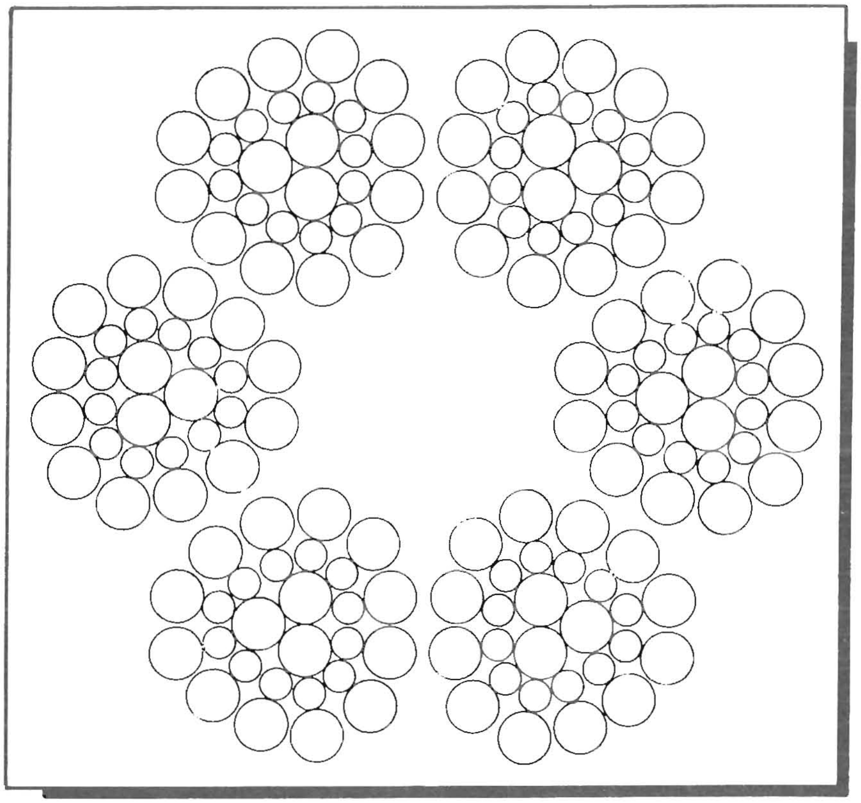
RI 9547

REPORT OF INVESTIGATIONS/1995

Bending Fatigue Tests on Flattened Strand Wire Rope at High Working Loads



UNITED STATES DEPARTMENT OF THE INTERIOR

MARCH 3, 1849

UNITED STATES BUREAU OF MINES

U.S. Department of the Interior Mission Statement

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

Cover: Flattened Strand Wire Rope Construction.

Report of Investigations 9547

Bending Fatigue Tests on Flattened Strand Wire Rope at High Working Loads

By Richard C. Wang and David E. Shapiro

UNITED STATES DEPARTMENT OF THE INTERIOR
Bruce Babbitt, Secretary

BUREAU OF MINES
Rhea L. Graham, Director

International Standard Serial Number
ISSN 1066-5552

CONTENTS

ILLUSTRATIONS

TABLES

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

With Factors for Conversion to U.S. Customary Units

To convert from—		To—	Multiply by—
cm/min	centimeter per minute	inch per minute	0.3937
deg	degree (angle)		
GPa	gigapascal	kip per square inch	145.04
kN	kilonewton	kip	0.2248
m	meter	foot	3.2808
m/min	meter per minute	foot per minute	3.2808
min	minute	inch	0.03937
mm	millimeter		
N•m	newton-meter	pound-foot	0.7376
N•m/kN	newton-meter per kilonewton	pound-foot per kip	3.2808
pct	percent		
pct•m/m	percent meter per meter		

BENDING FATIGUE TESTS ON FLATTENED STRAND WIRE ROPE AT HIGH WORKING LOADS

By Richard C. Wang[1] and David E. Shapiro[2]

ABSTRACT

The U.S. Bureau of Mines established a wire rope research laboratory to examine the factors that affect the safety and the useful life of wire rope. In the most recent work, two 32-mm 6x27H flattened strand ropes were degraded on a bending fatigue machine. The two tests were run at constant loads of 285 and 347 kN or safety factors of 2.5 and 2. Nondestructive and tensile strength tests were performed on samples of the ropes to determine the relationship between rope deterioration and rope breaking strength. Neither the area loss nor the number of broken wires measured from nondestructive tests could be used as clear indicators of the loss of strength. However, it was found from the tensile tests for both rope specimens that the strength loss was associated with the reduction of breaking strain. This suggests that measuring the strain of many short sections of a rope in the elastic region may locate the high stress sections and thus determine the condition of the rope.

---

[1] Civil engineer.
[2] Mechanical engineer.
Pittsburgh Research Center, U.S. Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

The Wire Rope Research Laboratory is located at the U.S. Bureau of Mines (USBM) Pittsburgh Research Center in Bruceton, PA. The laboratory was set up as part of the Hoisting System Development project, which has been a continuing effort by the USBM for several years. The primary goal of this project is to improve both the safety and efficiency of hoisting systems. A major part of this effort involves studying the degradation of wire rope during its service life. Personnel-carrying hoists are used for transporting miners in hundreds of mines, hence failure of the rope in a single high-capacity hoist could result in a catastrophic accident.

The reduction of rope diameter and the number of broken wires are specified in the current retirement criteria, but the effect of rope construction on these specifications has not been properly considered. Another criterion is loss of more than 10 pct of rope strength as determined by nondestructive testing, but there is no explanation of how the loss of strength is determined. In order to enhance the safety and to prevent the premature retirement of wire rope, controlled bending fatigue and nondestructive and tensile strength tests need to be conducted to quantify the degradation process. The research approach is to generate accurate data from each of these tests and then to use them to provide recommendations for developing or modifying regulations governing retirement criteria. Thus, it can be seen that the safety and economic concerns are interrelated and that the potential benefits of such research are high.

In the most recent work, two 32-mm 6x27H flattened strand ropes were tested. These were the sixth and seventh wire rope tests conducted to investigate the effect of bending fatigue on a variety of rope constructions and sizes. They are referred to as tests 6 and 7 in this report.

EQUIPMENT DESCRIPTION

BENDING FATIGUE MACHINE

Fatigue from bending over sheaves and drums is one of the primary modes of wire rope degradation. The principal machine in the laboratory is one designed to cause fatigue damage in varying degrees in a long sample of wire rope. By using a long sample, the possibility of variations among short samples due to manufacturing is avoided. The bending fatigue machine is shown in figure 1, and a schematic diagram of the rope path is shown in figure 2.

The three-sheave configuration not only shortens the load frame, but also multiplies the number of cycles of rope bending for each machine cycle. Nine levels of degradation can be obtained from each rope tested. The number by which the machine cycle is multiplied to obtain the number of bending cycles is called the cycle multiplier. The bending cycle profiles for these tests are shown in figure 3.

Overall control of the machine is provided by a computer. The computer manages the hydraulic system as well as the drive system. The hydraulic system maintains constant rope tension and compensates for stretch in the rope through a ram on the center sheave. It also manages the braking system used for emergency shut down when the computer detects an abnormal operating condition. Drum rotation is changed by a regenerative braking system in the drive. The hydraulically controlled friction brake serves as a backup system. The computer is programmed to monitor the output from a variety of sensors and to react to emergency situations, such as when the tension cylinder runs out of travel, when the rope is nearing the end on the drum, or if the rope should break. Operations are monitored continuously throughout a test.

The current drum liner is flat, but can be replaced with other surfaces such as urethane-coated materials or grooved liners. The rim of each sheave is made with bolt-on segments that are replaceable for different rope diameters.

The specifications for the fatigue machine are given in table 1.

Table 1.—Bending fatigue machine specifications

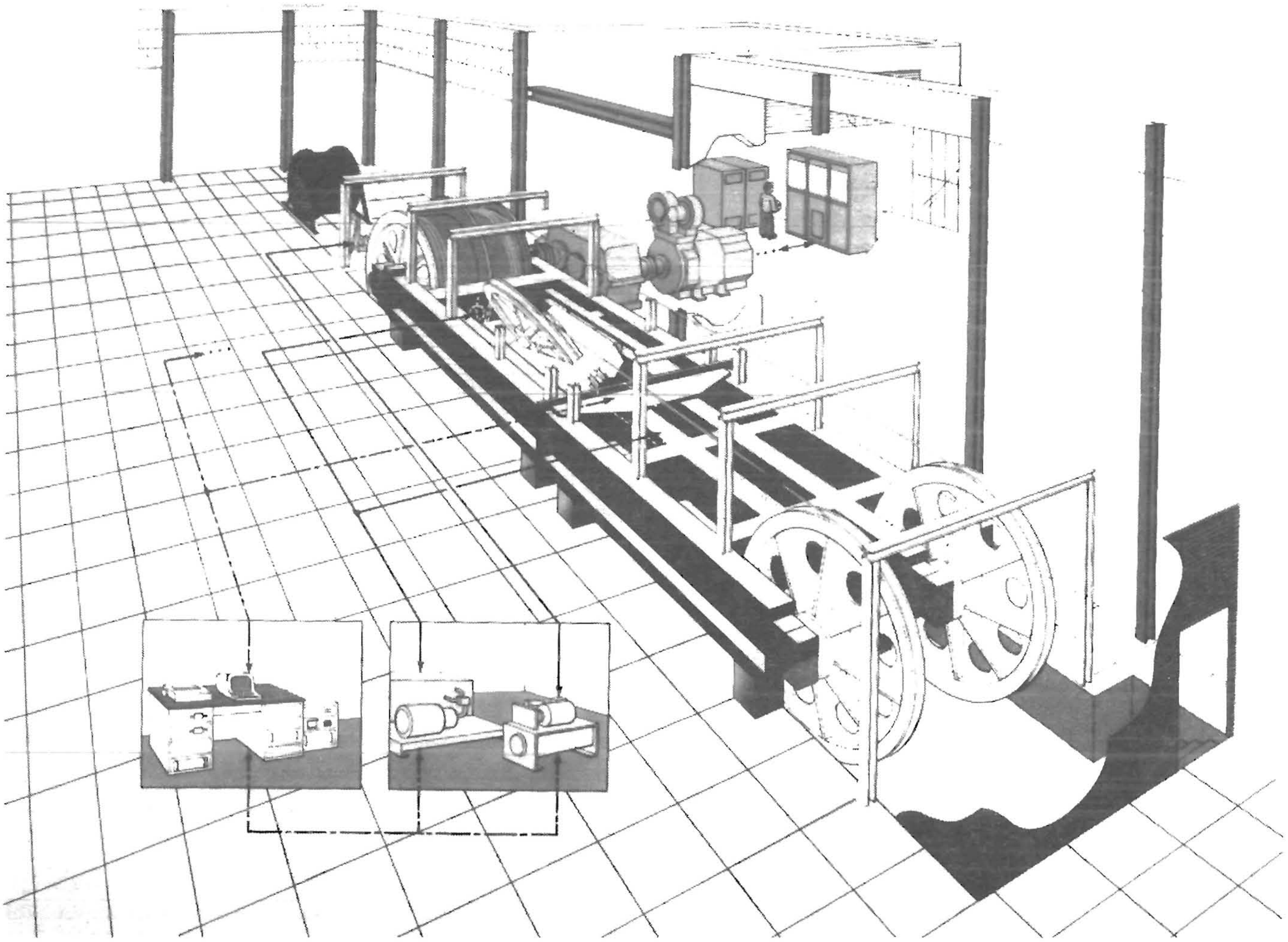
Drum:	
Diameter, m	3.05
Fleet angle, maximum, deg	2.9
Width, m	2.56
Idler sheave diameter, m	2.44
Rope:	
Diameter, mm	2.54 - 57.2
Length, maximum, m	335.3
Speed, m/min	304.8
Stretch, maximum (without regripping), m	6.1
Tension, maximum, kN	1,334
Tension sheave diameter, m	3.05

NONDESTRUCTIVE TESTING EQUIPMENT

Two commercially available electromagnetic nondestructive testers (EM NDT) were used during these tests. One was the Magnograph Model MAG-1. The other was the NDT Technologies Model LMA-250.

Such devices can detect a loss of metallic area because of wear, corrosion, and separated broken wires that reduce

Figure 1



Bending fatigue machine.

the strength of a wire rope. However they are not prescribed for mandatory use under the wire rope retirement regulations issued by the Mine Safety and Health Administration (MSHA). The testers operate on the principle of magnetically saturating the test rope and then measuring any changes in the flux level caused by defects. A worn section of rope shows a lower level of flux density. The discontinuity caused by a broken wire causes a flux leakage. These sensors produce a two-channel chart showing the loss of metallic area and the number of broken wires. Because broken wires create magnetic anomalies, they are recorded as spikes on the chart and can be counted. These broken wire indications are known as local flaws and are caused by either brittleness or excessive wear of the individual wires.

Figure 2

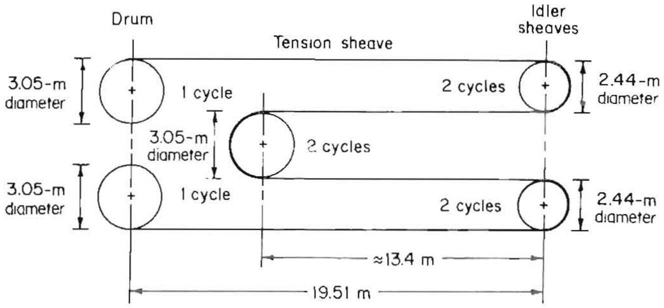
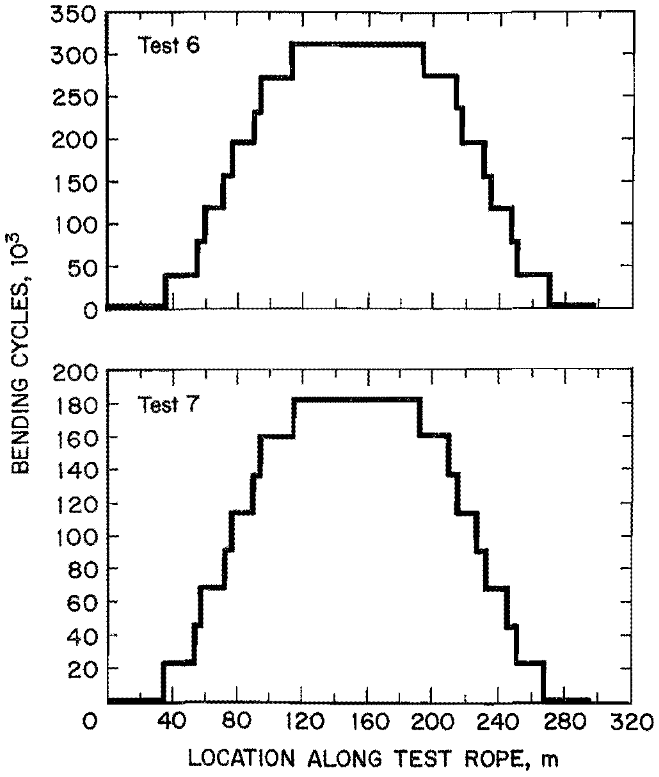


Diagram of rope path.

Figure 3



Bending cycle profile.

TENSILE AND AXIAL FATIGUE TESTING MACHINE

The second major piece of equipment in the laboratory is the tensile and axial fatigue testing machine. It was only used in these tests to measure the actual breaking strengths, elongations, and torques of samples cut from the bending fatigue test rope. The performance of this machine was reported in a previous publication.[3]

The tensile testing machine is hydraulically actuated and operates in a horizontal position rather than the usual vertical position to reduce vertical height requirements and for ease of access. The load is applied through a closed-loop servohydraulic system. The controllable parameters are displacement of the actuator, load applied to the specimen, and torque generated by the specimen as the axial load is applied. In these tests, the actuator displacement was controlled at 2.54 cm/min. The system specifications are listed in table 2.

Table 2.—Tensile and axial fatigue testing machine specifications

Actuator speed, maximum, cm/min	81.28
Rope diameter, mm	2.54 - 57.2
Sample length, m	0.61 - 10.06
Tension, maximum, kN	3,559
Torque, maximum, N•m	28,201

TEST ROPE DESCRIPTION

The test rope specifications were: 32-mm diameter, 6x27H flattened strand (FS) construction, right lang lay (RLL) of 24.6-cm lay length, improved plow steel (IPS), and fiber core (FC). The rope construction is shown in figure 4. There are six triangular strands. Each strand is made up of three 0.0034-mm-diameter center wires, a layer of twelve 0.0021-mm-diameter wires surrounding the center wires, and an outer layer of twelve 0.0035-mm-diameter wires. Thus, each rope is composed of 162 wires. The two ropes tested were from the same reel and had a tested breaking strength of 705 kN.

TEST PROCEDURES

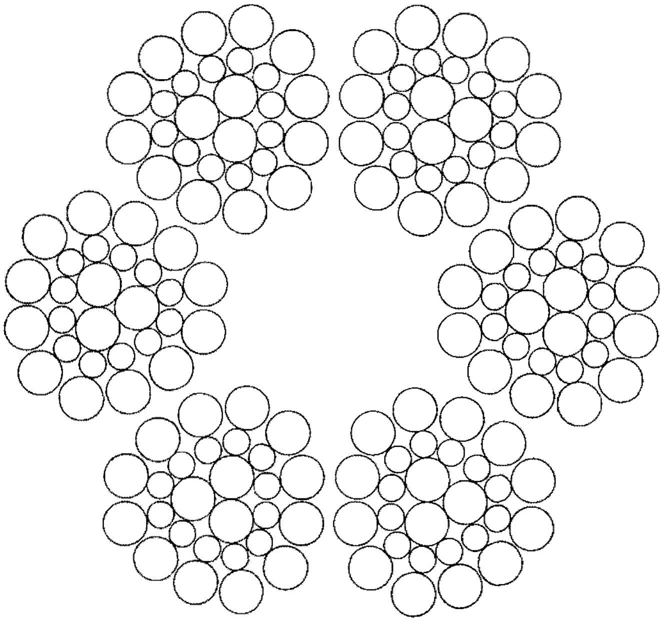
BENDING FATIGUE TEST

The rope specimens were reeved through the machine and wound onto the drum. Test 6 was run at a constant tension of 285 kN, which is equivalent to 40 pct of the breaking strength of a new rope or an initial safety factor of about 2.5. The test was run at a speed of 274 m/min until the specimen broke on the machine at 39,339 machine cycles, or equal to a maximum 314,712 bending cycles. Test 7 was run at a constant tension of 347 kN, which is equivalent to 49 pct of the breaking strength of a new rope or an initial safety factor of about 2. This test was also run at a speed of 274 m/min for a total of 22,812 machine cycles, or equal to a maximum of 182,496 bending cycles. The test parameters are summarized in table 3. The safety factors exceed those allowed for field operating conditions.

---

[3] McKewan, W. M., and A. J. Miscoe. Baseline Tensile Testing at the Wire Rope Research Laboratory. USBM IC 9255, 1990, 23 pp.

Figure 4



Rope construction.

Table 3.—Parameters for bending fatigue tests

Parameter	Test 6	Test 7
Fleet angle, maximum, deg . .	1.476	1.027
Rope:		
Diameter, mm	32	32
Length, m	298	296
Safety factor	2.5	2.0
Speed, m/min	274.3	274.3
Tension, kN	284.7	347.0

When the ropes were removed, they were cut into 7.62-m pieces. The selection of samples for further testing was based on the number of bending cycles. These samples were cut into three sections. The 5.182-m-long pieces were used for destructive tensile tests, the 1.524-m-long pieces were used for wire-by-wire examination, and the 0.914-m pieces were stored for other purposes.

TENSILE TEST

The samples were terminated with resin-filled, standard, closed sockets. This resulted in a finished specimen gauge length of about 4.9 m. This length was chosen based on the results of a baseline tensile testing program, which determined that shorter samples would show abnormally high breaking strengths.[4]

The terminated samples were then placed in the tensile machine. Initially, a prestretch load of about 20 pct of the breaking strength was placed on the sample for 15 min to reduce constructional stretch. Once this load was removed, certain physical measurements were made on the sample. These were gauge length, rope diameter, and lay length. The tensile test was then conducted at a 2.54 cm/min displacement of the actuator rod. The load applied to the specimen and the torque generated by the specimen as the strain was applied were automatically logged.

NONDESTRUCTIVE TEST

For the nondestructive tests, extra pieces of crown (outer) wire were embedded underneath the strands, in coded order, at 15.24-m intervals to act as permanent markers on the EM NDT chart traces. To conduct a test, the rope is run through the instrument once to properly magnetize it. The sensor head is removed during rewinding to prevent a change in the magnetic polarity of the rope and then the head is remounted. The rope is then run through the instrument while the data are being recorded. For these tests, the Magnograph instrument was mounted on the rope near the top of the drum and the NDT Technologies instrument was mounted on the rope near the bottom of the opposite side of the drum. In these locations, the 76.2 m of rope that ran through the sheaves could not be tested by both machines. However, with the sensors placed at opposite ends, the maximum length of rope was covered and the two chart traces overlapped for comparison. EM NDT tests were run weekly but only the data obtained at the end of bending fatigue tests were used in this study.

TEST RESULTS

The configuration of the bending fatigue machine allows a range of degradation to be achieved from a single test run. The data obtained from these tests were indicative of wire rope condition ranging from minimal wear or no loss of strength to a condition of imminent rope failure. The controlled laboratory conditions allowed the rope to be degraded beyond the limits specified in the MSHA retirement criteria. The sample locations along the two ropes, the numbers of bending cycles, and the data obtained from the tensile tests are shown in table 4.

Figure 5 shows the breaking load versus the sample location along each test rope. The center section of the rope, which was located in the cycle multiplier zone of 8,

---

[4] Work cited in footnote 3.

had the most degradation and strength loss. The maximum loss of strength was over 30 pct for both tests. There were also cycle multiplier zones of 2, 4, and 6, however, no samples were taken from these zones because they were too short. Because of this, these zones were not shown in figure 5. Owing to the machine configuration, the strength loss in the first half of the rope was approximately a mirror image of the second half.

Table 4.—Tensile test samples and data

Sample	Sample location, m	Cycle multiplier	Number of bending cycles	Breaking load, kN	Breaking strain, pct•m/m
			TEST 6		
1	9.14 - 14.33	0	0	708.6	4.03
2	32.00 - 37.19	1	39,339	714.8	4.08
3	39.62 - 44.81	1	39,339	716.2	3.97
4	54.86 - 60.05	3	118,017	714.4	3.85
5	62.48 - 67.67	3	118,017	715.7	3.46
6	77.72 - 82.91	5	196,695	705.0	2.92
7	92.96 - 98.15	7	275,373	698.4	2.78
8	100.58 - 105.77	7	275,373	678.4	2.31
9	115.82 - 121.01	8	314,712	495.5	1.13
10	131.06 - 136.25	8	314,712	635.2	1.94
11	146.30 - 152.40	8	314,712	478.2	1.39
12	154.84 - 160.02	8	314,712	664.1	2.14
13	162.46 - 167.64	8	314,712	637.0	1.79
14	170.08 - 175.26	8	314,712	595.6	1.43
15	185.32 - 190.50	7	275,373	702.4	2.89
16	192.94 - 198.12	7	275,373	708.2	2.97
17	208.18 - 213.36	5	196,695	717.9	4.03
18	223.42 - 228.60	3	118,017	720.6	4.28
19	231.04 - 236.22	3	118,017	715.7	4.10
20	246.28 - 251.46	1	39,339	715.3	4.07
21	253.90 - 259.08	1	39,339	710.4	3.87
22	284.38 - 289.56	0	0	708.2	4.07
			TEST 7		
1	9.14 - 14.33	0	0	708.2	3.97
2	39.62 - 44.81	1	22,812	708.6	4.03
3	47.24 - 52.43	1	22,812	706.4	3.88
4	62.48 - 67.67	3	68,436	706.8	3.63
5	77.72 - 82.91	5	114,060	705.9	3.40
6	92.96 - 98.15	7	159,684	709.0	3.61
7	100.58 - 105.77	7	159,684	697.5	2.96
8	115.82 - 121.01	8	182,496	692.6	2.78
9	121.92 - 127.10	8	182,496	488.0	1.50
10	129.54 - 134.72	8	182,496	686.4	2.56
11	160.02 - 165.20	8	182,496	696.6	2.93
12	175.26 - 180.44	7	159,684	705.9	3.64
13	182.88 - 188.06	7	159,684	705.0	3.73
14	198.12 - 203.30	5	114,060	701.0	3.15
15	220.98 - 226.16	3	68,436	705.0	4.03
16	236.22 - 241.40	1	22,812	704.6	3.75
17	243.84 - 249.02	1	22,812	703.3	3.85
18	281.94 - 287.12	0	0	693.9	4.01

Figure 6 shows the effect of the number of bending cycles on breaking strength. The rope experienced a sharp decrease in strength at the maximum bending cycles.

The rope diameter of each sample for the tensile tests was measured by a caliper and averaged from three positions around the rope. Data are tabulated in table 5. Those diameters larger than the nominal size are within the oversize limit adopted by the Wire Rope Technical Board.[5] The sample numbers in the first column are the same as those used in table 4, which correlates to their locations along the test rope. Figure 7 shows the effect of the number of bending cycles on the rope diameter. Initially, there is a rapid loss of diameter as the tops of the crown wires are worn. Then, loss of diameter occurs at a slower rate as a larger bearing area is created by the wear.

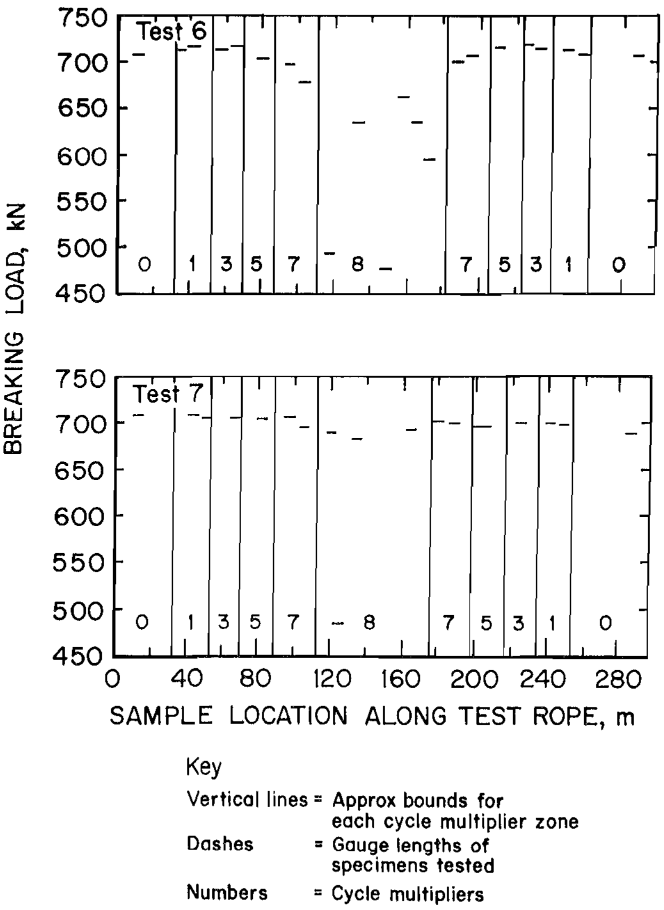
Two factors are generally considered when the breaking strength of a wire rope needs to be estimated nondestructively: loss of aggregate metallic area and the number of broken wires.

The loss of area determined from the two EM NDT sensors is tabulated in table 5. The effect of the number of bending cycles on the measured area loss is shown in figure 8. This loss is considered to be small for the number of bending cycles. The ratio of sheave diameter to rope diameter is 76.8, large when compared to the Wire Rope Technical Board suggested minimum ratio of 30.[6] Therefore, both wear and fatigue are reduced.

Table 5 also shows the tabulation of a visual count of the number of broken wires per lay on the surface of the rope. These were the averages for two lay lengths. There are no broken wires when the number of bending cycles is less than 280,000 in test 6 or 160,000 in test 7. Unlike the gradual increase in broken wires found in 6x25 FW FC wire ropes, which will be reported in another publication, the loss of strength in these ropes occurs suddenly and is not indicated clearly by the number of broken wires.

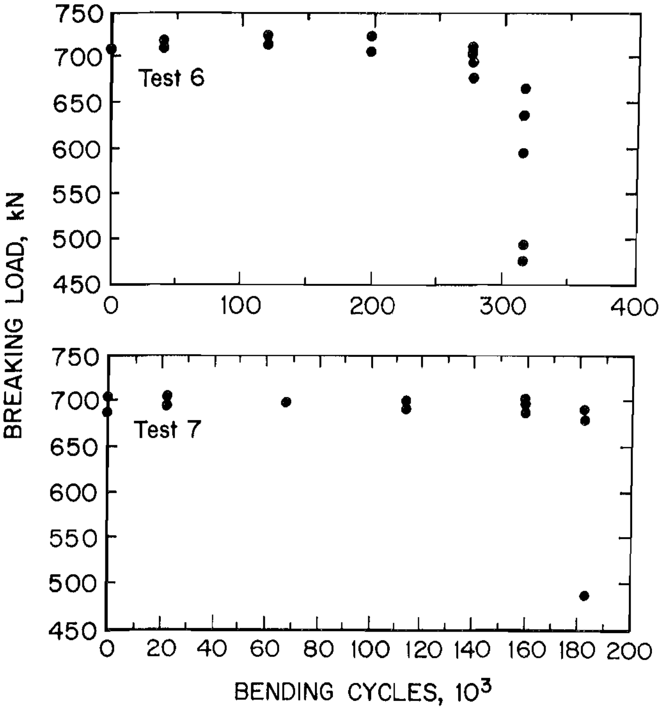
Table 6 shows the data computed from the measurements made during the tensile tests.

Figure 5



Breaking load versus sample location.

Figure 6



Breaking load versus bending cycles.

---

[5] Wire Rope Technical Board. Wire Rope Users Manual. Third Edition. 1993, 164 pp.

[6] Work cited in footnote 5.

Table 5.—Area loss and broken wires per lay

Sample	Number of bending cycles	Rope diameter, mm	Area loss measure by EM NDT, pct	Broken wires per lay
		TEST 6		
1	0	33.12	NA	0
2	39,339	33.15	0.001	0
3	39,339	31.83	0.001	0
4	118,017	31.57	0.500	0
5	118,017	31.85	0.500	0
6	196,695	32.05	0.500	0
7	275,373	31.85	0.500	0
8	275,373	32.08	0.500	0
9	314,712	32.05	1.000	0
10	314,712	31.93	1.000	0
11	314,712	31.98	0.500	1.5
12	314,712	31.72	0.500	0
13	314,712	31.88	0.500	0
14	314,712	31.70	0.500	0
15	275,373	32.08	0.500	0
16	275,373	32.13	0.500	0
17	196,695	32.16	0.500	0
18	118,017	32.00	0.001	0
19	118,017	32.18	0.001	0
20	39,339	32.49	0.001	0
21	39,339	32.51	0.001	0
22	0	32.97	NA	0
		TEST 7		
1	0	32.61	NA	0
2	22,812	32 08	0.000	0
3	22,812	31.93	0.000	0
4	68,436	31.37	0.000	0
5	114,060	31.32	0.000	0
6	159,684	31.27	0.000	0
7	159,684	31.14	0.000	0
8	182,496	30.94	0.500	0
9	182,496	31.04	1.000	0
10	182,496	30.96	0.250	0
11	182,496	30.99	0.000	0.5
12	159,684	31.01	0.000	0
13	159,684	31.01	0.000	0
14	114,060	31.32	0.000	0
15	68,436	31.45	0.000	0
16	22,812	31.95	0.000	0
17	22,812	31.65	0.000	0
18	0	32.69	NA	0

NA Not available.

Table 6.—Calculated tensile test data

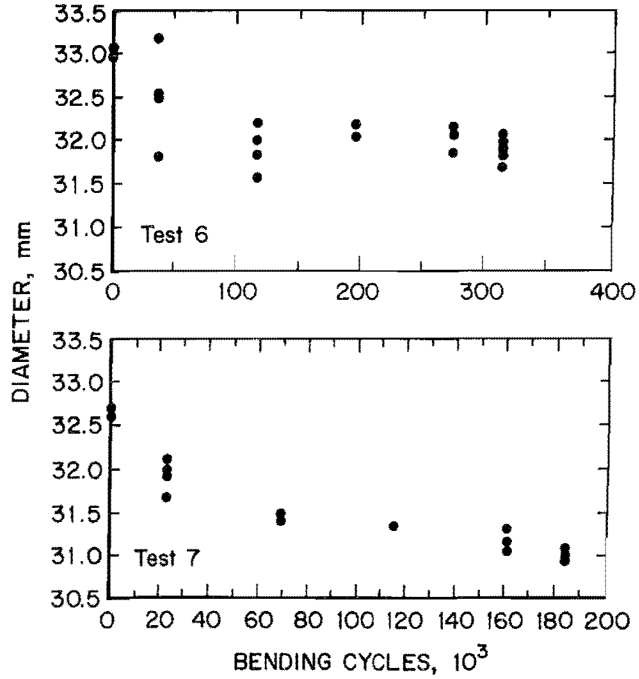
Sample	Number of bending cycles	Apparent modulus of elasticity, GPa	Torque K, N•m/kN
		TEST 6	
1	0	100.7	4.100
2	39,339	109.6	3.950
3	39,339	109.6	3.959
4	118,017	113.8	3.877
5	118,017	116.5	3.862
6	196,695	113.8	3.889
7	275,373	113.1	3.819
8	275,373	111.7	3.868
9	314,712	110.3	3.847
10	314,712	109.6	3.850
11	314,712	93.8	3.469
12	314,712	110.3	3.868
13	314,712	111.7	3.895
14	314,712	113.1	3.868
15	275,373	112.4	3.874
16	275,373	112.4	3.938
17	196,695	113.1	3.911
18	118,017	111.0	NA
19	118,017	110.3	3.953
20	39,339	107.6	4.008
21	39,339	107.6	4.026
22	0	100.7	4.109
		TEST 7	
1	0	98.6	4.093
2	22,812	113.8	4.121
3	22,812	113.1	4.023
4	68,436	115.1	3.725
5	114,060	113.8	3.731
6	159,684	111.7	3.673
7	159,684	113.8	3.700
8	182,496	110.3	3.527
9	182,496	89.6	3.530
10	182,496	113.1	3.673
11	182,496	112.4	3.734
12	159,684	112.4	3.706
13	159,684	113.1	3.786
14	114,060	114.5	3.764
15	68,436	113.8	3.837
16	22,812	109.6	3.895
17	22,812	109.6	3.908
18	0	98.6	4.075

NA Not available.

The modulus of elasticity of a wire rope not only depends on the rope construction, but it also varies when the rope structure deforms. However, the variation becomes small once the construction stretch diminishes, and a linear relationship can be approximated between stress and strain of the rope. The apparent modulus of elasticity is determined based on a constant cross-sectional rope area.

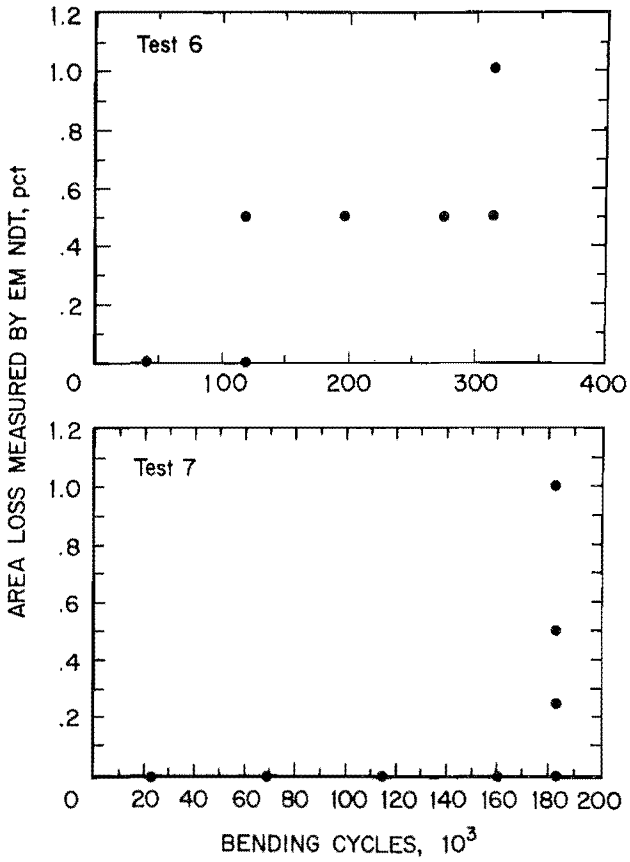
The effect of the number of cycles on the apparent modulus of elasticity is shown in figure 9. The apparent modulus of elasticity increases initially with the number of bending cycles and then remains approximately constant as

Figure 7



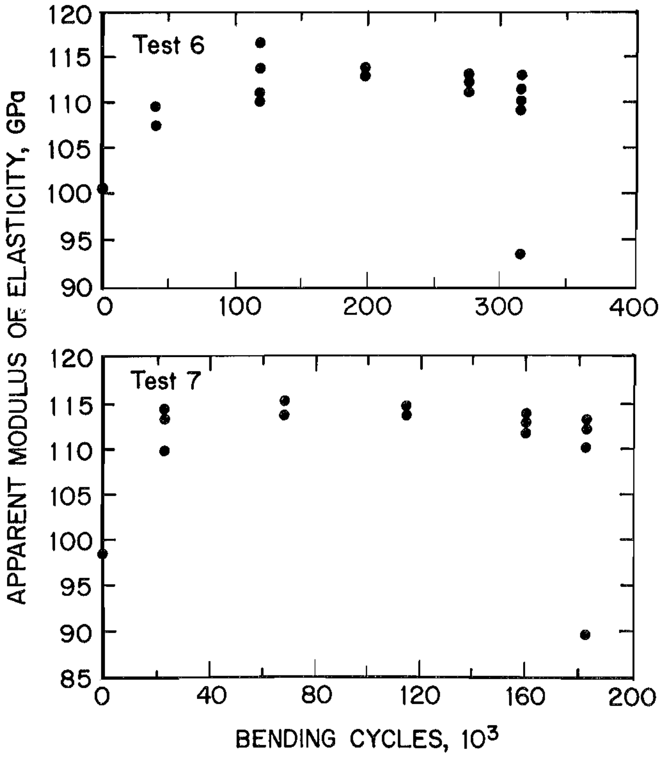
Rope diameter versus bending cycles.

Figure 8



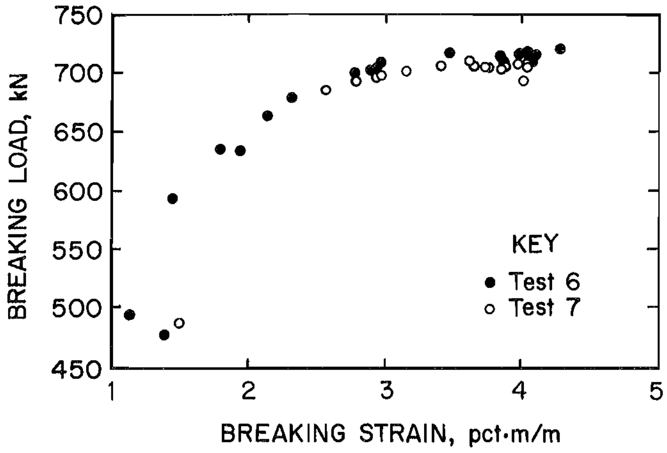
Area loss versus bending cycles.

Figure 9



Apparent modulus of elasticity versus bending cycles.

Figure 10



Relation between breaking load and breaking strain.

the number of bending cycles increases further. The lowest apparent modulus in either test is from the sample whose breaking strength is the lowest.

Torque K is the slope of the linear portion of the torque-load plot. Unlike the stress-strain plot, the torque is linear with load until just before rupture. Torque K is not clearly associated with increased cycling or strength loss, probably due to the helical configuration of the wires in the rope structure.

A plot between the breaking load and the breaking strain is shown in figure 10. It is interesting to note that the data of the two bending fatigue tests have yielded a similar relationship, although their tensile loads or safety factors and maximum bending cycles are significantly different. This clearly shows that the reduction in breaking load is associated with decreasing breaking strain and that the rate of the reduction increases as the breaking strain decreases. Because the breaking load represents the load at which the wires have reached their ultimate strength, figure 10 also implies that the wire stresses increase more in a deteriorated rope for each unit of strain. In other words, a smaller amount of load is required to achieve a unit of strain in a deteriorated rope. If a certain load is applied to a rope where varying degrees of deterioration exist, the wire stresses would be higher in the section that has suffered more loss of strength. However, stress is proportional to strain in the elastic region. This suggests that measuring the strain of many short sections of a rope in the elastic region may locate the high stress sections and determine the condition of the rope.

CONCLUSIONS

Two 32-mm-diameter 6x27H FS RLL IPS FC ropes were degraded on a bending fatigue machine. These were the sixth and seventh tests conducted to investigate the effect of bending fatigue on a variety of rope constructions and sizes; they were the first flattened strand lang lay ropes tested. The results show that both tests have caused a strength loss of over 30 pct. The loss was achieved in 314,712 bending cycles under the constant load of 285 kN or a safety factor of 2.5 for test 6, and 182,496 bending cycles under the constant load of 347 kN or safety factor of 2 for test 7.

The rope diameter decreased rapidly as the tops of the crown wires were worn initially, but then the reduction became much slower as a larger bearing area was created by the wear. The loss of strength of the rope tested could not be detected reliably by the rope diameter because of the lack of association between them.

The maximum area loss for both tests was 1 pct based on the EM NDT sensor measurements. This is considered to be insignificant for the number of bending cycles. There were no broken wires below 280,000 bending cycles in test 6 or below 160,000 bending cycles in test 7. Higher bending cycles resulted in an average of only 1.5 broken wires and 0.5 broken wires per lay, respectively. Therefore, area loss and broken wires are not clear indicators for the loss of strength of the rope currently studied. Whether or not this is true for ropes under normal mine-hoisting conditions has not yet been established. Unlike the gradual increase in broken wires found in 6x25 FW FC wire ropes tested earlier, the strength loss occurs so suddenly that reliance on the area loss measurements or a visual count of the number of broken wires to predict the rope condition is risky.

The similarity in the relationships between the breaking load and the breaking strain that both bending fatigue tests have yielded indicates that the wire stresses increase more in a deteriorated rope for each unit of strain. Because stress is proportional to strain in the elastic region, this suggests that measuring the strain of many short sections of a rope in the elastic region may locate the high stress sections and determine the condition of the rope.

More studies of the effect of bending fatigue on strain in wire rope are needed before the strain can be used to improve current retirement criteria. Further testing and analysis on this rope construction will also be necessary to determine if a more accurate measurement of area loss and the number of broken wires, or some other indicators, are needed for reliable detection of imminent failure condition in wire rope.

INT.BU.OF MINES,PGH.,PA 30084

☆ U.S.G.P.O. 1995-609-012/ 20,009