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INSPECTION AND TENSILE TESTS OF SOME WORN WIRE ROPES

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ABSTRACT

In cooperation with the Special Research Committee on Wire Rope of the American Society of Mechanical Engineers, the National Bureau of Standards tested 229 specimens taken from 79 worn wire ropes.

The condition and strength of each sample were determined. The strength was estimated using charts prepared by the Roebling Co. It was found that the estimated strength and the actual strength were nearly the same. These data indicate that the strength of worn ropes may be determined with sufficient accuracy for deciding when the rope should be replaced by measuring the length of wear on the outside wires and counting the number of broken wires.

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I. INTRODUCTION

The problem of determining when a wire rope which has been worn or damaged in service should be replaced by a new rope has received an increasing amount of study during recent years. In the past, no data were available by which an inspector could determine from the surface condition the probable strength and the safety of the rope. Consequently, some inspectors condemned a worn rope either when its actual strength was nearly equal to that of a new rope or, a more dangerous but much less frequent practice, allowed a rope to be used after its strength had become so much reduced that it was unsafe.

To study this problem, the American Society of Mechanical Engineers appointed a Special Research Committee on Wire Rope, W. H. Fulweiler, chairman. This committee asked the users of wire ropes to furnish worn specimens for inspection and tensile tests, and also requested information concerning the service to which the ropes had been subjected so that data might be collected which would serve as a guide to inspectors in determining when a worn wire rope should be replaced. The committee decided to have the inspection and tests made at the National Bureau of Standards under the Bureau research associate plan, directed by H. L. Whittemore, chief of the Engineering Mechanics Section, and A. H. Stang, senior engineer. A program outlining the test procedure was approved by the committee. The results of these tests are given in this report.

In the meantime, John A. Roebling's Sons Co., Trenton, N. J., had published in their magazine, Wire Engineering, articles on the strength of worn ropes. Charts were given from which the strength of a worn wire rope can be estimated if the number of broken wires and the amount of wear on the wires are known. The charts were based on the results of inspection and tests of a large number of worn wire ropes. A. J. Morgan, chief engineer, wire rope division of this company, discussed the proposed program with members of the Bureau staff and made many helpful suggestions which were of great assistance in carrying out the committee's program. Through Mr. Morgan, his company kindly permitted these articles and charts to be used in preparing this report.

II. PRELIMINARY TENSILE TESTS OF NEW WIRE ROPES

The use of zinc sockets for holding wire ropes during tensile tests is now established as a satisfactory method, but the preparation of the samples and the casting of the sockets is an expensive and time-consuming process. A method of holding wire ropes in grips has been developed which is less expensive than the socket method. With the grips no preparation of the wire rope before test is necessary except the removal of the lubricant from the outer surface at the ends of the rope. The seizings at the ends of the specimen come outside the grips.

Before proceeding with the tensile tests of the worn wire ropes it was considered desirable to make tensile tests of new wire ropes when holding the ends by these two methods to determine whether the less expensive method—grips—would be satisfactory for testing the worn ropes.

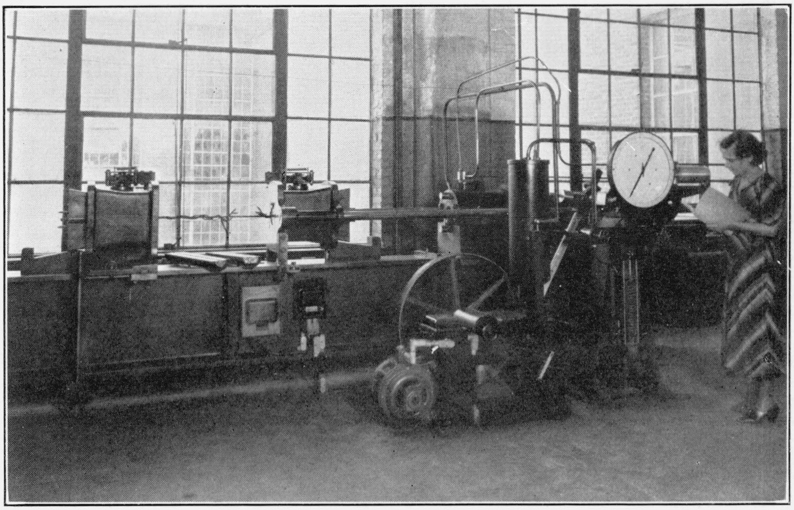

FIGURE 1.—*Horizontal pendulum testing machine, having a capacity of 100,000 pounds, in which the new wire ropes were tested.*

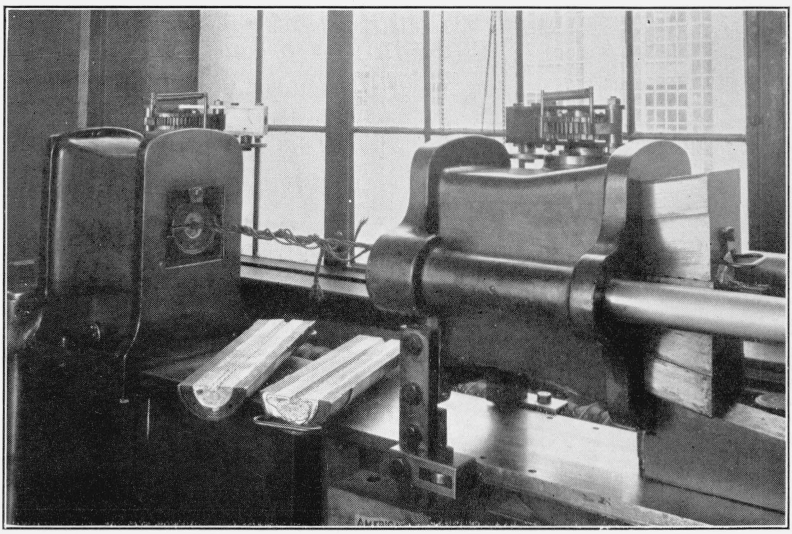

FIGURE 2.—*Grips of the testing machine.*

Two grips lined with cast zinc are shown on the bed of the machine and a wire rope after rupture in other grips in the heads of the machine. As the tensile load on the rope increases, the wedges in the heads move inward, increasing the compressive forces on the ends of the rope. The outside wires of the rope are imbedded in the zinc lining.

One hundred and thirty foot lengths of both ⅝ and 1-inch diameter new wire ropes were donated for this purpose by the American Steel and Wire Co., and by the John A. Roebling's Sons Co. The ropes were of 6 by 19 construction, high-grade plow steel.

Ten specimens to be held by grips and ten specimens to have zinc sockets cast on the ends were cut alternately from the 130 foot length of each size of rope. The specimens to be tested in grips were 8 feet long, and those with sockets 5 feet long. The free length of each specimen (that is, the distance between the inner ends of the sockets or grips) was 4 feet. The specimens were numbered consecutively along the length of the ropes, those tested in grips having odd numbers and those with sockets, even numbers.

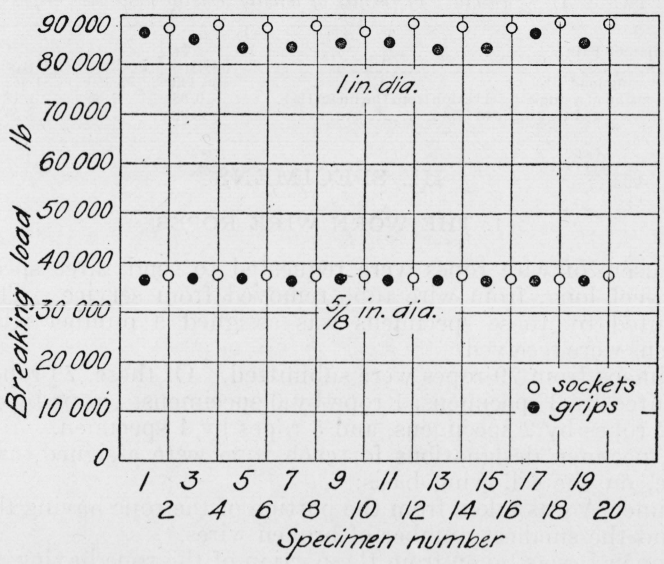

FIGURE 3.—*Tensile strength of new wire ropes held in grips and in sockets.*

The preparation of the specimens having sockets was carried out as described in Federal Specification RR–R–571 for wire rope, except that hot gasoline instead of muriatic acid was used for the final cleaning of the wires. The sockets were 6 inches long, 1⅞ inches in diameter at the small end of the cone, and 4⅛ inches in diameter at the large end.

All specimens of new wire rope were tested in a horizontal pendulum hydraulic machine having a capacity of 100,000 lb. This machine is shown in figure 1, and the grips are shown in figure 2. The grips were 19.25 inches long. They were lined with cast zinc and a 90-degree V-groove was machined in the zinc. The size of this groove depended upon the diameter of the rope to be tested. The compressive force on the grips caused by the tensile load on the rope during a test embedded the outside wires in the zinc. The same zinc linings were used for many tests of rope of the same size. The results of the tensile tests of these ropes are given in figure 3, and a summary of the results is given in table 1.

In order to expedite the work and reduce the cost, the committee approved the use of grips for the tensile tests of worn wire ropes having diameters not exceeding 1 inch because the differences between the results for grips and for sockets were negligible compared with the expected differences in the strengths of the worn ropes. Worn ropes having diameters exceeding 1 inch were socketed with zinc because the strength might exceed 100,000 lb, which is the capacity of the pendulum machine, and because the tests of new ropes indicated that the difference in percent between the results with grips and with sockets increased with size, being approximately proportional to the diameter.

TABLE 1.—*Summary of results of tensile tests of new wire ropes*

Wire rope diameter (in.)	5/8	5/8	1	1
Rope held in	Grips	Sockets	Grips	Sockets
Average breaking load (lb)	36,440	37,180	84,450	87,790
Average deviation of a single observation from the mean (%)	0.58	0.55	1.12	0.45
Difference in average breaking load (%)	−1.99	----------	−3.53	----------

III. SPECIMENS

1. THE WORN WIRE ROPES

The users of wire ropes were requested to send three specimens, each 8 feet long, from wire rope removed from service. The rope represented by these specimens was assigned a number when the specimens were received.

Specimens from 79 ropes were submitted. Of these, 70 ropes were represented by 3 specimens, 1 rope by 6 specimens, 1 rope by 4 specimens, 2 ropes by 2 specimens, and 5 ropes by 1 specimen.

The specimen designations for each rope were assigned, as far as possible, on the following basis:

Specimen A was taken from the portion of the rope having the least wear and the smallest number of broken wires.

Specimen B was taken from the portion of the rope having average wear and an average number of broken wires.

Specimen C was taken from the portion of the rope having the greatest wear and the greatest number of broken wires.

A portion of each of these specimens from rope 20 is shown in figure 4.

Specimens A for 59 of the ropes had no visible broken wires or measurable wear. Either broken wires or wear or both were present on all the specimens from the other 20 ropes. The total number of specimens tested was 229.

2. CONSTRUCTION

The ropes represented 16 types of construction. For convenience, the types of construction have been given the numbers shown in table 2.

The number of worn wire ropes of each construction is given in table 3.

3. DATA FROM SERVICE-DATA SHEETS

The data from the service-data sheets which accompanied the specimens have been tabulated in table 4.

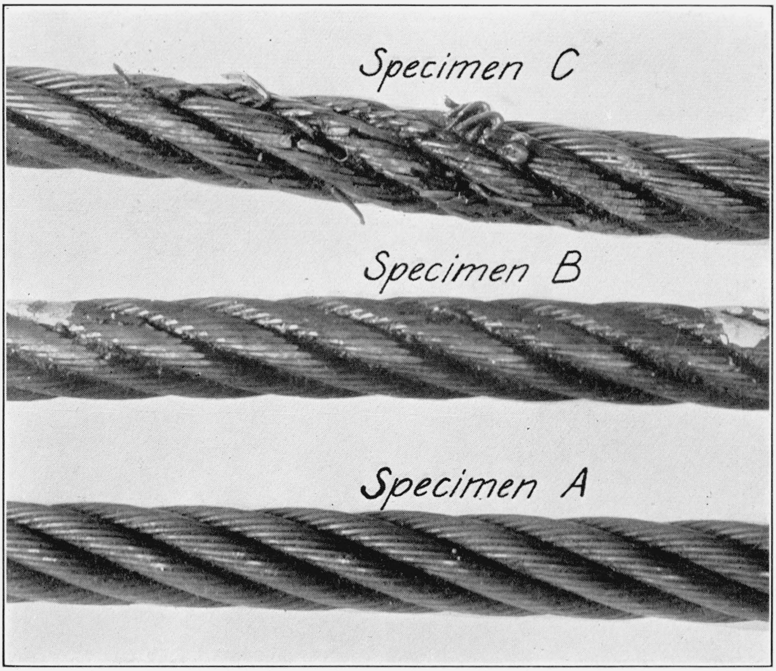

FIGURE 4.—*Specimens from rope 20.*

Specimen A.—Least wear and smallest number of broken wires.
Specimen B.—Average wear and average number of broken wires.
Specimen C.—Greatest wear and greatest number of broken wires.

TABLE 2.—*Wire-rope constructions*

Construction	See figure—	Number of strands and wires per strand	Trade name	Arrangement of wires: Center wires	Inside wires: S[1]	Inside wires: L[1]	Filler wires	Outside wires: S[1]	Outside wires: L[1]	Type of core
1	12, 18	6 by 7	Coarse laid rope	1					6	Fiber.
2	13, 19	6 by 19	Seale	1		9			9	Do.
3	15, 21	6 by 19	Roebling Special Seale	1		5	5		10	Do.
4	16, 22	6 by 19	Modified Seale	1		6	6		12	Do.
5	17	6 by 19	Warrington	1		6		6	6	Do.
6		6 by 37	Patented	1	9	9		9	9	Do.
7		8 by 19	Seale	1		9			9	Do.
8		8 by 19	Warrington	1		6		6	6	Do.
9		8 by 19	Modified Seale	1		6	6		12	Do.
10		7 by 7	Metallic center	1					6	7-wire strand.
11		6 by 19		1		6			12	Fiber.
12		6 by 37	(1+6+12+18). All wires in the outside layer had the same diameter. The next layer had large and small wires laid alternately. No filler wires. Fiber core.							
13		6 by 37	Construction 6, with independent wire-rope core of construction 5, regular lay.							
14		6 by 52	(1+6+9+18+18). All wires in the outside layer had the same diameter. The next layer had large and small wires laid alternately. No filler wires. Independent wire-rope core, construction 2, Lang lay.							
15		6 by 27	(1+6+10+10). All wires of each layer had the same diameter. No filler wires. Fiber core.							
16			Construction 3, with independent wire-rope core of construction 10.							
17		6 by 37	Construction 6, with independent wire-rope core of construction 2, regular lay.							
18	14, 20	6 by 16	Special Seale (1+4+8). Four filler wires. Fiber core.							

[1] S=Small wires, L=Large wires.

TABLE 3.—*Number of worn wire ropes of each construction*

Construction (see table 2)	Rope diameter, inches: 1/4	7/16	1/2	9/16	5/8	3/4	1	1 1/4	1 3/8	1 1/2	1 3/4	1 7/8	2 1/4	3 1/4
1							3							
2			4		48			3						
3			21					1	6		3			
4			3		9	3				3	6	3		
5		6	17	3	30			3						
6					6									
7			6											
8			3											
9									3					
11	3		6		3	3								
12						3								
13														7
14														3
15					2									
16											3			
17													3	

TABLE 4.—*Summary of service data sheets*

Rope	Nominal rope diameter	Construction	Lay	Material	Manufacturer [1]	Type of equipment	Loading	Service life		Mileage	Height of rise	Sheave diameter	Number of bends	Number of reverse bends
	in.						lb	Years	Months		ft	in.		
1	5/8	2	Regular	Traction steel	R	Elevator	[2] 6,000	7	2	53,340	250	36	3	0
2	1/2	5	do	Plow steel	R	Coal scraper	2,000	1	9	19,000	---	12	1	0
3	5/8	6	do	do	R	Crane	5,000	1	2	---	25	12	2	1
4	1/4	11	do		---	Hoist	500	---	---	---	---	---	---	---
5	5/8	5	do	Traction steel	H	Pass. elevator	1,000	3	0	15,890	165	36 & 34	4	0
6	5/8	2	do	do	R	do	---	1	9	16,000	535	36	3	0
7	5/8	6	do	Plow steel	---	Crane	17,000	0	9	---	8+	18	2	2
8	5/8	2	do	Steel	R	Pass. elevator	3,000	7	---	74,000	250	32	2	0
9	3/4	12	do	High grade plow steel	---	Crane fall	---	5	5	---	30	18	1	3
10	1/2	7	do	Iron	M	Pass. elevator	---	4	4	20,000	270	17	2	0
11	1 1/4	2	Lang	Plow steel	R	Mine hoist	22,000	---	---	19,471	1,400	84	1	1
12	1 3/4	4	Lang left	Steel	R	do	36,726	0	6	16,255	1,086	144	2	0
13–1	1 3/4	3	Regular	Plow steel	A	Mine incline	38,000	0	7	---	1,269	144,	2	1
13–2	1 3/4	16	do	do	A	do	38,000	0	5	---	1,269	144	2	1
14	1/2	11	do	Iron	A	Freight elevator	3,000	4	0	1,659	75	30	1	0
15	3/4	4	do	do	A	Pass. elevator	1,500	3	3	---	93	36	1	0
16	1/2	7	do	Traction steel	---	do	---	3	1	700	39	22	2	0
17	1/2	5	do	Iron	R	do	---	6	4	14,000	113	16	2	0
18	9/16	5	do	Steel	M	do	---	1	1	---	120	30	5	2
19	5/8	5	do	do	R	do	---	8	5	289,308	120	48	4	0
20	5/8	11	do	Mild steel	R	do	2,000	3	9	2,728	45	28	3	1
21	5/8	2	do	Steel	R	Elevator	1,800	3	6	35,000	380	38	4	0
22	5/8	5	do	do	---	do	1,000	7	0	2,500	70	42	3	0
23	5/8	5	do	Iron	R	Pass. elevator	3,000	1	6	---	---	30	7	0
24	1 7/8	4	do	do	L	Mine hoist	56,000	1	7	11,321	700	120	2	0
25	7/16	5	do	do	R	Governor cable	100	2	2	14,093	308	18	4	0
26	1/2	8	do	do	R	Compensating cable	180	3	2	23,769	321	27	2	0
27	7/16	5	do	do	R	Governor cable	100	6	0	27,639	239	18	4	0
28	1/2	3	do	Traction steel	R	Pass. elevator	---	7	0	---	32	30	3	1
29	1 3/8	9	do	Improved plow	C	---	---	---	---	---	---	27	2	1
30	1 1/4	5	do	Steel	L	Slope hoist	---	2	0	14,000	563	48	2	0

31	1	1	Lang	do	R	do		2	10	30,000	393	36	6	0
32	⅝	5	Regular	Mild steel	R	Pass. elevator	2,500	7	0	45,675	276	30	3	0
33	½	2	do	Steel	R	do	1,200	3	0		125	24	1	0
34	⅝	5	do	Iron	R	do	1,200	1	8		115	26	2	2
35	1⅜	3	Lang	Steel	R	Mine hoist	21,000	2	10			120	1	0
36	1⅜	3	do	do	R	do	21,000	2	10			120	1	0
37	⅝	2	Regular	do	R	Pass. elevator	1,200	6	4	51,894	500	36	3	0
38	⅝	2	do	Cast steel	R	Elevator	1,000	4	0			30	3	1
39	⅝	2	do	Traction steel	R	Freight elevator	2,500	12	0	5,000	50	30	1	0
40	⅝	2	do	Steel	R	Pass. elevator		2	6			34	1	0
41	⅝	2	do	do	R	Freight elevator	[2] 8,000	4	7		15	30	1	0
42	⅝	5	do	Iron		do	1,000	18	0	2,000	20	42	3	0
43	1½	4	Lang	Steel	A	Mine hoist	24,000	1	8		2,500	120	1	0
44	⅝	2	Regular	Traction steel	C	Pass. elevator		5	9			36	2	0
45	⅝	2	do	Steel		do	500	4	2		150	36	1	0
46	⅝	2	do	do		do	500	4	2		150	36	1	0
47	⅝	5	do	Traction steel		do	2,000	4	2		57	30	1	0
48	⅝	4	do	Iron		do		3	0		91	36	1	0
							yd/hr	working hr						
49	3¼	13	do	Plow steel	R	Dipper dredge (main hoist)	500	405-884			100	97	3	1
50	3¼	14	do	do	A	do	500	311			100	97	3	1
51	3¼	13	do	do	R	do	500	728			100	97	3	1
52	2¼	17	do	do	C	do	500	291			100	97	3	1
							lb	Years	Months					
53	½	2	do	Steel	R	Elevator	1,000				50	24	2	0
54	½	3	do	do		Pass. elevator	500	1	6	1,400	85	24	4	3
55	⅝	4	do	do	B	Freight elevator	1,000	11	8		45	26	3	0
56	⅝	4	do	do	B	do	1,000	11	8		45	26	3	0
57	⅝	5	do	do	A	Pass. elevator	1,200	5			60	30	2	0
58	½	5	do	Iron	H	do	148	0	10	730	275	16	1	0
59-1	½	3	do	Traction steel		do	2,500	2	6	11,668	75	26		
59-2	½	3	do	do		do	2,500	2	6	11,668	75	26		
59-3	½	3	do	do		do	2,500	2	6	11,668	75	26		
59-4	½	3	do	do		do	2,500	2	6	11,668	75	26		

See footnotes at end of table.

TABLE 4.—*Summary of service data sheets*—Continued

Rope	Nominal rope diameter	Construction	Lay	Material	Manufacturer[1]	Type of equipment	Loading	Service life		Mileage	Height of rise	Sheave diameter	Number of bends	Number of reverse bends
	in.						lb	*Years*	*Months*		ft	in.		
59–5	½	3	Regular	Traction steel		Pass. elevator	2, 500	2	6	11, 668	75	26		
60	½	5	do	Iron	C	Governor cable		2	8		(3)	16	2	0
61	½	5	do	do	C	do		2	8		(3)	16	2	0
62	⅝	5	do			Freight elevator	1, 000				60	26	3	0
63	½	4	do	Steel	H	Pass. and freight	1, 000	0	10	5, 305	300	24	2	0
64	⅝	15	do	do	R	do	1, 000	1	6		165	32	6	4
65	⅝	5	do	Iron		Pass. elevator	1, 800	7	0		50	28	1	0
66	¾	11	do	do	R	do	500	13	7	8, 000	50	48	2	0
67	½	11	do	Traction steel	R	Pass. and freight	1, 500	6	10		25	24	3	0
68–1	½	5	do	Iron	R	Governor cable		3	0	13, 990	260	16	2	0
68–2	½	5	do	do	R	do		4	11	27, 408	260	16	2	0
69	⅝	2	do	Steel	R	Pass. elevator	1, 000	4	5	46, 217	300	32	2	0
70	⅝	2	do	do	R	do	1, 000	4	5	44, 359	380	32	2	0
71	⅝	2	do	do	R	do	1, 000	2	5	39, 359	380	32	2	0
72	1¼	3	Lang	High-grade plow steel	U	Mine hoist	8, 000	2	0	415, 624 metric ton kilometers	2, 193	84	1	0

[1] A=American Steel and Wire Co.
B=Broderick and Bascom Rope Co.
C=American Cable Co.
H=Hazard Wire Rope Co.
L=A. Leschen and Sons Rope Co.
M=McWhyte Co.
R=John A. Roebling's Sons Co.
U=U. S. Steel Products Co.
[2] Total load on all ropes.
[3] 35 floors.

The rope specimens were supplied by the following firms:

Rope	Firm
1.	Engineering Societies Building, New York, N.Y.
2.	United States Aluminum Co., Edgewater, N. J.
3.	United Engineering and Foundry Co., Youngstown, Ohio.
4.	Shepard-Niles Crane and Hoist Corporation, Montour Falls, N. Y.
5.	Wall and Hanover Realty Co., New York, N. Y.
6.	40 Wall Street Bank, Manhattan, New York, N. Y.
7.	American Tube and Stamping Plant, Bridgeport, Conn.
8.	Travelers Insurance Co., Hartford, Conn.
9.	Navy Department, Washington, D. C.
10.	Zurich Insurance Co., Chicago, Ill.
11.	Phelps Dodge Corporation, Bisbee, Ariz.
12.	Miami Copper Co., Miami, Ariz.
13–1.	Clover Splint Coal Co., Pittsburgh, Pa.
13–2.	Clover Splint Coal Co., Pittsburgh, Pa.
14.	U. S. Casualty Co., Chicago, Ill.
15.	Hartford Accident and Indemnity Co., Hartford, Conn.
16.	Hartford Accident and Indemnity Co., Hartford, Conn.
17.	Globe Indemnity Co., New York, N.Y.
18.	Great American Indemnity Co., New York, N. Y.
19.	Hartford Accident and Indemnity Co., Hartford, Conn.
20.	U. S. Casualty Co., New York, N. Y.
21.	U. S. Casualty Co., New York, N. Y.
22.	U. S. Casualty Co., New York, N. Y.
23.	U. S. Casualty Co., New York, N. Y.
24.	Valier Coal Co., Valier, Ill.
25.	Ocean Accident and Guaranty Corporation, New York, N. Y.
26.	Ocean Accident and Guaranty Corporation, New York, N. Y.
27.	Ocean Accident and Guaranty Corporation, New York, N. Y.
28.	The Travelers, Detroit, Mich.
29.	Utah Copper Co., Bingham, Utah.
30.	Union Pacific Coal Co., Rock Springs, Wyo.
31.	Union Pacific Coal Co., Rock Springs, Wyo.
32.	Standard Accident Insurance Co., Detroit, Mich.
33.	Travelers Insurance Co., Boston, Mass.
34.	Travelers Insurance Co., Boston, Mass.
35.	Corrigan McKinney Steel Co., Bessemer, Mich.
36.	Corrigan McKinney Steel Co., Bessemer, Mich.
37.	Equitable Building Corporation, New York, N. Y.
38.	Aetna Casualty and Surety Co., New York, N. Y.
39.	Aetna Life Insurance Co., New York, N. Y.
40.	Aetna Life Insurance Co., Hartford, Conn.
41.	Hartford Accident & Indemnity Co., Houston, Tex.
42.	Hartford Accident & Indemnity Co., Hartford, Conn.
43.	Montreal Mining Co., Hurley, Wis.
44.	National Association of Building Owners and Managers, Chicago, Ill.
45.	Aetna Life Insurance Co., Hartford, Conn.
46.	Aetna Life Insurance Co., Hartford, Conn.
47.	National Bureau of Standards, Washington, D. C.
48.	Aetna Life Insurance Co., Hartford, Conn.
49.	The Panama Canal, Dredging Division, Paraiso, Canal Zone.
50.	The Panama Canal, Dredging Division, Paraiso, Canal Zone.
51.	The Panama Canal, Dredging Division, Paraiso, Canal Zone.
52.	The Panama Canal, Dredging Division, Paraiso, Canal Zone.
53.	Hartford Accident and Indemnity Co., Manchester, N. H.
54.	Royal Indemnity Co., New York, N. Y.
55.	Aetna Life Insurance Co., Hartford, Conn.
56.	Aetna Life Insurance Co., Hartford, Conn.
57.	Continental Casualty Co., Chicago, Ill.
58.	Royal Indemnity Co., New York, N. Y.
59.	U. S. Department of Agriculture, Washington, D. C.
60.	Aetna Life Insurance Co., New York, N. Y.
61.	Aetna Life Insurance Co., New York, N. Y.
62.	Royal Indemnity Co., New York, N. Y.
63.	Aetna Life Insurance Co., New York, N. Y.
64.	Great American Indemnity Co., New York, N. Y.
65.	Hartford Accident and Indemnity Co., Philadelphia, Pa.
66.	Hartford Accident and Indemnity Insurance Co., Kansas City, Mo.
67.	Aetna Life Insurance Co., Hartford, Conn.
68.	Engineering Societies Building, New York, N. Y.
69.	Hartford Accident and Indemnity Insurance Co., Kansas City, Mo.
70.	Hartford Accident and Indemnity Insurance Co., Kansas City, Mo.
71.	Hartford Accident and Indemnity Insurance Co., Kansas City, Mo.
72.	El Potosi Mining Co., Chihuahua, Mexico.

The acceleration and deceleration of the load were given on the service-data sheets for only three ropes. It was not considered necessary to give these values.

IV. DESCRIPTION OF INSPECTION AND TESTS

1. TYPE OF LAY

The type of lay was determined by inspection. Ropes of regular right lay, Lang right lay, and Lang left lay were included in the investigation.

2. CONSTRUCTION

The construction of the rope was determined by unlaying the wires in a short length cut from specimen A, counting the number of wires in each layer, and observing whether they were of the same or of different diameters.

The designations for the construction were in accordance with table 2.

3. DIAMETER OF WIRES

The diameters of three wires in each layer, of three spacer wires (if any), and of the center wire were measured with a micrometer caliper to the nearest 0.001 inch. In the case of ropes of Warrington construction (nos. 5, 6, and 8) the diameters of two wires of each of the two sizes in the outside layer were measured. Average wire diameters were calculated to the nearest 0.0001 inch. These measurements were made on wires from specimen A.

4. DETERMINATION OF "WORST LAY"

The portion of a wire rope having the greatest number of broken wires and the greatest wear has the least tensile strength. The number of broken wires and the wear should be determined for a definite distance, as 1 foot or 1 rope lay. The rope lay is the distance, parallel to the axis of the rope, in which a strand makes one complete turn about the axis of the rope. One rope lay is probably better for this determination than a foot because a rope lay is proportional to the nominal diameter of the rope.

The location of the "worst lay" in these worn ropes was determined by inspection and not by an actual count of the number of broken wires in different rope lays. Usually there was little doubt as to which was the worst lay. For some specimens, however, one lay appeared to have about as many broken wires as another. As counting the broken wires in each lay for the entire length of the specimen did not appear to be justified, the observers used their best judgment in selecting the worst lay. Any difference there may have been between the lay selected as the worst lay and any lay having a greater number of broken wires is believed to be negligible. The worst lay was marked on the specimen by a paint mark at each end.

Some ropes had no broken wires and had, apparently, uniform wear. In such cases the midlength of the rope was considered the worst lay.

5. ROPE DIAMETER

The diameter of the rope was measured at three places along the worst lay to the nearest 0.001 inch. For ropes having a nominal diameter of not more than 1 inch a micrometer caliper was used and for ropes having a nominal diameter greater than 1 inch a vernier caliper was used. The three values were averaged for this report.

6. ROPE LAY

A length of five rope lays was marked on the specimen, the middle one being the worst lay. This length was measured to the nearest 0.1 inch. The rope lay was taken as one-fifth of this length and the values are given to the nearest 0.01 inch.

7. STRAND LAY

The number of wires in the outside layer of a strand had been counted to determine the rope construction. A length equal to five strand lays was measured to the nearest 0.05 inch. The strand lay was taken as one-fifth of this length and the values are given to the nearest 0.01 inch.

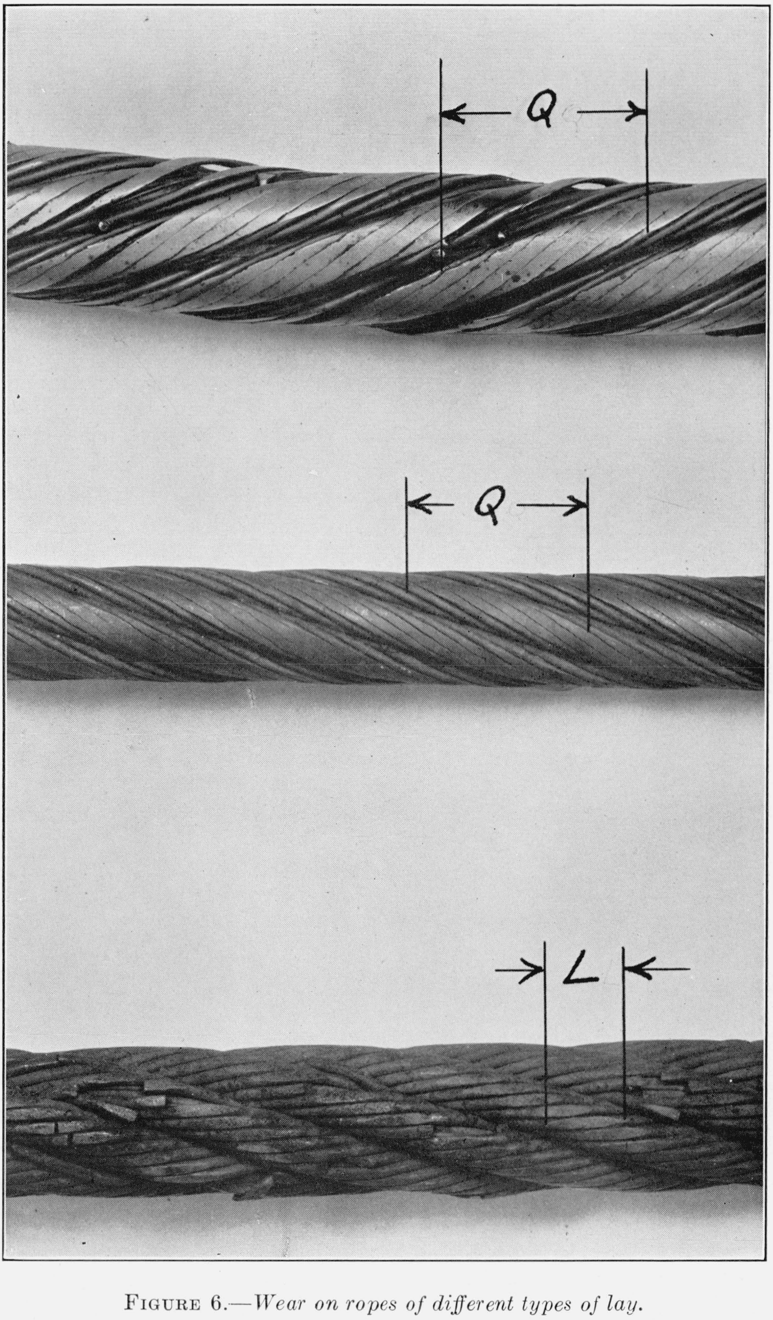

FIGURE 6.—*Wear on ropes of different types of lay.*

At top.—Rope 12-C, Lang lay rope, left lay.
Middle.—Rope 36-C, Lang lay rope, right lay.
Bottom.—Rope 13(1)-B, regular lay rope, right lay.
The distance Q on the Lang lay ropes and the distance L on the regular lay ropes is a measure of the wear.

8. NUMBER OF BROKEN WIRES

The number and location of the broken wires in the worst lay of each specimen were determined for each strand. Both "crown breaks" on the crest of the strand and "valley breaks" were counted. A valley break is a break of a wire which is not on the surface of the rope but on the interior surface of a strand, where it faces and is in contact with another strand. The total number of broken wires in the rope, the number of strands having at least one broken wire, and the smallest number of strands for which the sum of the number of broken wires equaled or exceeded 80 percent of the total number of broken wires in the rope lay were determined.

9. WEAR

A worn outside wire of a regular lay wire rope is shown in figure 5. The smallest cross-sectional area, at X, hereafter referred to as the "remaining area", can be determined if d and either w or t is known. It is impossible to determine the value t by direct measurement unless the wire can be cut from the rope. The width of the worn surface w can be measured, but it is very small. Moreover, for each value of w (except when it is equal to d) there are two possible values of t, and hence the area is not uniquely determined from w and d. The length L of the worn surface, however, increases continuously as t decreases, and if a relation can be found between L and t for a given size of rope and type of construction, the remaining area can be found from the length L.

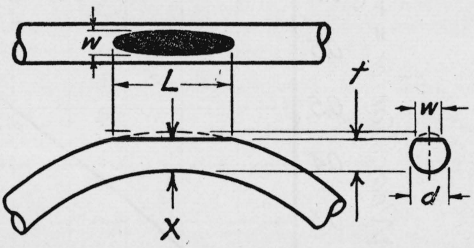

FIGURE 5.—*A worn outside wire of a regular lay rope.*

In this study, the length L was measured on five worn outside wires cut from the specimen after the tensile test had been made. It was found that the diameter of these wires was the same as the diameter before the test. If the length L was less than ¼ inch it was measured to the nearest 0.01 inch using a Brinell microscope having a scale in the field. If longer, it was measured using a steel scale.

On ropes of Warrington construction the length L was measured on three large and three small outside wires.

Lang lay ropes become worn in a slightly different manner, as may be seen in figure 6. While the length L is measurable on a Lang lay rope, the distance Q across a given number of wires is also a definite measure of the amount of wear and is more easily measured. For Lang lay rope, Q was measured between the closest points of wear on the first and fourth wires in a strand for ropes of 6 by 7 construction and between the closest points of wear on the first and sixth wires in a strand for ropes of 6 by 19 construction. It should be noted that as the wear increases, the distance Q becomes smaller. With no wear, Q is infinitely large.

10. REMAINING DIAMETER OF OUTSIDE WIRES

The length t, figure 5, which is the "remaining diameter" of the worn outside wires, was measured on the same wires on which the wear, L or Q, was determined. The measurements were made to the nearest 0.001 inch, using a micrometer caliper having either a ball or a line anvil.

11. REMAINING AREA OF THE ROPE

The area of the specimens was calculated by taking into account the number of wires not broken and the remaining diameter t of the

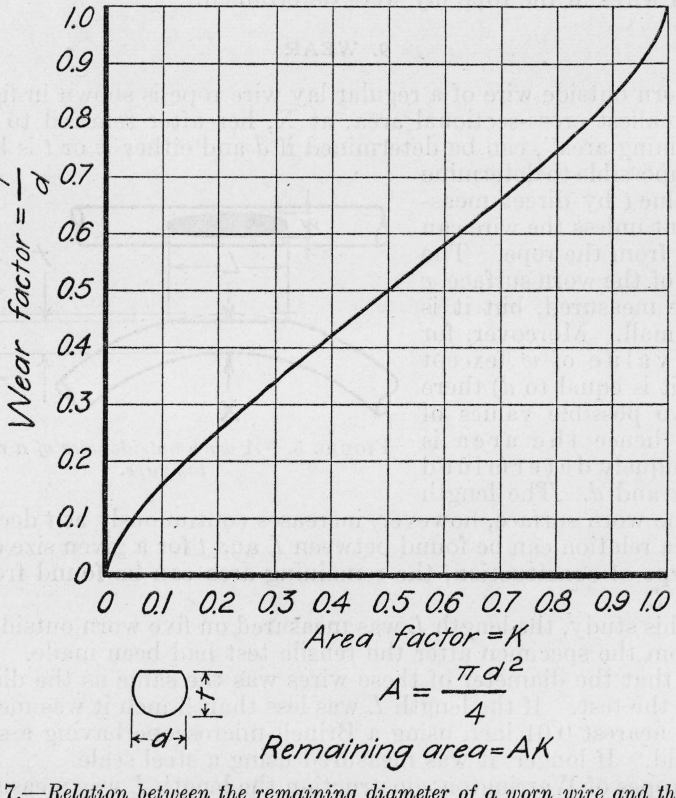

FIGURE 7.—*Relation between the remaining diameter of a worn wire and the cross-sectional area of the wire.*

outside wires. The cross-sectional area of a worn wire may be calculated by the aid of figure 7. In this figure, the ordinate represents the ratio of the remaining to the original diameter t/d, while corresponding values of area factors K are plotted as abscissas. If A is the cross-sectional area of the wire when no wear is present (diameter $=d$), then KA is the area of the worn wire for which the remaining diameter is t.

The areas of the inside wires were considered as full circles, and corresponding calculations were made.

In these calculations the total remaining area has been taken as the sum of the right sections across each separate wire. Actually in

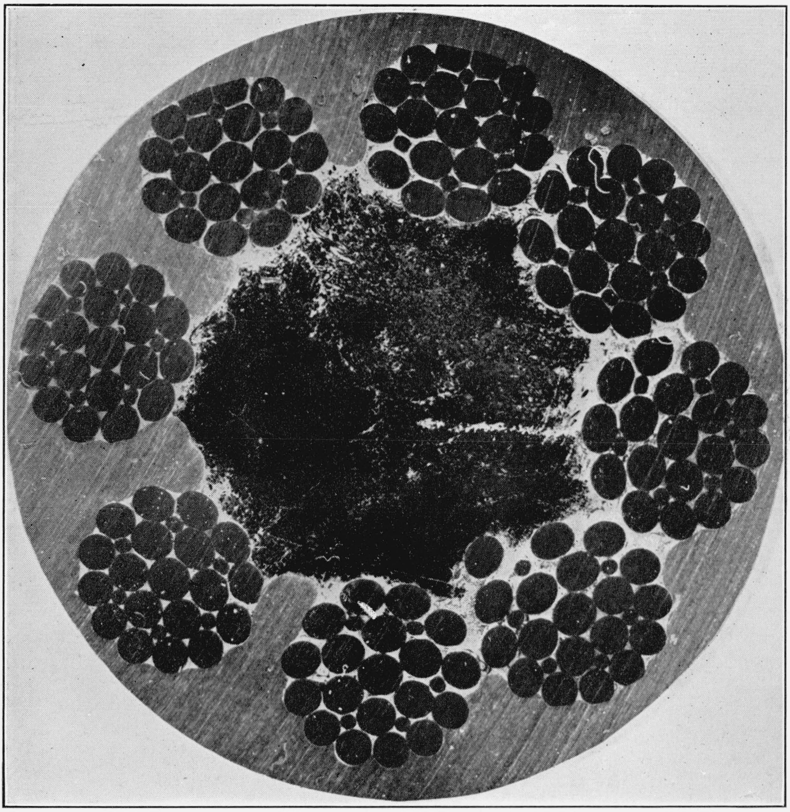

FIGURE 8.—*A section across rope 29–C, an 8-strand regular lay rope.*

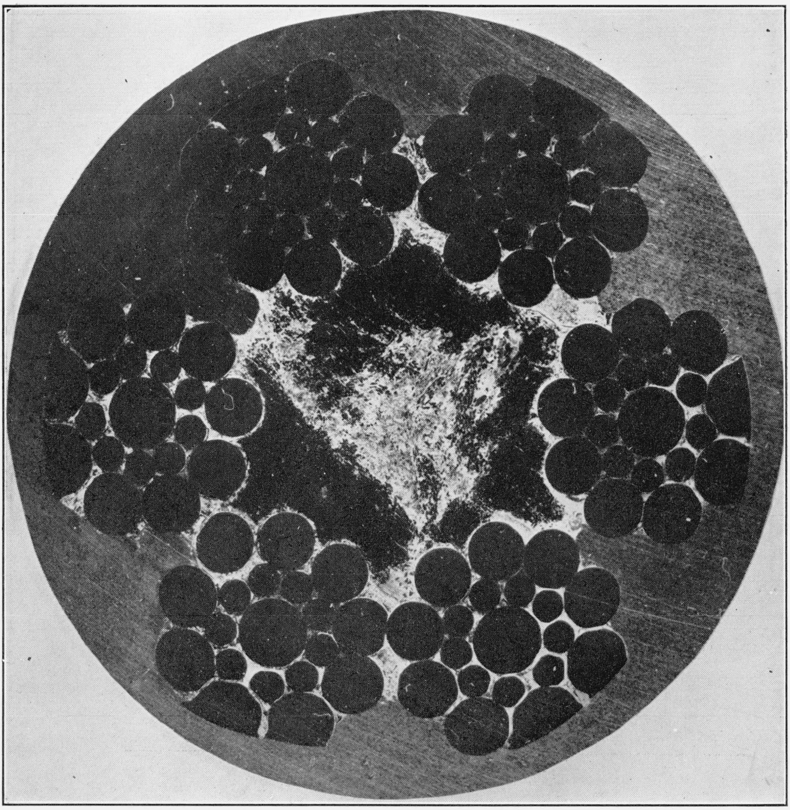

FIGURE 9.—*A section across rope* 11–C, *a 6-strand Lang lay rope.*

a rope, however, a right section across the rope does not cut all of the wires at right angles to their individual axes, as may be seen in figures 8 and 9. In the section of the regular lay rope, figure 8, the outside wires of each strand are cut very nearly at right angles to the axes of the wires, while the wires near the fiber core are cut at a relatively large angle to their axes. The reverse is obviously true in the section of the Lang lay rope, figure 9.

These figures show that in some cases the worn surface of the outside wires was deformed so that the sections are no longer portions of true circles. Generally, however, the area computed from the remaining diameter, *t*, is less than the actual remaining area and will therefore be on the side of safety if the tensile strength of the wire is not decreased by the wear.

12. CORE DIAMETER

The diameter of the fiber core near the end of each sample was measured to the nearest 0.01 inch, using a steel scale. This diameter was taken as the diameter of the inscribed circle of the cross section of the core.

13. CORE CONDITION

An estimation of the lubrication in the fiber core was made for each sample. It varied from "very dry" to "well lubricated". For the specimens having a "dry core" it was observed that no oil appeared on the surface of the rope during the tensile test, while in the specimens for which the core was considered well lubricated oil usually appeared on the surface of the rope at comparatively low tensile loads.

The fibers of the core were examined to determine whether or not they had been broken. For cores in apparently good condition the fibers were listed as long. In other cases short fibers were found in various proportions to the number of long fibers. The cores in a few ropes appeared to be rotted; the fibers were very short and appeared to have no tensile strength.

14. TENSILE TESTS

The specimens having a nominal diameter not greater than 1 inch were tested in a horizontal pendulum hydraulic testing machine, which could be adjusted for maximum loads of 10,000, 20,000, 50,000, and 100,000 lb. (see fig. 1). The ends of the specimen were held in grips 19.25 inches long. The free length was 4 feet for specimens having sufficient length. For the other specimens it was as long as the specimen permitted.

The specimens having a nominal diameter greater than 1 inch but less than 2¼ inches were tested in a vertical beam and poise testing machine having a capacity of 600,000 lb. but using an auxiliary poise which gave a maximum load of 300,000 lb. The specimens having a nominal diameter of 2¼ inches and 3¼ inches were tested in a horizontal fluid-support weighing scale testing machine having a capacity of 1,150,000 lb. in tension. The ends of the specimens were socketed with zinc. The free length was about 5 feet for these specimens.

The rate of separation of the heads of the testing machines was 0.4 in./min at no load.

The load at which oil appeared on the surface of the rope, the "breaking load" at which the rope failed, and the manner of failure were recorded.

The "tensile strength" was calculated by dividing the breaking load of the rope by the remaining area.

In this report the load at which the rope failed will be called the "breaking load" and the stress at failure the "tensile strength" (lb/in^2).

V. RESULTS OF INSPECTION AND TENSILE TESTS, WITH DISCUSSION

The results of the inspection and tensile tests of the ropes are given in table 5. Since, for many of these ropes, the wear and broken wires were distributed very uniformly along the length of the specimen, it is believed that the wear and broken-wire data given in table 5 adequately describe the ropes.

TABLE 5.—*Results of inspection and tensile tests of worn wire ropes*

LAY REGULAR, RIGHT—CONSTRUCTION 2, 6 BY 19 SEALE

Nominal diameter	Rope	Diameter of measured rope	Rope lay	Strand lay	Number of broken wires in worst lay	Distribution of broken wires		Wear		Core		Rope			
						Strands [a]	Strands [b]	L	t/d	Diameter	Condition [c]	Breaking load	Remaining strength [d]	Remaining area	Tensile strength
in.		in.	in.	in.				in.		in.		lb	%	in.^{2}	lb/in.^{2}
½	33-C	0.478	3.06	0.93	8	2	1	0.14	0.98	0.28	Ec	12,950	-----	0.0745	174,000
½	53-A	.488	3.16	.86	0	0	0	.00	1.00	.27	Aa	15,700	100	.0850	185,000
	-B	.470	3.22	.90	8	2	1	.12	.96	.27	Da	14,300	91	.0761	188,000
	-C	.466	3.22	.88	14	2	2	.11	.95	.26	Db	11,200	71	.0699	160,000
⅝	1(1)-A	.643	3.80	1.00	0	0	0	.00	1.00	.30	Aa	25,200	100	.1410	179,000
	-B	.616	3.88	1.02	0	0	0	.11	.97	.28	Dc	25,700	102	.1401	183,000
	-C	.618	3.84	1.06	0	0	0	.09	.99	.31	Dc	26,950	107	.1409	191,000
⅝	1(2)-A	.643	3.85	1.02	0	0	0	.00	1.00	.32	Aa	25,450	100	.1435	177,000
	-B	.621	3.94	1.03	0	0	0	.12	.94	.31	Dd	25,740	101	.1409	183,000
	-C	.624	3.86	1.04	0	0	0	.13	.92	.33	Dd	25,950	102	.1399	186,000
⅝	6-A	.627	4.04	1.08	0	0	0	.19	.95	.26	Aa	25,450	98	.1419	180,000
	-B	.603	4.02	1.07	3	1	1	.15	.93	.28	Da	25,000	97	.1359	184,000
	-C	.595	4.14	1.09	5	2	1	.13	.94	.30	Db	23,200	90	.1327	175,000
⅝	8-A	.633	3.86	1.10	0	0	0	.00	1.00	.30	Aa	25,300	100	.1449	175,000
	-B	.607	3.88	1.04	2	1	1	.16	.92	.30	Dc	22,950	91	.1377	166,000
	-C	.584	3.98	.99	14	4	3	.15	.91	.30	Dc	19,850	78	.1165	170,000
⅝	21-A	.617	3.82	1.02	0	0	0	.00	1.00	.28	Ba	25,200	100	.1403	180,000
	-B	.594	3.83	1.02	0	0	0	.12	.94	.29	Dc	25,000	99	.1381	181,000
	-C	.598	3.84	1.05	12	3	2	.15	.93	.29	Db	23,600	94	.1172	201,000
⅝	37-A	.630	3.80	1.01	0	0	0	.00	1.00	.30	Aa	25,100	100	.1462	172,000
	-B	.615	3.90	1.05	5	1	1	.16	.94	.30	Dc	24,700	98	.1346	184,000
	-C	.617	3.95	1.04	11	3	2	.15	.93	.28	Dc	17,850	71	.1234	145,000
⅝	38-A	.620	3.76	1.03	0	0	0	.00	1.00	.30	Aa	25,820	100	.1497	172,000
	-B	.620	3.86	1.06	8	2	2	.11	.96	.31	Da	17,800	69	.1336	133,000
	-C	.609	3.84	1.05	21	3	2	.14	.95	.30	Ca	17,100	66	.1090	157,000
⅝	39-A	.619	3.82	1.00	0	0	0	.00	1.00	.29	Aa	25,250	100	.1444	175,000
	-B	.617	3.87	1.03	9	5	4	.14	.94	.31	Cc	22,450	89	.1258	178,000
	-C	.606	3.86	1.03	12	6	4	.14	.93	.30	Cb	22,200	88	.1202	185,000

See footnotes at end of table.

TABLE 5.—*Results of inspection and tensile tests of worn wire ropes*—Continued

LAY REGULAR, RIGHT—CONSTRUCTION 2, 6 BY 19 SEALE—Continued

Nominal diameter	Rope	Diameter of measured rope	Rope lay	Strand lay	Number of broken wires in worst lay	Distribution of broken wires: Strands [a]	Distribution of broken wires: Strands [b]	Wear: L	Wear: t/d	Core: Diameter	Core: Condition [c]	Rope: Breaking load	Rope: Remaining strength [d]	Rope: Remaining area	Rope: Tensile strength
in.		in.	in.	in.				in.		in.		lb	%	in.²	lb/in.²
	40–A	.642	3.86	1.04	0	0	0	.00	1.00	.30	Aa	25,150	100	.1458	172,000
⅝	–B	.617	3.87	1.04	8	3	2	.11	.97	.30	Ca	20,600	82	.1304	158,000
	–C	.626	3.93	1.01	14	3	2	.11	.96	.31	Ac	19,300	77	.1194	162,000
	41–A	.620	3.88	1.02	0	0	0	.00	1.00	.30	Ac	25,550	100	.1447	176,000
⅝	–B	.600	3.97	1.05	29	6	4	.13	.96	.29	Dc	17,500	69	.0914	192,000
	–C	.593	4.01	1.04	37	6	5	.13	.96	.30	Dc	15,250	60	.0772	198,000
	44–A	.633	3.75	1.04	0	0	0	.00	1.00	.30	Aa	22,800	100	.1440	158,000
⅝	–B	.620	3.85	1.01	6	4	3	.10	.97	.33	Dc	20,050	88	.1321	152,000
	–C	.614	3.88	1.04	7	3	3	.08	.98	.33	Dc	17,750	78	.1306	136,000
	45–A	.631	3.81	1.05	0	0	0	.00	1.00	.32	Aa	25,150	100	.1449	174,000
⅝	–B	.616	3.88	1.03	2	1	1	.15	.92	.28	Db	24,750	98	.1376	180,000
	–C	.608	3.86	1.02	5	1	1	.15	.94	.27	Dc	22,950	91	.1334	172,000
	46–A	.624	3.80	1.00	0	0	0	.00	1.00	.24	Aa	25,200	100	.1463	172,000
⅝	–B	.626	3.84	1.03	0	0	0	.13	.99	.31	Ca	25,450	101	.1462	174,000
	–C	.613	3.92	1.02	5	1	1	.13	.96	.31	Cd	22,000	87	.1357	162,000
	69–A	.624	3.92	1.04	0	0	0	.00	1.00	.31	Aa	23,800	100	.1445	165,000
⅝	–B	.596	3.96	1.20	12	3	2	.11	.98	.31	Dc	18,800	79	.1225	153,000
	–C	.603	3.96	1.20	22	6	3	.11	.96	.31	Cb	11,500	48	.1038	111,000
	70–A	.619	3.93	1.04	0	0	0	.00	1.00	.31	Ba	25,000	100	.1445	173,000
⅝	–B	.596	3.90	1.04	0	0	0	.09	.96	.32	Cb	25,400	102	.1431	177,000
	–C	.608	4.00	1.03	19	6	4	.10	.96	.32	Ba	19,700	79	.1092	180,000
	71–A	.649	3.88	1.04	0	0	0	.00	1.00	.32	Aa	24,000	100	.1399	172,000
⅝	–B	.622	3.92	1.05	0	0	0	.10	.99	.35	Bc	25,400	106	.1398	181,000
	–C	.629	3.99	1.04	14	5	3	.10	.95	.37	Dc	15,800	66	.1141	138,000

LAY REGULAR, RIGHT—CONSTRUCTION 3, 6 BY 19, ROEBLING SPECIAL SEALE

	28–A	0.497	3.11	0.89	0	0	0	0.00	1.00	0.27	Aa	16,350	100	0.0890	184,000
½	–B	.481	3.15	.87	5	2	1	.10	.94	.24	Cb	17,200	105	.0832	207,000
	–C	.473	3.18	.84	13	2	2	.13	.91	.23	Cc	13,200	81	.0753	175,000
	54–A	.495	3.18	.92	0	0	0	.00	1.00	.28	Aa	16,800	100	.0903	186,000
½	–B	.496	3.19	.89	0	0	0	.08	.96	.28	Db	16,800	100	.0896	188,000
	–C	.481	3.26	.91	20	5	2	.09	.96	.25	Dc	11,600	69	.0713	163,000
	59–1–A	.487	3.00	.82	0	0	0	.00	1.00	.30	Ca	17,200	100	.0893	193,000
½	–B	.495	2.99	.87	0	0	0	.00	1.00	.26	Ca	16,800	98	.0893	188,000
	–C	.490	3.01	.86	2	2	2	.10	.96	.25	Da	17,000	99	.0852	199,000
	59–2–A	.497	3.01	.86	0	0	0	.00	1.00	.29	Ca	16,800	100	.0890	189,000
½	–B	.484	3.00	.85	6	3	2	.11	.97	.25	Cb	16,500	98	.0832	198,000
	–C	.485	3.01	.86	9	2	2	.11	.91	.24	Cb	15,600	93	.0789	198,000
	59–3–A	.491	3.01	.87	0	0	0	.00	1.00	.26	Ca	17,200	100	.0893	193,000
½	–B	.487	3.01	.87	1	1	1	.00	1.00	.26	Ca	17,000	99	.0884	192,000
	–C	.475	2.95	.87	6	1	1	.11	.94	.25	Cb	15,700	91	.0826	190,000
	59–4–A	.509	2.92	.85	0	0	0	.00	1.00	.23	Ca	16,600	100	.0890	186,000
½	–B	.492	2.96	.88	2	1	1	.10	.94	.24	Ca	16,400	99	.0860	191,000
	–C	.483	3.08	.90	4	1	1	.09	.97	.22	Cb	16,800	101	.0850	198,000
	59–5–A	.499	2.92	.84	0	0	0	.00	1.00	.26	Ca	16,600	100	.0863	192,000
½	–B	.491	2.98	.83	2	1	1	.10	.97	.26	Ca	17,700	107	.0842	210,000
	–C	.497	2.97	.87	4	2	2	.00	1.00	.27	Cb	16,500	99	.0829	199,000
	13(1)–A	1.814	10.20	2.88	0	0	0	.29	.99	1.00	Ca	245,800	100	1.249	196,000
1¾	–B	1.680	11.48	2.86	26	6	3	.75	.85	.78	Dc	171,500	70	.863	199,000
	–C	1.691	11.46	2.86	40	6	4	.75	.85	.78	Dc	158,100	64	.694	228,000

See footnotes at end of table.

TABLE 5.—*Results of inspection and tensile tests of worn wire ropes*—Continued

Nominal diameter	Rope	Diameter of measured rope	Rope lay	Strand lay	Number of broken wires in worst lay	Distribution of broken wires: Strands [a]	Distribution of broken wires: Strands [b]	Wear: L	Wear: t/d	Core: Diameter	Core: Condition [c]	Rope: Breaking load	Rope: Remaining strength [d]	Rope: Remaining area	Rope: Tensile strength
LAY REGULAR, RIGHT—CONSTRUCTION 4, 6 BY 19, MODIFIED SEALE															
in.		in.	in.	in.				in.		in.		lb	%	in.²	lb/in.²
½	63-A	0.514	3.12	0.85	0	0	0	0.00	1.00	0.28	Da	15,800	100	0.0990	160,000
	-B	.503	3.15	.85	2	2	2	.09	.97	.26	Ca	16,200	103	.0968	167,000
	-C	.509	3.09	.85	6	3	2	.08	.97	.27	Cb	16,700	106	.0936	178,000
⅝	48-A	.616	3.80	1.05	0	0	0	.00	1.00	.28	Aa	12,750	100	.1498	85,000
	-B	.612	3.86	1.04	3	3	3	.10	.95	.27	Db	12,500	98	.1446	86,000
	-C	.607	3.84	1.04	3	1	1	.13	.93	.27	Da	12,500	98	.1437	87,000
⅝	55-A	.654	4.64	1.24	0	0	0	.00	1.00	.28	Aa	37,250	100	.1605	232,000
	-B	.640	4.60	1.25	3	2	2	.00	1.00	.28	Aa	36,500	98	.1565	233,000
	-C	.613	4.68	1.26	9	4	3	.11	.99	.29	Aa	35,250	95	.1483	238,000
⅝	56-A	.638	4.60	1.24	0	0	0	.00	1.00	.26	Aa	37,050	100	.1658	223,000
	-B	.648	4.58	1.24	1	1	1	.00	1.00	.29	Aa	37,000	100	.1645	225,000
	-C	.628	4.62	1.29	21	6	5	.00	1.00	.29	Da	33,650	91	.1367	246,000
¾	15-A	.750	4.74	1.34	0	0	0	.14	.95	.34	Aa	18,700	99	.2201	85,000
	-B	.746	4.80	1.32	0	0	0	.20	.89	.37	Aa	18,150	96	.2154	84,000
	-C	.737	4.80	1.30	35	6	5	.20	.88	.32	Ca	16,600	88	.1580	105,000
1⅞	24-A	1.779	13.90	3.70	0	0	0	.00	1.00	.80	Aa	260,900	100	1.323	197,000
	-B	1.745	13.90	3.68	0	0	0	.45	.98	.83	Ca	259,400	100	1.319	197,000
	-C	1.732	14.10	3.64	5	5	5	.38	.95	.82	Da	253,500	97	1.255	202,000
LAY REGULAR, RIGHT—CONSTRUCTION 5, 6 BY 19, WARRINGTON															
7⁄16	25-A	0.439	2.80	0.75	0	0	0	0.00	1.00	0.17	Aa	5,600	100	0.0773	72,000
	-B	.448	2.79	.75	0	0	0	.09	.92	.16	Ca	5,650	101	.0761	74,000
	[e]-C	.440	2.82	.76	111	6	6	.08	.92	.19	Da	360	6	.0024	--------
7⁄16	27-A	.499	3.01	.92	0	0	0	.00	1.00	.18	Da	8,400	100	.1000	84,000
	-B	.488	3.06	.94	0	0	0	.08	.99	.21	Da	8,400	100	.0998	84,000
	-C	.509	3.12	.90	[f] 45	6	4	.10	.97	.17	Da	1,700	20	.0625	27,000
½	2-A	.466	3.10	.88	0	0	0	.21	.57	.20	Ca	11,350	78	.0797	142,000
	-B	.475	2.89	.91	0	0	0	.26	.58	.21	Da	10,950	76	.0801	137,000
	-C	.449	3.14	.88	14	6	5	.28	.60	.20	Dd	9,850	68	.0736	134,000
½	17-A	.508	2.98	.87	0	0	0	.00	1.00	.24	Aa	11,500	100	.1048	110,000
	-B	.503	3.08	.85	6	2	2	.10	.93	.23	Cb	9,300	81	.0981	95,000
	-C	.508	3.04	.87	45	5	4	.09	.95	.21	Ca	7,400	64	.0657	113,000
½	58-A	.507	3.20	.88	0	0	0	.00	1.00	.27	Ba	11,200	100	.0947	118,000
	-B	.503	3.24	.85	0	0	0	.00	1.00	.22	Ca	9,700	87	.0947	102,000
	-C	.507	3.27	.86	[g] 14	1	1	.12	.94	.21	Ca	1,900	17	.0829	23,000
½	60-C	.452	2.82	.75	[h] 19	1	1	.10	.93	.20	Ca	2,400	-----	.0650	36,200
½	61-A	.456	2.80	.71	0	0	0	.00	1.00	.21	Ca	5,700	100	.0835	68,000
½	68-1-A	.504	3.20	.89	2	2	2	.07	.96	.24	Ba	10,000	98	.0992	101,000
	-B	.506	3.14	.96	7	3	2	.08	.95	.22	Ca	9,800	96	.0946	103,000
	-C	.505	3.17	.84	10	4	3	.05	.98	.22	Ca	10,300	101	.0932	111,000
½	68-2-A	.508	3.09	.89	0	0	0	.00	1.00	.22	Ca	12,200	100	.1040	117,000
	-B	.496	3.14	.88	6	2	1	.12	.87	.22	Ca	9,500	78	.0951	100,000
	-C	.493	3.20	.90	30	5	3	.12	.87	.22	Ca	8,200	67	.0762	108,000
9⁄16	18-A	.569	3.46	1.07	0	0	0	.00	1.00	.27	Db	23,550	100	.1326	178,000
	-B	.571	3.45	1.05	0	0	0	.00	1.00	.25	Aa	22,900	97	.1326	172,000
	-C	.565	3.50	1.12	9	5	4	.10	.97	.25	Ca	20,250	86	.1219	166,000
⅝	5-A	.623	3.82	1.08	0	0	0	.08	.96	.28	Da	19,750	99	.1635	121,000
	-B	.609	3.79	1.10	7	5	4	.12	.96	.28	Da	19,650	99	.1529	128,000
	-C	.602	3.84	1.09	14	6	5	.10	.95	.28	Da	19,600	98	.1446	136,000

See footnotes at end of table.

TABLE 5.—*Results of inspection and tensile tests of worn wire ropes*—Continued

LAY REGULAR, RIGHT—CONSTRUCTION 5, 6 BY 19 WARRINGTON—Continued

Nominal diameter	Rope	Diameter of measured rope	Rope lay	Strand lay	Number of broken wires in worst lay	Distribution of broken wires		Wear		Core		Rope			
						Strands [a]	Strands [b]	L	t/d	Diameter	Condition [c]	Breaking load	Remaining strength [d]	Remaining area	Tensile strength [e]
in.		in.	in.	in.				in.		in.		lb	%	in.[2]	lb/in.[2]
5/8	19-A	0.624	3.70	1.02	0	0	0	0.00	1.00	0.30	Aa	18,300	100	0.1505	122,000
	-B	.605	3.68	1.05	18	4	2	.12	.92	.28	Bc	17,500	96	.1269	138,000
	-C	.615	3.74	1.05	28	5	3	.13	.92	.29	Cc	16,700	91	.1155	145,000
5/8	22-A	.590	3.74	1.14	0	0	0	.00	1.00	.28	Ca	10,850	100	.1466	74,000
	-B	.572	3.77	1.15	1	1	1	.30	.66	.28	Da	10,050	93	.1193	84,000
	-C	.557	3.77	1.10	4	2	2	.24	.76	.27	Da	9,950	92	.1268	78,000
5/8	23-A	.615	3.78	1.04	0	0	0	.00	1.00	.28	Aa	17,000	100	.1503	113,000
	-B	.598	3.84	1.08	0	0	0	.20	.76	.28	Ab	14,350	84	.1331	108,000
	-C	.594	3.92	1.06	22	6	4	.18	.86	.28	Ac	13,300	78	.1190	112,000
5/8	32-A	.649	3.54	1.16	0	0	0	.00	1.00	.30	Aa	20,300	100	.1592	128,000
	-B	.612	3.65	1.18	5	3	2	.24	.84	.28	Dc	18,800	93	.1389	135,000
	-C	.608	3.68	1.16	10	4	3	.14	.95	.28	Ed	19,300	95	.1440	134,000
5/8	34-C	.602	3.80	1.00	19	5	4	.12	.89	.32	Aa	14,200	-----	.1212	117,000
5/8	42-A	.660	4.10	1.14	0	0	0	.00	1.00	.27	Aa	28,750	100	.1740	165,000
	-B	.651	4.20	1.18	0	0	0	.00	1.00	.30	Aa	28,800	100	.1740	166,000
	-C	.633	4.16	1.18	0	0	0	.28	.73	.28	Aa	25,100	87	.1515	166,000
5/8	47-A	.643	3.82	1.08	0	0	0	.00	1.00	.28	Da	19,650	100	.1685	117,000
	-B	.610	3.84	1.12	8	4	3	.10	.96	.28	Db	19,650	100	.1562	126,000
	-C	.606	3.92	1.12	19	6	4	.14	.93	.27	Db	19,200	98	.1399	137,000
5/8	57-A	.516	3.38	.93	0	0	0	.00	1.00	.30	Ca	21,500	100	.1064	202,000
	-B	.492	3.40	.95	3	2	2	.19	.75	.24	Ca	21,300	99	.0908	235,000
	-C	.491	3.40	.89	4	1	1	.19	.74	.28	Ca	20,200	94	.0924	219,000
5/8	62-A	.654	3.84	1.11	0	0	0	.00	1.00	.30	Aa	20,700	100	.1590	130,000
	-B	.633	3.89	1.12	3	3	3	.18	.85	.31	Aa	11,600	56	.1469	79,000
	-C	.645	3.68	1.20	55	6	5	.16	.92	.31	Ab	7,100	34	.0871	82,000
5/8	65-B	.612	3.86	1.06	28	6	4	.16	.87	.31	Ba	8,000	-----	.1187	67,000
	-C	.600	3.85	1.09	[i] 44	5	3	.18	.83	.31	Ca	6,600	-----	.0950	69,000
1¼	30-A	1.23	9.62	2.44	0	0	0	.61	.82	.52	Ca	124,850	93	.6196	202,000
	-B	1.16	9.20	2.50	3	2	2	.70	.60	.48	Db	109,500	81	.5143	213,000
	-C	1.16	9.34	2.48	22	5	2	.74	.64	.50	Db	85,800	64	.4619	186,000

LAY REGULAR, RIGHT—CONSTRUCTION 6, 6 BY 37, PATENTED

Nominal diameter	Rope	Diameter of measured rope	Rope lay	Strand lay	Number of broken wires in worst lay	Strands [a]	Strands [b]	L	t/d	Core diameter	Condition [c]	Breaking load	Remaining strength [d]	Remaining area	Tensile strength [e]
5/8	3-A	0.672	3.80	1.09	0	0	0	0.00	1.00	0.33	Da	34,950	100	0.1700	205,000
	-B	.645	3.88	1.11	12	4	3	.16	.87	.31	Dc	34,800	100	.1569	222,000
	-C	.667	3.76	1.14	[j] 50	4	2	.00	1.00	.32	Da	16,000	46	.1313	122,000
5/8	7-A	.685	3.94	1.15	0	0	0	.00	1.00	.32	Aa	33,650	100	.1584	212,000
	-B	.621	4.00	1.18	4	3	3	.28	.88	.28	De	32,650	97	.1516	215,000
	-C	.605	4.06	1.22	[k] 101	6	6	-----	-----	.29	De	24,200	72	.0954	254,000

LAY REGULAR, RIGHT—CONSTRUCTION 7, 8 BY 19 SEALE

Nominal diameter	Rope	Diameter of measured rope	Rope lay	Strand lay	Number of broken wires in worst lay	Strands [a]	Strands [b]	L	t/d	Core diameter	Condition [c]	Breaking load	Remaining strength [d]	Remaining area	Tensile strength [e]
1/2	10-A	0.488	3.16	0.82	0	0	0	0.16	0.82	0.28	Da	4,500	92	0.0758	59,000
	-B	.486	3.22	.79	34	7	5	.16	.79	.28	Ca	3,100	63	.0517	60,000
	-C	.475	3.08	.84	50	8	6	.14	.86	.27	Cb	2,550	52	.0424	60,000
1/2	16-A	.498	3.17	.78	0	0	0	.00	1.00	.27	Aa	11,550	100	.0848	136,000
	-B	.496	3.16	.78	10	6	4	.09	.95	.26	Dc	10,860	94	.0759	143,000
	-C	.481	3.24	.79	30	7	3	.08	.97	.27	Dc	9,650	83	.0603	160,000

See footnotes at end of table.

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TABLE 5.—*Results of inspection and tensile tests of worn wire ropes*—Continued

LAY REGULAR, RIGHT—CONSTRUCTION 8, 8 BY 19 WARRINGTON

Nominal diameter	Rope	Diameter of measured rope	Rope lay	Strand lay	Number of broken wires in worst lay	Distribution of broken wires		Wear		Core		Rope			
						Strands [a]	Strands [b]	*L*	*t/d*	Diameter	Condition [c]	Breaking load	Remaining strength [d]	Remaining area	Tensile strength
in.		in.	in.	in.				in.		in.		lb.	%	in.²	lb/in.²
½	26-A	0.511	2.82	0.73	0	0	0	0.00	1.00	0.30	Aa	5,950	100	0.0798	74,000
	-B	.515	2.88	.72	0	0	0	.16	.87	.30	Ca	4,550	76	.0748	61,000
	-C	.489	2.91	.79	16	3	2	.17	.66	.26	Da	3,950	66	.0576	69,000
LAY REGULAR, RIGHT—CONSTRUCTION 9, 8 BY 19 MODIFIED SEALE															
1⅜	29-A	1.380	8.22	1.84	0	0	0	0.00	1.00	0.80	Ca	127,800	100	0.6218	206,000
	-B	1.320	8.10	1.86	0	0	0	.37	.79	.70	Ca	121,900	95	.5684	214,000
	-C	-------	-------	------	[l] 95	5	5	.51	.73	.70	Ca	22,350	17	.2048	109,000
LAY REGULAR, RIGHT—CONSTRUCTION 11															
¼	4-A	0.267	1.49	0.55	3	3	3	0.11	0.94	0.16	Ba	4,600	96	0.0250	184,000
	-B	.271	1.50	.51	7	6	5	.14	.88	.12	Ba	4,750	99	.0235	202,000
	-C	.255	1.57	.58	10	6	4	.12	.88	.12	Bb	4,200	88	.0228	184,000
½	14-A	.507	3.04	.92	0	0	0	.00	1.00	.20	Aa	6,650	100	.1009	66,000
	-B	.501	3.08	.94	10	3	2	.18	.87	.20	Ca	6,200	93	.0873	71,000
	-C	.490	3.10	.91	38	6	5	.18	.86	.22	Ea	5,100	77	.0631	81,000
½	67-A	.487	3.23	1.06	0	0	0	.00	1.00	.21	Aa	7,000	100	.0870	80,000
	-B	.466	3.40	1.11	60	6	5	.12	.84	.22	Da	5,200	74	.0407	128,000
	-C	.464	3.40	1.11	60	6	5	.14	.90	.22	Eb	4,600	66	.0412	111,000
⅝	20-A	.614	3.55	1.08	0	0	0	.16	.91	.26	Cc	8,800	97	.1476	60,000
	-B	.598	3.66	1.10	7	4	3	.34	.57	.29	Db	7,450	82	.1075	69,000
	-C	.594	3.60	1.11	28	4	3	.34	.59	.29	Da	6,650	73	.0923	72,000
¾	66-A	.749	4.64	1.29	0	0	0	[m] .00	1.00	.36	Aa	13,700	100	.2087	66,000
	-B	.720	4.71	1.30	0	0	0	.23	.87	.35	Ca	14,700	107	.1992	74,000
	-C	.725	4.71	1.36	15	2	2	.25	.83	.35	Ca	8,000	58	.1704	47,000
LAY REGULAR, RIGHT—CONSTRUCTION 12															
¾	9-A	0.751	4.90	1.60	1	1	1	0.33	0.73	0.30	Da	39,360	90	0.2122	185,000
	-B	.728	4.72	1.59	1	1	1	.33	.71	.32	De	36,450	84	.2087	175,000
	-C	.730	5.50	1.54	15	4	2	.36	.66	.30	De	34,920	80	.1936	180,000
LAY REGULAR, RIGHT—CONSTRUCTION 13															
3¼	49-A	-------	-------	------	0	0	0	0.00	1.00	-----	Aa	985,000	100	5.029	196,000
	-B (2)	3.16	20.9	6.0	6	3	2	.63	.93	0.50	Dc	901,000	91	4.824	187,000
	-B (1)	3.21	21.4	6.4	73	6	5	1.16	.74	.48	Dc	700,000	71	3.489	201,000
	-C (3)	3.18	20.8	6.4	[n] 127	6	6	.69	.92	.49	Dc	429,000	44	2.563	167,000
3¼	51-A	3.35	-------	------	0	0	0	.00	1.00	-----	Aa	957,000	100	5.028	190,000
	[o] -B (6)	3.18	21.6	6.8	4	3	3	.77	.90	.69	Dd	899,000	94	4.874	184,000
	[o] -C (7)	3.17	21.7	6.8	95	6	6	.71	.87	.73	Dd	727,000	76	3.180	229,000
LAY REGULAR, RIGHT—CONSTRUCTION 14															
3¼	50-A	-------	-------	------	0	0	0	0.00	1.00	-----	Aa	918,000	100	4.984	184,000
	-B (4)	3.23	20.9	6.4	0	0	0	1.30	.74	.72	Dd	908,000	99	4.611	197,000
	[p] -C (5)	3.33	20.0	6.2	[q] 10	----	----	.00	1.00	.70	Dd	825,000	90	4.887	169,000

See footnotes at end of table.

TABLE 5.—*Results of inspection and tensile tests of worn wire ropes*—Continued

LAY REGULAR, RIGHT—CONSTRUCTION 15

Nominal diameter	Rope	Diameter of measured rope	Rope lay	Strand lay	Number of broken wires in worst lay	Distribution of broken wires: Strands [a]	Distribution of broken wires: Strands [b]	Wear: L	Wear: t/d	Core: Diameter	Core: Condition [c]	Rope: Breaking load	Rope: Remaining strength [d]	Rope: Remaining area	Rope: Tensile strength
in.		in.	in.	in.				in.		in.		lb.	%	in.²	lb/in.
5/8	64-A	0.617	3.90	1.05	0	0	0	0.00	1.00	.32	Ba	24,100	100	0.1395	173,000
	-C	.593	3.99	1.05	18	4	3	.21	.74	.32	Aa	14,200	59	.1009	141,000

LAY REGULAR, RIGHT—CONSTRUCTION 16

Nominal diameter	Rope	Diameter of measured rope	Rope lay	Strand lay	Number of broken wires in worst lay	Strands [a]	Strands [b]	L	t/d	Core diameter	Core condition [c]	Breaking load	Remaining strength [d]	Remaining area	Tensile strength
1¾	13(2)-A	1.793	11.00	2.90	0	0	0	.51	0.99	-----	-----	282,200	100	1.483	190,000
	-B	1.709	11.55	2.98	30	6	4	.72	.99	-----	-----	199,300	71	1.086	183,000
	-C	1.719	11.28	2.98	58	6	6	.76	.85	-----	-----	164,500	58	.714	230,000

LAY REGULAR, RIGHT—CONSTRUCTION 17

Nominal diameter	Rope	Diameter of measured rope	Rope lay	Strand lay	Number of broken wires in worst lay	Strands [a]	Strands [b]	L	t/d	Core diameter	Core condition [c]	Breaking load	Remaining strength [d]	Remaining area	Tensile strength
2¼	52-A	2.30	-----	-----	0	0	0	0.00	1.00	-----	Aa	397,000	100	2.2876	174,000
	-B(9)	2.23	14.1	4.4	4	2	2	.00	1.00	.40	Cb	360,000	91	2.2548	160,000
	-C(8)	2.23	14.3	5.1	54	6	5	.00	1.00	.40	Cc	297,000	75	1.8546	160,000

LAY, LANG, RIGHT—CONSTRUCTION 1, 6 BY 7 COARSE LAID

Nominal diameter	Rope	Diameter of measured rope	Rope lay	Strand lay	Number of broken wires in worst lay	Strands [a]	Strands [b]	Wear: Q	Wear: t/d	Core diameter	Core condition [c]	Breaking load	Remaining strength [d]	Remaining area	Tensile strength
								in.							
1	31-A	0.949	7.92	5.48	0	0	0	2.40	0.84	0.48	Dc	70,000	92	0.3662	191,000
	-B	.948	8.08	5.42	0	0	0	2.22	.84	.53	Dc	75,000	98	.3662	205,000
	[r]-C	.911	8.20	6.14	2	2	2	2.37	.82	.48	Dc	44,000	58	.3434	128,000

LAY, LANG, RIGHT—CONSTRUCTION 2, 6 BY 19 SEALE

Nominal diameter	Rope	Diameter of measured rope	Rope lay	Strand lay	Number of broken wires in worst lay	Strands [a]	Strands [b]	Wear: Q	Wear: t/d	Core diameter	Core condition [c]	Breaking load	Remaining strength [d]	Remaining area	Tensile strength
1¼	11-A	1.307	8.66	5.10	0	0	0	2.50	0.89	0.70	Ca	137,500	96	0.6258	220,000
	-B	1.207	8.85	5.20	1	1	1	2.09	.78	.67	Da	128,500	90	.5685	226,000
	-C	1.173	8.84	5.31	1	1	1	2.10	.76	.60	Da	122,700	86	.5595	220,000

LAY, LANG, RIGHT—CONSTRUCTION 3, 6 BY 19 ROEBLING SPECIAL SEALE

Nominal diameter	Rope	Diameter of measured rope	Rope lay	Strand lay	Number of broken wires in worst lay	Strands [a]	Strands [b]	Wear: Q	Wear: t/d	Core diameter	Core condition [c]	Breaking load	Remaining strength [d]	Remaining area	Tensile strength
1¼	72-C	1.24	8.50	4.4	0	0	0	1.51	0.92	0.62	Aa	134,300	-----	0.593	226,000
1⅜	[s]35-A	1.348	9.18	6.36	0	0	0	-----	1.00	.78	Db	136,000	100	.7680	177,000
	[s]-B	1.339	9.40	6.16	0	0	0	2.05	.85	.70	Dc	131,800	97	.7230	182,000
	[s]-C	1.294	10.14	6.22	0	0	0	1.82	.62	.68	Dc	140,500	103	.5990	234,000
1⅜	[t]36-A	1.321	9.40	5.93	0	0	0	2.35	.84	.64	Dc	133,600	94	.7270	184,000
	[t]-B	1.315	9.30	6.19	0	0	0	2.02	.75	.68	Dc	131,200	92	.6810	193,000
	[t]-C	1.261	10.00	6.39	0	0	0	2.12	.60	.70	Dc	133,100	93	.5930	225,000

LAY, LANG, RIGHT—CONSTRUCTION 4, 6 BY 19 MODIFIED SEALE

Nominal diameter	Rope	Diameter of measured rope	Rope lay	Strand lay	Number of broken wires in worst lay	Strands [a]	Strands [b]	Wear: Q	Wear: t/d	Core diameter	Core condition [c]	Breaking load	Remaining strength [d]	Remaining area	Tensile strength
1½	43-A	1.557	10.30	5.22	0	0	0	-----	1.00	0.80	Cb	213,000	100	0.9190	232,000
	-B	1.497	10.28	5.38	0	0	0	1.50	.87	.68	Ca	211,000	99	.8780	240,000
	-C	1.473	10.46	5.32	2	2	2	1.65	.79	.70	Ca	209,900	99	.8300	253,000

See footnotes at end of table.

TABLE 5.—*Results of inspection and tensile tests of worn wire ropes*—Continued

LAY, LANG, LEFT—CONSTRUCTION 4, 6 BY 19 MODIFIED SEALE

Nominal diameter	Rope	Diameter of measured rope	Rope lay	Strand lay	Number of broken wires in worst lay	Distribution of broken wires: Strands [a]	Distribution of broken wires: Strands [b]	Wear: L	Wear: t/d	Core: Diameter	Core: Condition [c]	Rope: Breaking load	Rope: Remaining strength [d]	Rope: Remaining area	Rope: Tensile strength
in.		in.	in.	in.				in.		in.		lb	%	in.²	lb/in.²
1¾	12–A	1.779	11.74	7.20	0	0	0	-----	1.00	0.85	Da	241,300	100	1.266	190,000
	–Ba	1.700	11.68	6.78	0	0	0	1.94	.66	.80	Db	219,500	91	1.050	209,000
	–Bb	1.726	11.52	6.94	0	0	0	2.00	.80	.72	Db	242,700	101	1.164	209,000
	–Bc	1.670	11.68	6.82	0	0	0	1.81	.63	.82	Db	210,600	87	1.025	205,000
	–Bd	1.723	11.40	7.00	0	0	0	1.80	.74	.80	Db	216,300	90	1.118	193,000
	–C	1.685	11.66	6.94	27	6	4	1.80	.65	.73	Db	197,600	82	.960	206,000

[a] The number of strands having broken wires.
[b] The number of strands having 80 percent of the total number of broken wires.
[c] Core condition symbols:

For the lubrication of the core:
- A=Well lubricated.
- B=Fairly well lubricated.
- C=Rather dry.
- D=Dry.
- E=Very dry.

For the condition of the fibers:
- a=Long.
- b=Some short.
- c=Many short.
- d=All short.
- e=Rotted.

[d] The remaining strength is the ratio of the breaking load of the specimen to the breaking load of the specimen if there had been no wear and no broken wires.
[e] Three inside wires and core not broken. All others broken. Measurements of diameter and lay were made away from the break.
[f] These outside wire breaks were valley breaks. It is probable some inside wires were also broken.
[g] All outside wires and two inside wires of one strand were broken. The rope had been kinked.
[h] One strand was completely broken. No visible broken wires in remaining strands.
[i] All wires in one strand were broken plus other outside wires.
[j] One strand and about half of another were burned through, apparently by an electric arc. Other wires were doubtless decreased in strength.
[k] These are all outside wires.
[l] Five strands and core broken. No broken wires in remaining three strands.
[m] Some wires were locally crushed but apparently not worn.
[n] All wires in one outside strand were broken plus other outside wires.
[o] Wires of independent wire rope core somewhat rusty.
[p] The independent wire rope core was displaced.
[q] The broken wires were in the independent wire rope core; none was in the main rope.
[r] Wires rusty.
[s] All samples badly rusted and pitted.
[t] All samples badly rusted and pitted.

The following is a summary of the relation of the fracture in the rope to the worst lay. Of the ropes in which the worst lay could be definitely located, over 60 percent broke in the worst lay.

Total number of specimens for which the worst lay could be definitely located	124
Number of specimens C which broke in worst lay	57
Number of specimens C which broke within 12 inches of worst lay	8
Number of specimens C which broke more than 12 inches from worst lay	7
Number of specimens B which broke in worst lay	20
Number of specimens B which broke within 12 inches of worst lay	17
Number of specimens B which broke more than 12 inches from worst lay	12
Number of specimens A which broke in worst lay	2
Total number of specimens which broke in worst lay	79
Total number of specimens which did not break in worst lay	45

1. ROPE DIAMETER AND BREAKING LOAD

For a particular rope there usually was a decrease in diameter if there was a decrease in breaking load. Since the breaking load was decreased by broken wires which did not decrease the diameter of the rope, a direct relation between diameter and breaking load was not to be expected. There appears to be no relation which holds for the different ropes. For example, for rope 53, the diameter of specimen C was 95.5 percent of that of specimen A, while the corresponding ratio of the breaking loads was 71.4 percent. On the other hand, for rope 6, the diameter of specimen C was 94.8 percent of that for specimen A, while the corresponding ratio of the breaking loads was 91.2 percent. In fact, table 5 gives values for remaining strengths (specimen C to specimen A) which range from less than 60 to 100 percent, with a corresponding decrease in rope diameter (specimen A to specimen C) of 5 percent.

It should, however, be pointed out that all the rope specimens A had been in use and under tension so that the measured diameters for specimens A were probably less than when these ropes were new.

2. ROPE AND STRAND LAY AND ROPE STRENGTH

For a particular rope there usually was an increase in the rope lay if there was a decrease in breaking load. However, the rope lay for specimen C was only a few percent greater than for specimen A. Again, it should be noted that all the specimens had been stretched by the service loading.

The strand lay did not vary consistently with variations in the breaking load for the different ropes.

3. CORE CONDITION AND ROPE STRENGTH

A study of the values given in table 5 does not indicate that there is any direct relation between either the diameter or the condition of the core and the breaking load.

For a particular rope there usually was considerably more lubricant in the core of specimen A than in the cores of specimens B and C. This was confirmed by the fact that, as the load on specimen A increased, considerable lubricant appeared on the surface of the rope. There appeared to be somewhat less lubricant in specimen C than in specimen B. The data in table 5 do not indicate any appreciable difference in the diameters of the cores in the three specimens from the same rope. This diameter could not be measured very accurately, which may be the reason that measurements were obtained which show that the diameter of the core of specimen C is sometimes greater than that of specimens A and B.

For most of the ropes the fibers in the cores of specimen C were shorter than those in specimen B. Those in specimens B and C were shorter than those in specimen A.

In most cases, the cores having little lubricant and the shortest fibers were found in the specimens having the most wear and the greatest number of broken wires. This made it impossible to determine the effect of the core upon the breaking load.

4. REMAINING AREA AND ROPE STRENGTH

If the breaking load of a worn wire rope depends only on the remaining area of the wires, then the ratio of the breaking load to the remaining area should be constant for all specimens from a given rope. This ratio is the tensile strength (lb/in.^{2}), the values for which are given in table 5.

In some cases the tensile strength for specimen C is greater and in some cases less than for specimen A. It is probable that these differences are caused by the distribution of broken wires in specimen C. Table 6 gives the number of ropes for which the tensile strength of specimen C was greater or less than that of specimen A. Only six-strand ropes showing no corrosion were selected when preparing this table. Definite conclusions should not be drawn from the results obtained on only 40 ropes. There are indications that, if the tensile strength of specimen C was greater than that of specimen A, the broken wires were quite uniformly distributed; that is, there were broken wires in four or more of the strands. If the tensile strength of specimen C was less than that of specimen A, the broken wires were not uniformly distributed; that is, there were broken wires in only one, two, or three of the strands. In other words, the more uniform the distribution of the broken wires,the greater the tensile strength.

TABLE 6.—*Comparison of breaking loads for specimens C and A of six-strand ropes showing no corrosion*

[Specimen A had no wear and no broken wires]

Breaking load	Number of strands of specimen C having broken wires						
	0	1	2	3	4	5	6
Specimen C greater than specimen A (number of ropes)	3	1	2	4	4	6	2
Specimen C less than specimen A (number of ropes)	0	3	9	2	3	1	0

For those ropes in which one or two strands had most of the broken wires (80 percent or more)—that is, the broken wires were not uniformly distributed—the tensile strength for specimen C was usually less than for specimen A. It appears then that if the broken wires are not uniformly distributed among the strands the remaining area cannot safely be used as a criterion of the strength of the rope. Some fractional part of the remaining area (to be determined from the results of a large number of tests) might be satisfactory. It is probable that the effect of the distribution of the broken wires on rope strength extends to the distribution of the broken wires in each strand. This conclusion is supported by the data of table 6, since for some ropes specimen C had a smaller tensile strength than specimen A when there were broken wires in four and five strands.

The same effect of the distribution of the broken wires was found by comparing the tensile strength of the B specimens and the A specimens. The indication, however, was less definite because the B specimens had comparatively few broken wires.

5. CORROSION

Corrosion of the wires decreases their cross-sectional area. The actual cross-sectional area of a corroded wire rope, therefore, may be much less than the remaining area determined from the number of broken wires and the amount of wear. Probably the strength of a corroded wire rope can only be determined by a tensile test of a specimen cut from the rope.

6. THE BREAKING LOADS OF SPECIMENS C AND A

Specimen C was supposed to have been taken from the portion of the rope which was in the poorest condition and which was supposedly used by the inspector in determining when the rope should be discarded. For the ropes received, figure 10 shows the number of ropes

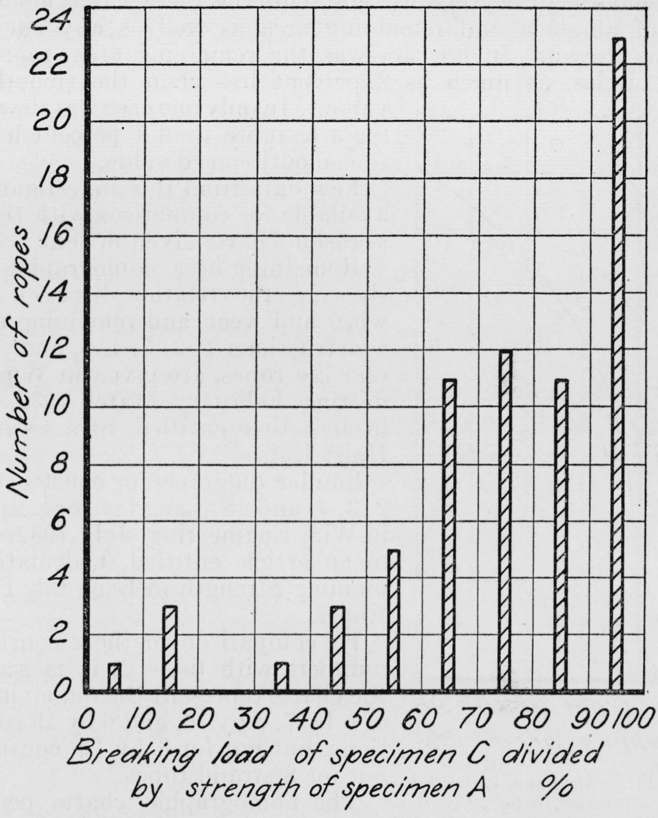


FIGURE 10.—*Relative strengths of specimens* C *and* A.

in comparison with the relative strengths of specimens C and A. Forty-nine percent of these discarded ropes had a strength for specimen C, which was at least 80 percent of that for specimen A.

VI. COMPARISON OF RESULTS WITH ROEBLING CHARTS

1. THE ROEBLING CHARTS

The strength of worn wire ropes is discussed in Wire Engineering, June–July 1931, page 7, in an article entitled Re-Roping Charts. In this article are shown curves giving the relation between length of abrasion and the remaining area for a few types and diameters of ropes. Among these charts is chart 6 for ⅝ inch diameter, 6 by 19 Seale, Roebling Special Traction Steel Rope, Construction 2. Table

3 of this report shows that 48 specimens of this size and construction were included in this investigation. Some of these ropes were not manufactured by this company. The remaining area and length of abrasion for these 16 lots of rope have been plotted in figure 11, as has the smooth curve which was taken from chart 6 of the article, Re-Roping Charts. While a few erratic values are shown in figure 11, the smooth curve probably represents the average relation between length of abrasion and remaining area as well as any curve that might be drawn. In no case was the remaining area, represented by the circles, as much as 2 percent less than the smooth-curve value. In only one case was the remaining area more than 1 percent less than the smooth-curve value.

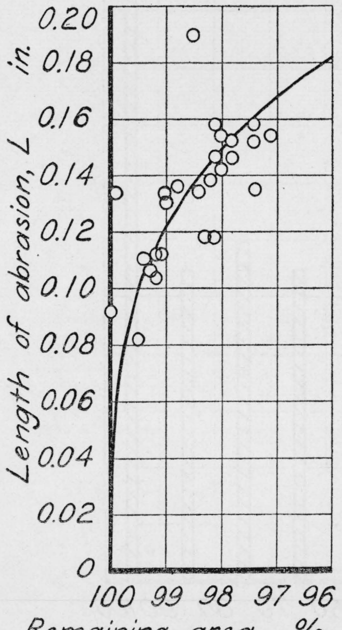


FIGURE 11.—*Abrasion chart for ⅝-inch diameter, 6 by 19 Seale construction 2, wire ropes.*

The smooth curve was taken from chart 6, Wire Engineering, p. 18, June–July 1931.

Few data from this investigation are available for comparison with the other abrasion charts given in that article.

Remaining area nomographic charts, showing the relation between broken wires and wear, and remaining area for constructions 1, 2, 3, 4, 5, and 18, regular lay ropes, are given in Wire Engineering, February–March 1932, page 2, in an article entitled, Stresses in Shaft Hoist Ropes.

Similar diagrams for constructions 1, 2, 3, 4, and 18, Lang lay rope, are given in Wire Engineering, July 1932, page 2, in an article entitled, Calculating Remaining Strength in Lang Lay Hoisting Ropes.

By comparison of these construction numbers with table 2, it is seen that the charts represent the remaining areas of 6 by 7, 6 by 16, and 6 by 19 constructions, but not for 6 by 37 construction nor for 8 strand ropes.

The nomographic charts pertaining to the rope constructions represented by these tests, copied from those given in the articles in Wire Engineering, are given in this report in figures 12 to 22, inclusive. The procedure in using these charts is as follows:

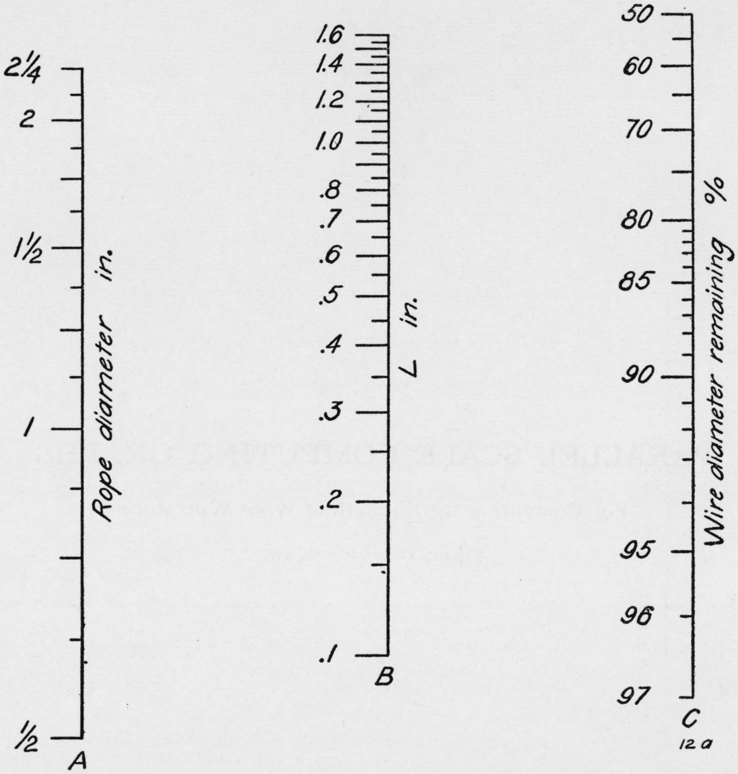
Draw a line from the rope diameter on scale A through the average length of wear L or Q on scale "B" to intersect scale C. At this intersection read the percentage of the wire diameter remaining. Connect this percentage of the wire diameter remaining on scale D to the number of broken wires in the worst rope lay on scale F and read the percentage of the rope area remaining intact at the intersection on scale E.

Reference has been made to the effect of the distribution of broken wires in the various strands on the tensile strength of the rope and the necessary correction to the remaining rope area if the distribution is not uniform. The Roebling wire engineers have found, from

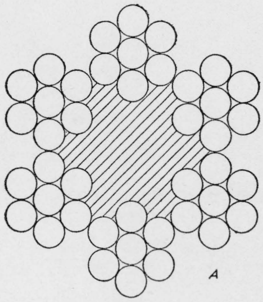
PARALLEL SCALE COMPUTING GRAPHS

For Computing the Strength of Worn Wire Rope

Figures 12 to 22, inclusive



2¼
2
1½
1
½
Rope diameter in.
A
1.6
1.4
1.2
1.0
.8
.7
.6
.5
.4
.3
.2
.1
L in.
B
50
60
70
80
85
90
95
96
97
Wire diameter remaining %
C
12a



A

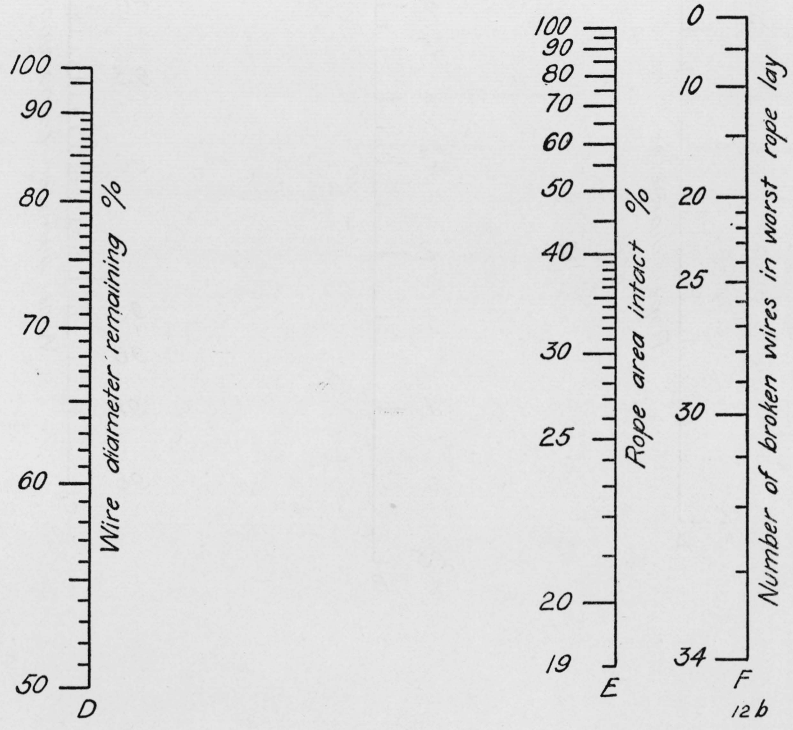
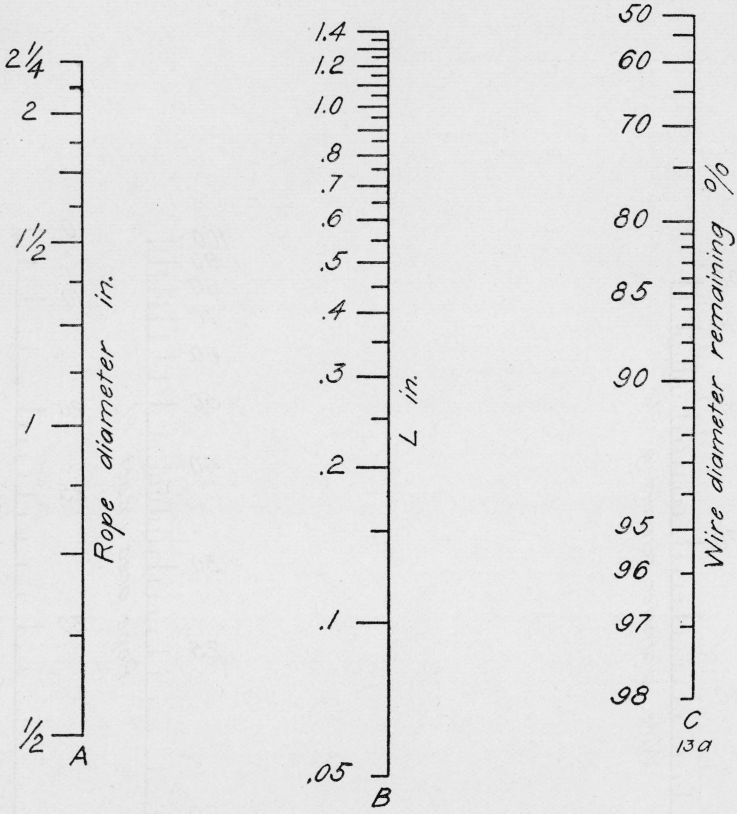
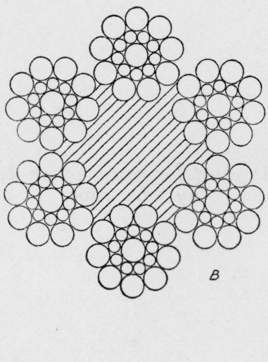


FIGURE 12.—*Remaining area chart for construction 1, 6 by 7 coarse laid, regular lay wire rope.*


2¼
2
1½
1
½
A
Rope diameter in.
1.4
1.2
1.0
.8
.7
.6
.5
.4
.3
.2
.1
.05
B
L in.
50
60
70
80
85
90
95
96
97
98
C
Wire diameter remaining %

13a



B

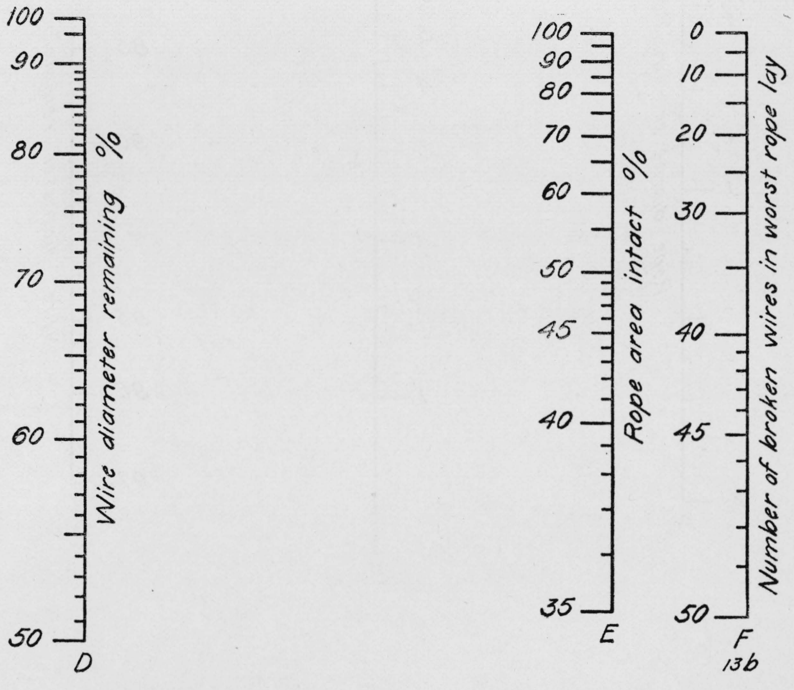
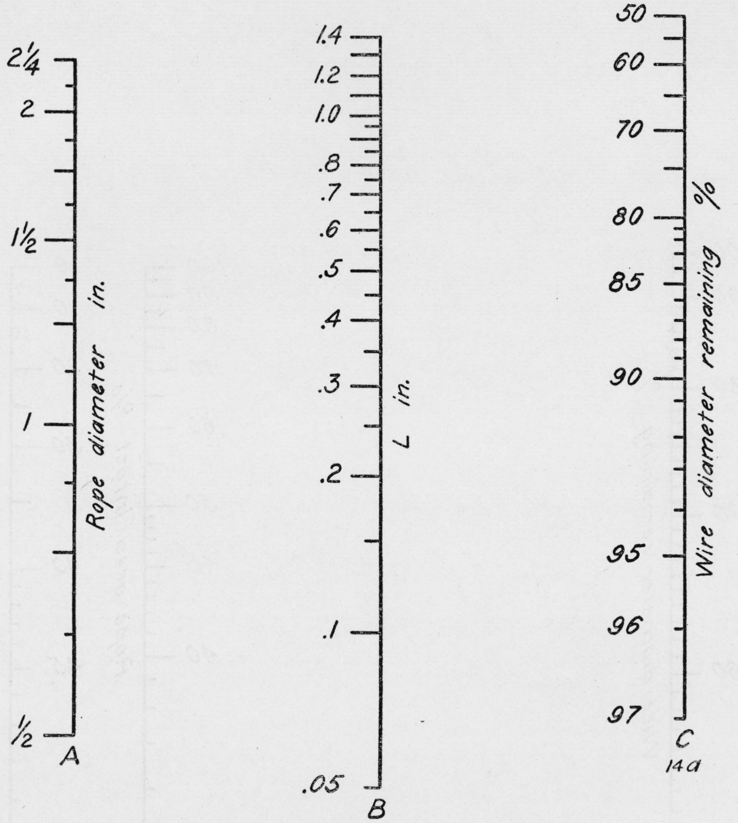
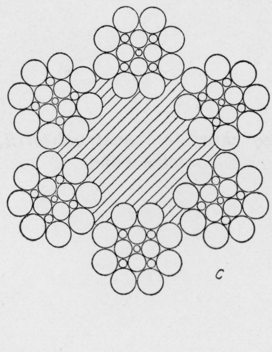


FIGURE 13.—*Remaining area chart for construction 2, 6 by 19 Seale, regular lay wire rope.*


2¼
2
1½
1
½
Rope diameter in.
A
1.4
1.2
1.0
.8
.7
.6
.5
.4
.3
.2
.1
.05
L in.
B
50
60
70
80
85
90
95
96
97
Wire diameter remaining %
C

14a



c

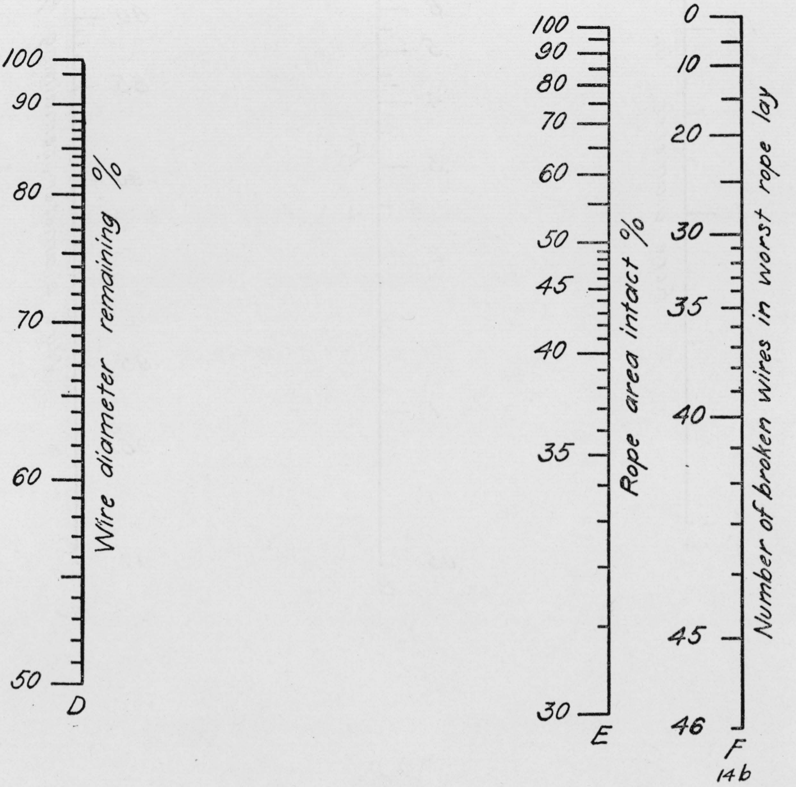
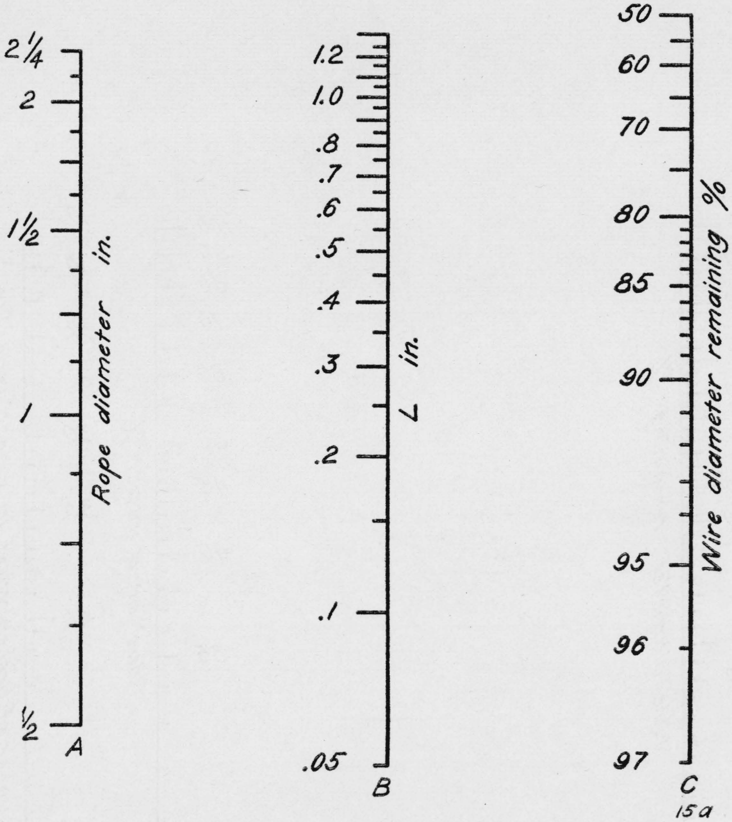
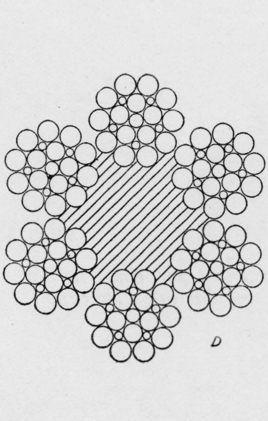


FIGURE 14.—*Remaining area chart for construction 18, 6 by 16 special Seale, regular lay wire rope.*


2 1/4
2
1 1/2
1
1/2
Rope diameter in.
A
1.2
1.0
.8
.7
.6
.5
.4
.3
.2
.1
.05
L in.
B
50
60
70
80
85
90
95
96
97
Wire diameter remaining %
C
15a


D

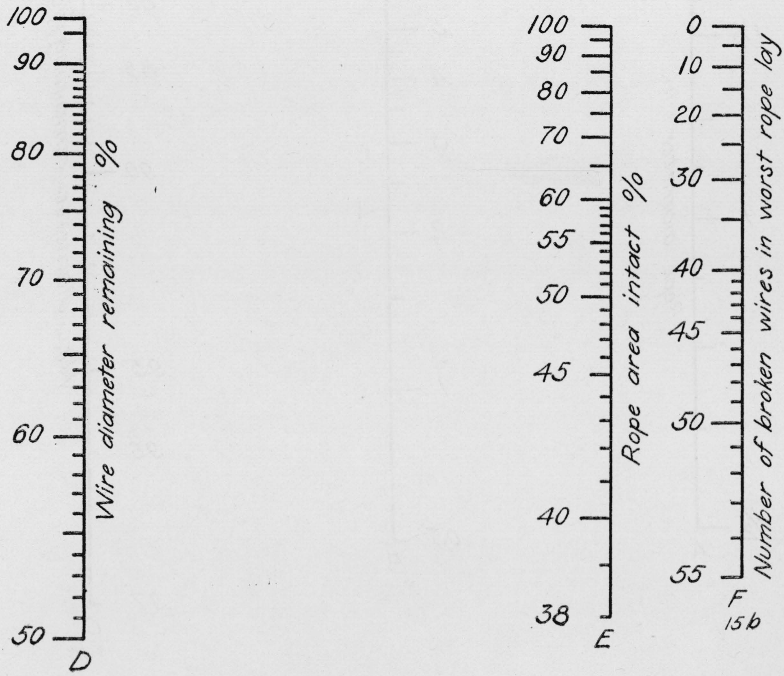
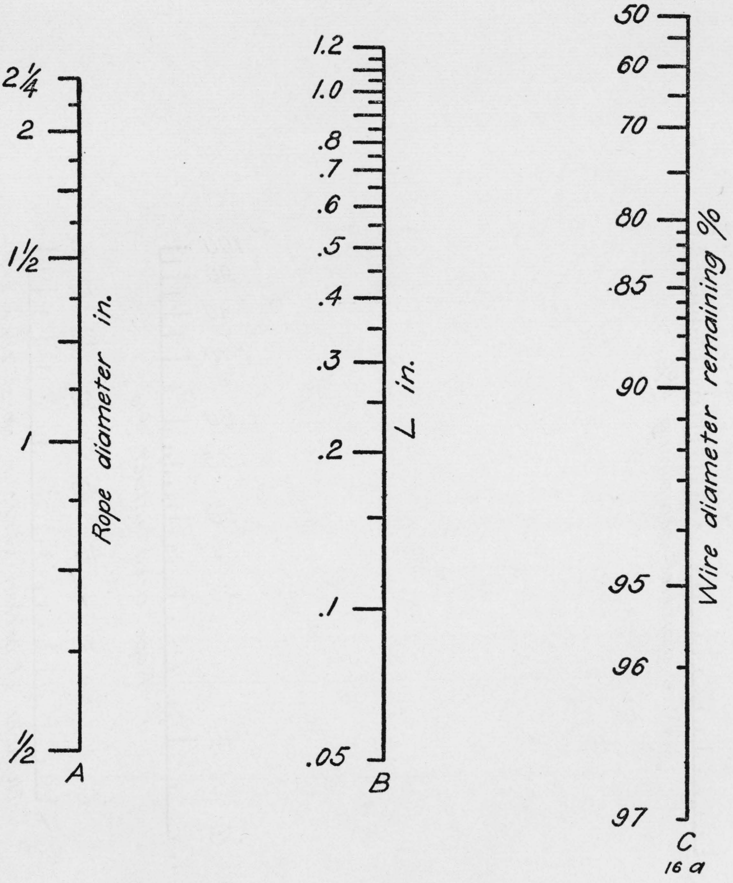
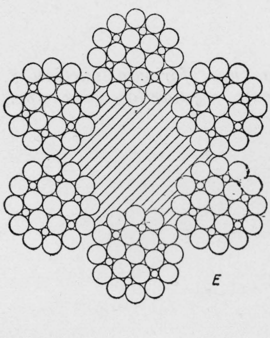


FIGURE 15.—*Remaining area chart for construction 3, 6 by 19 Roebling special Seale, regular lay wire rope.*

85753—36——8


2¼
2
1½
1
½
Rope diameter in.
A
1.2
1.0
.8
.7
.6
.5
.4
.3
.2
.1
.05
L in.
B
50
60
70
80
85
90
95
96
97
Wire diameter remaining %
C
16 a


E

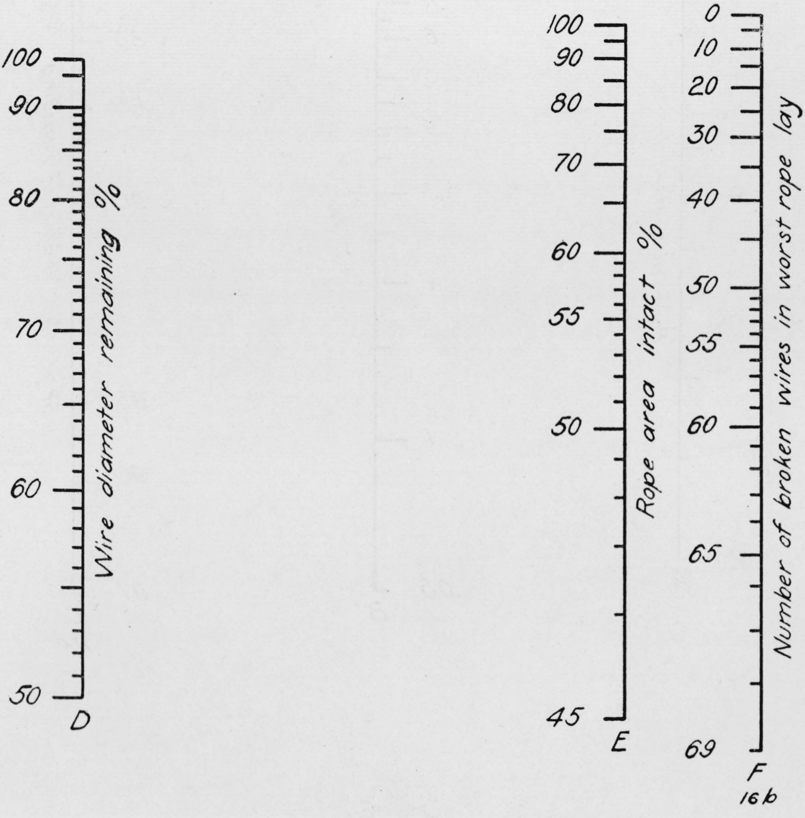
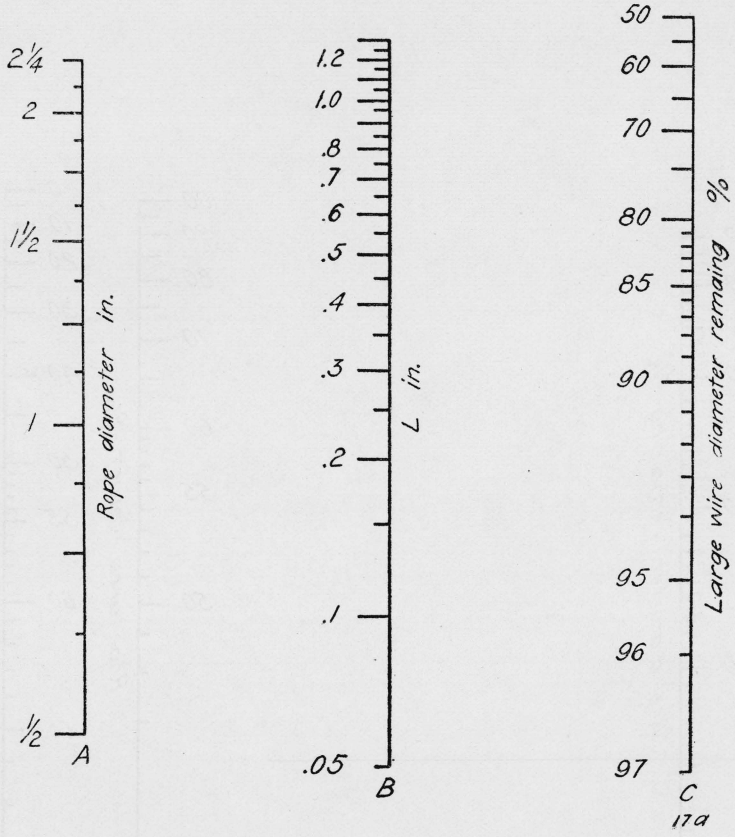
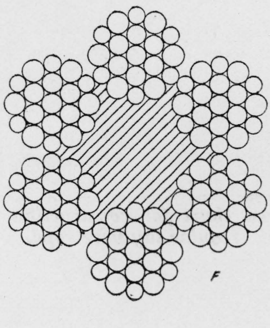


FIGURE 16.—*Remaining area chart for construction 4, 6 by 19 modified Seale, regular lay wire rope.*


2¼
2
1½
1
½
Rope diameter in.
A
1.2
1.0
.8
.7
.6
.5
.4
.3
.2
.1
.05
L in.
B
50
60
70
80
85
90
95
96
97
Large wire diameter remaing %
C
17a


F

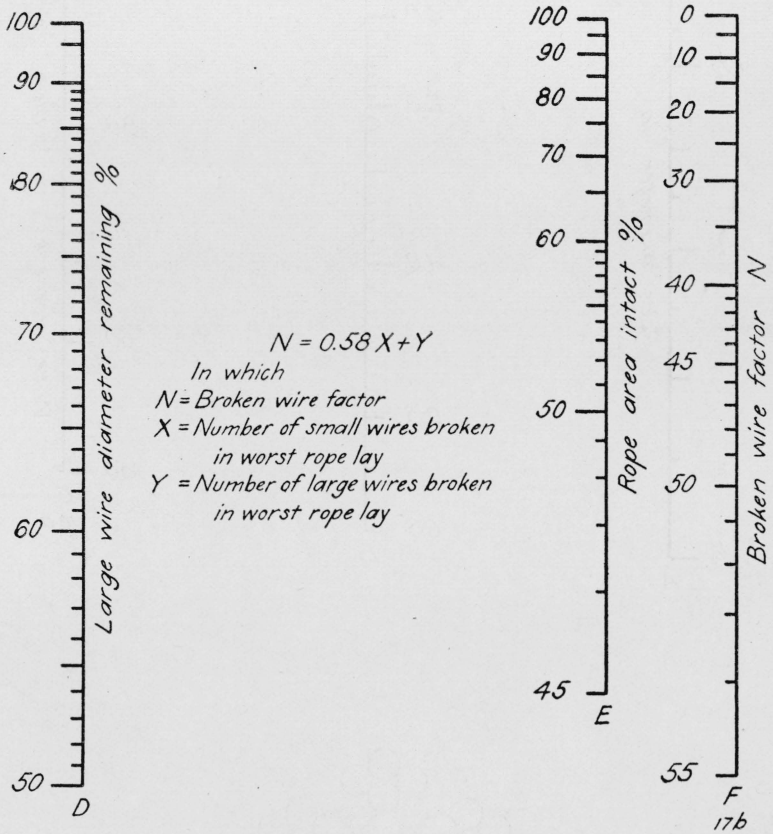
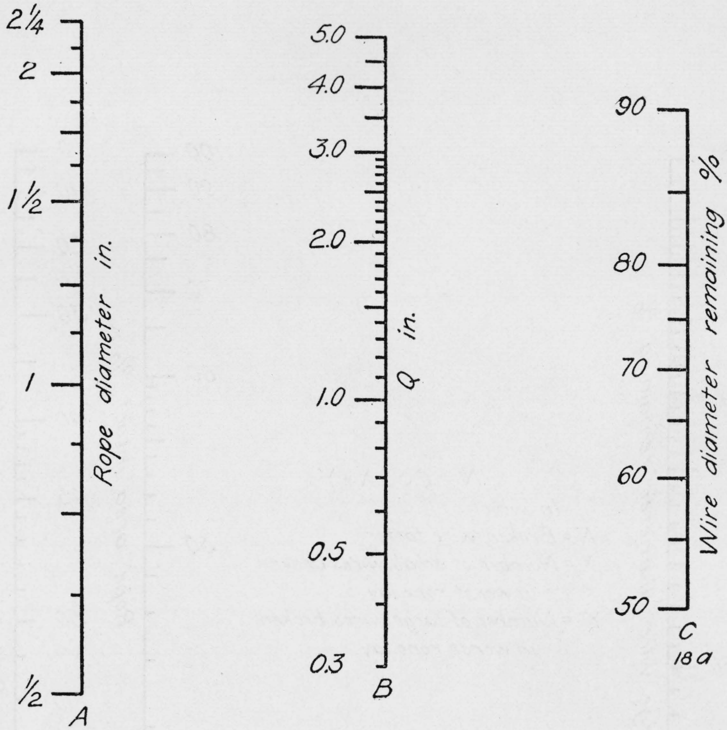
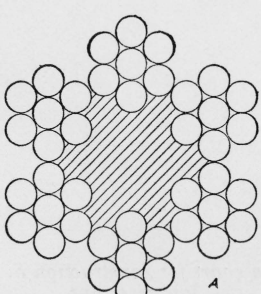


FIGURE 17.—*Remaining area chart for construction 5, 6 by 19 Warrington, regular lay wire rope.*



2¼
2
1½
1
½
Rope diameter in.
A
5.0
4.0
3.0
2.0
1.0
0.5
0.3
Q in.
B
90
80
70
60
50
Wire diameter remaining %
C
18 a



A

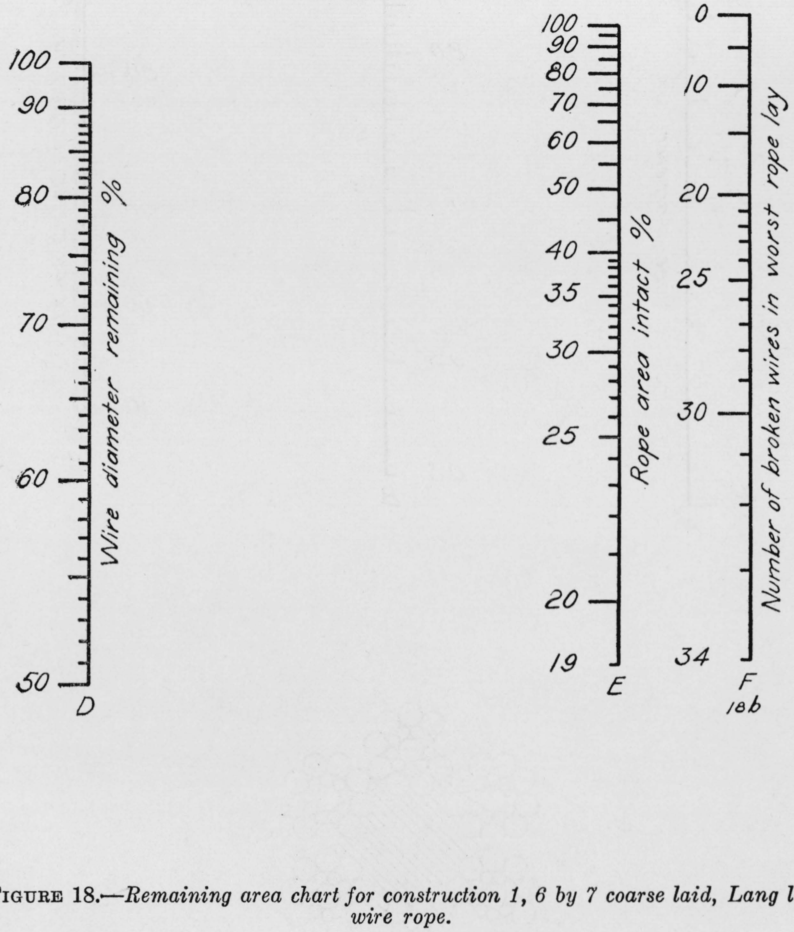
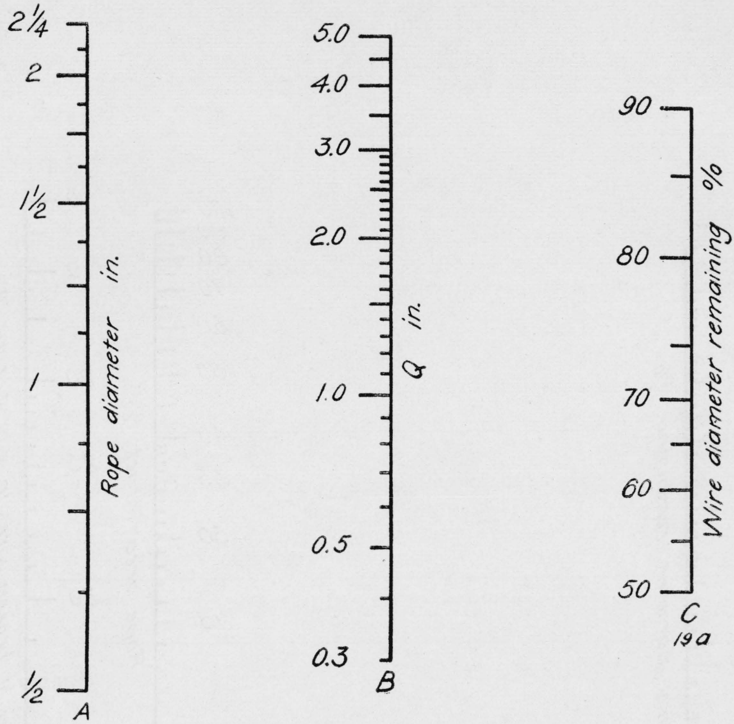
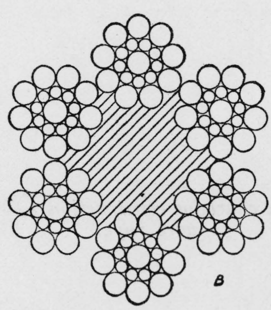


FIGURE 18.—*Remaining area chart for construction 1, 6 by 7 coarse laid, Lang lay wire rope.*


2¼
2
1½
1
½
A
Rope diameter in.
5.0
4.0
3.0
2.0
1.0
0.5
0.3
B
Q in.
90
80
70
60
50
C
Wire diameter remaining %
19a



B

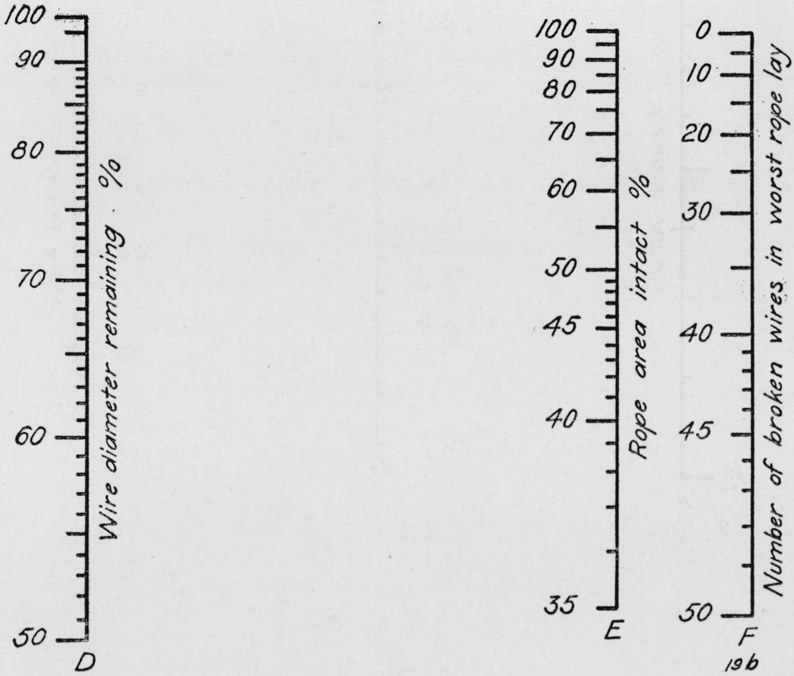
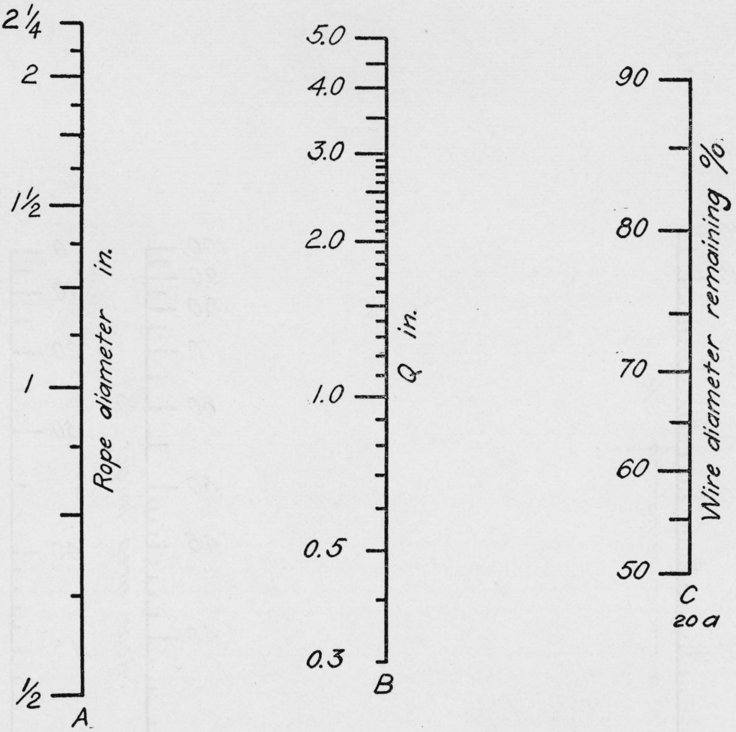
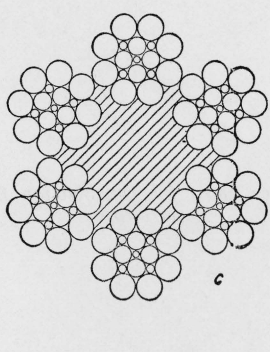


FIGURE 19.—*Remaining area chart for construction 2, 6 by 19 Seale, Lang lay wire rope.*


2 1/4
2
1 1/2
1
1/2
A
Rope diameter in.
5.0
4.0
3.0
2.0
1.0
0.5
0.3
B
Q in.
90
80
70
60
50
C
Wire diameter remaining %

20 a



c

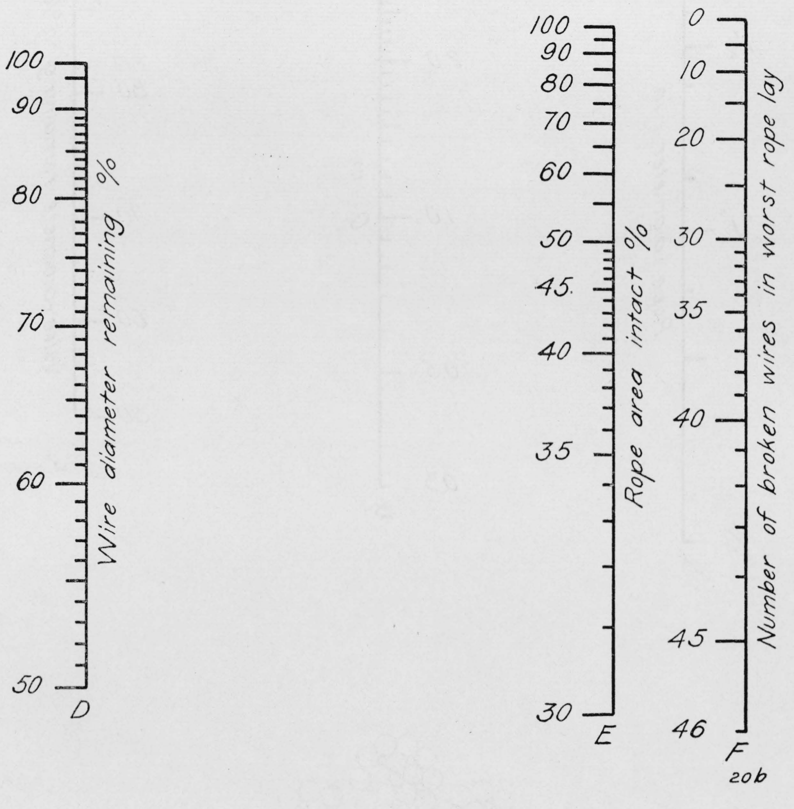
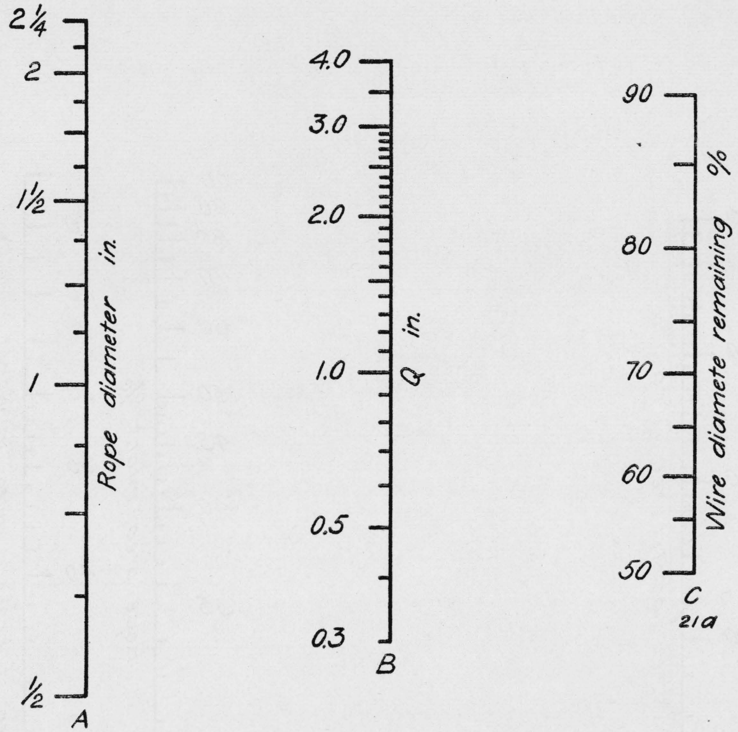
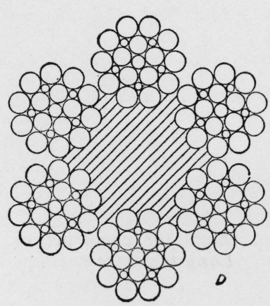


FIGURE 20.—*Remaining area chart for construction 18, 6 by 16 special Seale, Lang lay wire rope.*


2¼
2
1½
1
½
Rope diameter in.
A
4.0
3.0
2.0
1.0
0.5
0.3
Q in.
B
90
80
70
60
50
Wire diamete remaining %
C

21a



D

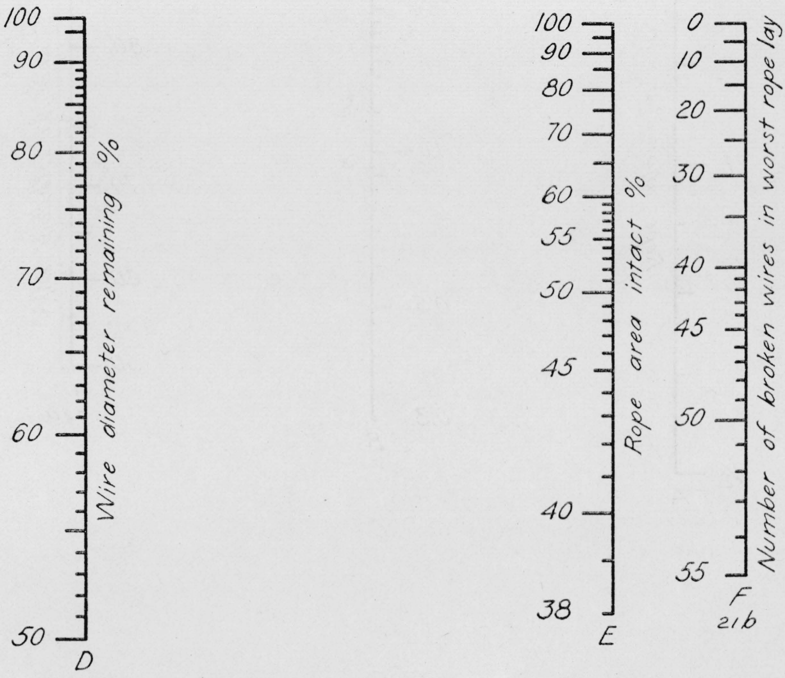
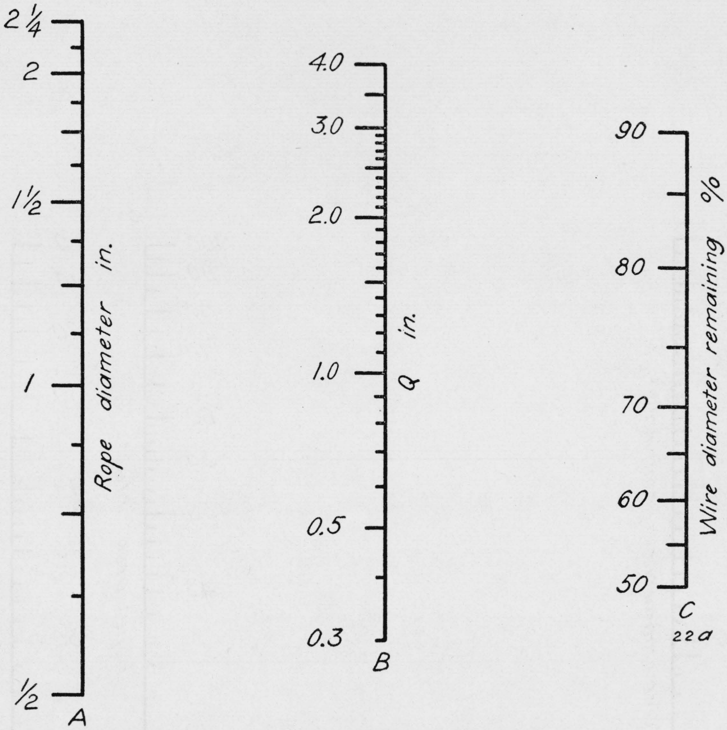
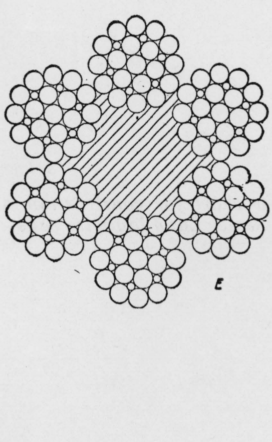


FIGURE 21.—*Remaining area chart for construction 3, 6 by 19 Roebling special Seale, Lang lay wire rope.*


2 1/4
2
1 1/2
1
1/2
A
Rope diameter in.
4.0
3.0
2.0
1.0
0.5
0.3
B
Q in.
90
80
70
60
50
C
Wire diameter remaining %

22a



E

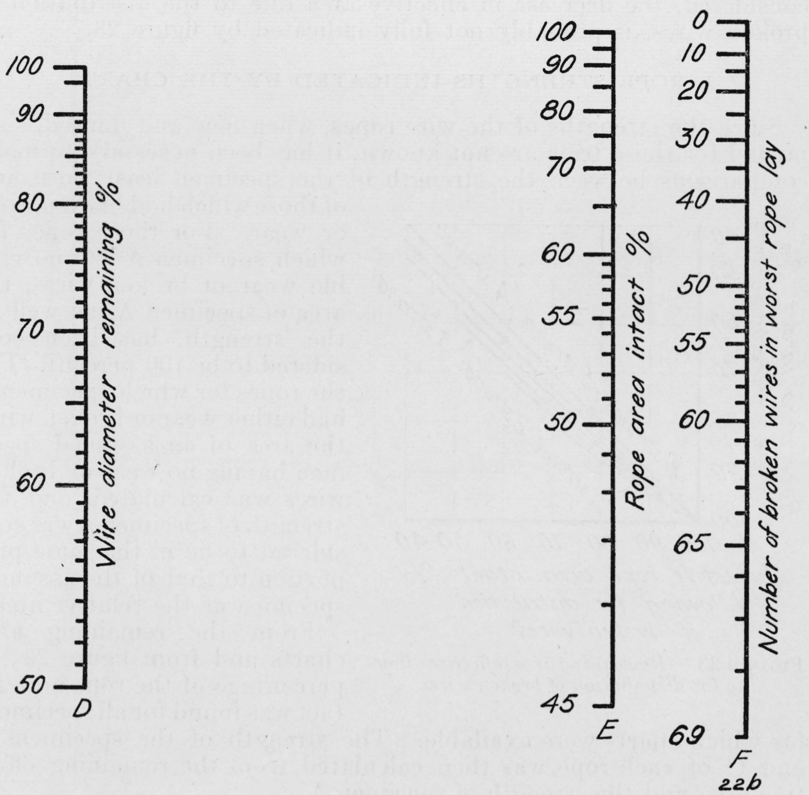


Figure 22.—*Remaining area chart for construction 4, 6 by 19 modified Seale, Lang lay wire rope.*

a large number of experiments, that the effective remaining area, allowing for the distribution of broken wires, is related to the remaining area found from calculations of the number of wires unbroken and wear on the outside wires, as shown in figure 23. In making a correction, allowing for the distribution of broken wires, the number of strands considered as having broken wires has been taken as the number of strands having 80 percent of the total number of broken wires (see table 5). If the total number of strands which had any broken wires (frequently only one or two wires in some strands) is considered, the decrease in effective area due to the distribution of broken wires, is probably not fully indicated by figure 23.

2. ROPE STRENGTHS INDICATED BY THE CHARTS

Since the strengths of the wire ropes, when new and unused, submitted for these tests are not known, it has been necessary to make comparisons between the strength of the specimen least worn and of those which had broken wires or wear. For those ropes for which specimen A had no visible wear or broken wires, the area of specimen A, as well as the strength, has been considered to be 100 percent. For the ropes for which specimen A had either wear or broken wires the area of an assumed specimen having no wear or broken wires was calculated, and the strength of specimen A was considered to be in the same proportion to that of the assumed specimen as the relative areas.

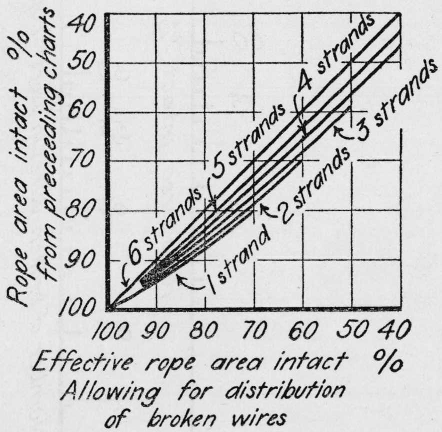


FIGURE 23.—*Remaining area, effective allowing for distribution of broken wires.*

From the remaining area charts and from figure 23 the percentage of the rope area intact was found for all specimens for which charts were available. The strength of the specimens B and C of each rope was then calculated from the remaining effective area and the strength of specimen A.

3. COMPARISON OF TEST RESULTS AND CHART VALUES

The relation between the actual breaking load and the values obtained from the charts is shown in figures 24 and 25. The 45-degree line in these figures obviously represents the condition for which these values would be equal. These figures show that, for most ropes, the actual breaking load was somewhat greater than the values obtained from the charts. Of 109 specimens (specimens B and C) available for comparison, 19 specimens are shown in these figures for which the actual breaking load was less than the chart value. Data for these specimens are given in table 7.

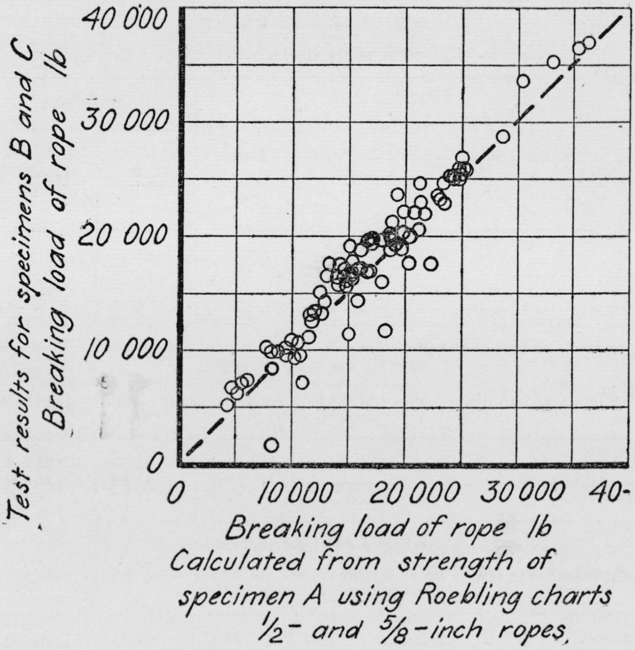


FIGURE 24.—*Relation between the actual breaking load and the values obtained from the charts for ½- and ⅝-inch diameter ropes*

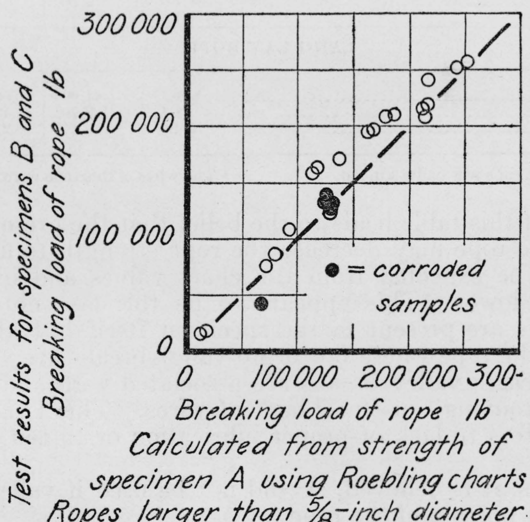


FIGURE 25.—*Relation between the actual breaking load and the values obtained from the charts for ropes having a diameter larger than ⅝ inch*

TABLE 7.—*Ropes for which the breaking load was less than the chart value*

REGULAR LAY ROPES

(Specimens in which all or nearly all of the breaks were valley breaks)

Construction	Rope	Breaking load		Difference between actual and chart value—percentage of chart value
		Test results	Chart value	
		lb	lb	%
2	69-C	11,500	15,000	23
5	17-B	9,300	10,700	13
5	58-C	[a] 1,900	8,150	77
5	62-C	7,100	11,000	36

REGULAR LAY ROPES

(Specimens B which had no valley breaks but for which valley breaks predominated in the corresponding specimen C)

2	8-B	22,950	23,500	2
2	38-B	17,800	22,200	20
5	62-B	11,600	18,400	37

REGULAR LAY ROPES

(Specimens which had very few or no valley breaks and for which valley breaks were not found in the corresponding specimen C)

2	37-C	17,850	19,600	9
2	40-B	20,600	21,300	3
2	44-B	20,050	20,300	1
2	44-C	17,750	20,300	13
2	53-C	11,200	11,300	1
2	71-C	15,800	18,000	12
5	18-C	20,250	20,400	1
5	23-B	14,350	15,800	10
5	68-2-B	9,500	10,600	10

LANG LAY ROPES

1	[b] 31-C	44,000	67,400	35
2	11-C	122,700	126,000	3
4	12-BC	210,600	212,200	1

[a] This rope was badly kinked. [b] The wires of this rope were rusty.

A study of this table leads to the belief that the presence of valley breaks in the rope may decrease the rope strength to a value lower than would be expected from the chart values and in some cases dangerously lower. This appears to be the case not only where valley breaks are present in the specimen itself but also for other portions of the rope where few or no valley breaks are visible.

In many cases valley breaks are associated with and are a direct result of "grooving" or "necking" of wires. This is attributed by some inspectors to lack of proper lubrication or to too small sheave diameters.

The charts, it is believed, should not be used if valley breaks are found in any portion of the rope.

In the ropes of table 7, however, in which few or no valley breaks were present, the actual breaking load was less than the chart value by a relatively small amount. Except for rope 31–C, which was corroded, 13 percent was the greatest difference.

The computed rope strength (chart value) depends on the strength of the single unworn specimen of the rope, on the amount of wear on the outside wires, and on the number and distribution of broken wires. It does not depend on the abrasion of the inside wires or on the core condition, which might be expected to have some effect on rope strength. The computed rope strengths, given in figures 24 and 25, take no account of the service to which the rope has been subjected, although the articles in Wire Engineering are careful to point out that the service does affect the strength and give corrections for elevator ropes. The values given in figures 24 and 25, however, based on the results of tests of ropes made by different manufacturers and used under a wide variety of conditions, show that the strength of a worn wire rope, without valley breaks or corrosion, can be estimated closely from surface inspection data and the use of the Roebling charts.

If the ropes showing corrosion or having valley breaks are disregarded, there remain only a few ropes for which the test results do not agree with the computed values. These cases are not a large proportion of the total number of ropes for an investigation of structures as varied and complicated as wire ropes. None of these discrepancies (valley break and corroded samples excepted) are considered large enough to be dangerous, provided the chart values showed the rope to have been safe.

WASHINGTON, April 13, 1936.