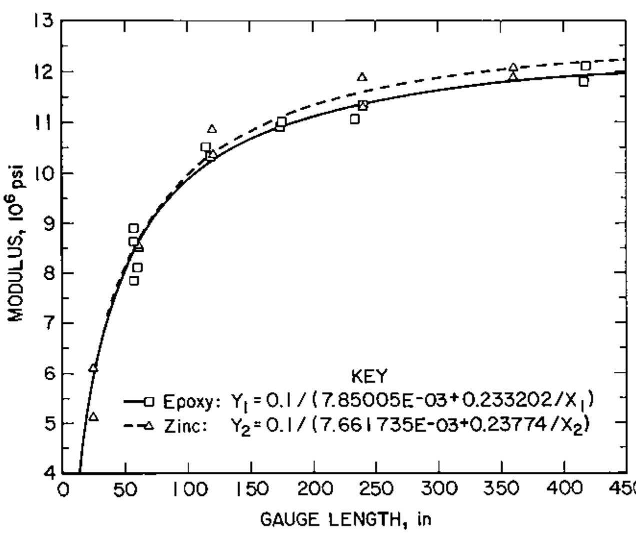

Figure 13.–Modulus versus gauge length for epoxy and zinc terminations.

sockets were as strong as the rope and has accepted them for use in mining (*4*). The findings in this report agree, which suggests that the CFR could be amended to allow the use of resin for the socketing of mine ropes.

TORQUE CALCULATIONS

The torque on the rope is measured directly by the tensile machine sensor as a function of time and is reported in kip-inches. This value is changed to pound (force) feet and reported in the data tables. Examples are shown in tables 2 and 3. Plots of torque in pound (force) feet versus load in kips are shown in plot C of figures 2 and 3. The plots show the data to be linear well into the plastic region of the rope. The slope of the plot is called the Torque K, and has the units pound (force) feet per kip. If the Torque K is known for a rope, it is possible to calculate the torque on the rope for virtually any load. The Torque K's for all of the rope series are shown in tables 5 through 12. A summary of the mean values and the standard deviations is shown in table 13.

A general equation for determining the approximate torque in ropes under load was developed by Gibson (*5*). This equation was developed for six-strand ropes with fiber cores. He found that the torque was directly proportional to the load and the square of the rope diameter and indirectly proportional to the lay length. His equation is given as

$$T = A(D^2)S/L, \tag{9}$$

where T = torque, lbf-in,

D = rope diameter, in,

S = load, lb,

L = lay length, in,

and A = 0.91 for Lang lay and 0.55 for regular lay ropes.

The constant A used by Gibson in equation 9 can be calculated from the experimental data in table 12, using the following equation:

$$A = 12KL/1{,}000D^2, \tag{10}$$

where K = Torque K, lbf-ft/kip.

The results of the calculations of the constant A are shown in table 22. Two additional ropes are shown in this table, Y and R, which refer to used mine hoist ropes. They were added for comparison purposes. The values for Gibson's constant A indicate that Gibson's approximations are very close to the experimental data as determined on the tensile machine.

Table 22.–Calculation of Gibson's torque constant

Diam, in	Rope[1]	Lay, in	Torque K, lbf-ft/kip	Gibson constant
Right Lang lay:				
3/4	D	5.25	8.25	0.915
1-1/4	C	8.00	14.14	.869
1-1/2	B	10.00	16.45	.877
	H	10.00	16.54	.882
1-7/8	E	12.75	20.18	.878
	Y[2]	14.50	17.43	.863
	R[3]	12.00	19.35	.793
Right regular lay:				
1	A	6.00	8.20	.590
1-1/4	G	8.07	9.50	.589
2	F	13.13	14.19	.559

[1]See table 2 for description.
[2]Mine hoist rope, 6 × 27 flattened strand.
[3]Mine hoist rope, 6 × 30 flattened strand.

SUMMARY

The operating characteristics of the tensile machine have been learned using a variety of rope samples. The machine has been determined to have high precision in the measurements of load, stroke, and torque.

All of the rope samples tested were shown to have uniform properties along the length of the reel. The stroke rate had no effect on either the breaking strength of the ropes or on the torque developed as the load increased. However, there was slight lessening of the breaking elongation at the higher stroke rates. There was no difference in the properties of the ropes when either zinc or epoxy resin was used as socketing material. The elongation of the ropes calculated from the stroke measurements was shown to vary with the length of the samples. This variation was caused by an unaccounted-for extrusion of the socketing material. This extrusion can be corrected in the computer program, but a series of tests would have to be run to determine the additional correction factor for each rope size and construction.

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16. Abstract (Limit: 200 words)

The U.S. Bureau of Mines has established a wire rope research laboratory to examine the factors that affect the life of wire rope. Ropes of sizes ranging from 3/4 to 2 in. in diameter and from 2 to 35 ft in length were tested to determine their breaking strength, elongation, and torque. This was done to characterize the test equipment on ropes used in mine hoisting systems.

17. Document Analysis a. Descriptors

Wire Rope
Tensile test

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement

Unlimited release

19. Security Class (This Report) unclassified

20. Security Class (This Page) unclassified

21. No. of Pages 23

22. Price

(See ANSI-Z39.18) See Instructions on Reverse

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