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An Analysis of 6X19 Classification Wire Hoist Rope

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UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	µm	micrometer
g	gram	pct	percent
in	inch	psi	pound per square inch
kip	thousand inch-pound	rpm	revolution per minute
lb	pound	wt pct	weight percent
lb/min	pound per minute	yr	year
mm	millimeter		

AN ANALYSIS OF 6X19 CLASSIFICATION WIRE HOIST ROPE

By R. R. Lowery [1] and G. L. Anderson [2]

ABSTRACT

An analysis of three 1-1/4-diam manufactured wire ropes of 6×19 classification was done to identify and describe reference conditions of new rope. Reference condition is of value when examining tested or retired ropes. Measurements of strand and rope pitch and of wire and rope diameter confirmed adherence of all ropes to those construction specifications. Mechanical properties of strength and ductility were determined by accepted methods for the ropes and wires from the ropes. Individual wires from one rope failed to meet minimum wire ductility values. Wire chemical composition varied in average carbon levels, from 0.70 to 0.78 wt pct, and in manganese content, from 0.45 to 0.80 wt pct. One manufacturer's product contained 1 to 3 wt pct Ni and Cr. Heavily wrought pearlitic steel microstructures were porous and contained inclusions. Cold work variations were evidenced by wrought grain width. Recorded anomalies reflected the condition of the manufactured products. The report provides data that compare the three wire ropes studied, but cannot verify the effects that these conditions or anomalies have on rope service life.

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INTRODUCTION

Wire rope has many uses in both surface and underground mining. Hoisting at underground mines requires rope to have high reliability under a broad range of operating conditions to provide safety during transporting of personnel and for economical operation. Shaft hoist rope failures are not frequent, but the potential is high for a catastrophic accident resulting in death and loss of production. In the 1978-80 3-yr period, there were 114 hoisting accidents associated with cages, elevators, or skips in metal and nonmetal mines resulting in four deaths, and 168 accidents in coal mines, resulting in three deaths.

The Bureau of Mines and the Mine Safety and Health Administration (MSHA) have expressed concern through correspondence and meetings (1-2)[3] about variations that exist within a wire rope and the effects these have on rope degradation and service life. The Bureau of Mines published Rules and Regulations for Metal Mines, Bulletin 75, in 1915 "in hope that the passage of such a uniform law by the mining States would tend to lower the number of fatal and serious accidents." The bulletin served well and paved the way for the more complex regulations in the Code of Federal Regulations (CFR) (3) that are currently enforced by MSHA under the U.S. Department of Labor.

This reported work was undertaken to obtain data that can be used to evaluate and improve the retirement criteria for mine hoist rope. The improved criteria primarily would protect personnel from catastrophic failures of ropes, and would also assure mine operators optimum life for an expensive expendable in their cost of operation. Prediction of the life of a mine hoist rope is a difficult task because it is hard to quantify CFR retirement with measurable data. A wire rope can absorb considerable fatigue damage and other energy before catastrophic failure because it is a well-engineered structure (multiple strand, controlled construction, wrought wires, etc.). The damage absorbed can be visually monitored in the cases of kinking, wear, external wire breaks, and corrosion, but internal damage can only be monitored by systems of nondestructive testing (NDT) to detect losses of section or breaks in wires. NDT methods indicate where internal damage is located, but quantitative measure of that damage is not obtained with repeatability needed to accurately assess rope conditions. A large bank of individual wire and rope fatigue data exists, but it has never been combined and analyzed to give a better prediction of retirement time than the 1915 Bureau of Mines Bulletin 75, section 34, version that uses accumulated visual damage and NDT-detected damage:

> "It shall be unlawful to use any rope or cable of the so-called 6 by 19 standard construction for the raising or lowering of men, either when the number of broken wires in one lay of said rope exceeds six, or when the wires on the crown of the strands are worn down to less than 65 per cent of their original diameter, or when the superficial inspection provided for in this section shows marked signs of corrosion: *Provided, however*, That when such broken wires are reduced by wear more than 30 per cent in cross section, the number of breaks in any lay of the rope shall not exceed three."

This report provides data that characterize the three wire ropes studied but cannot verify effects that the new rope conditions or service conditions have upon rope service life.

[3]Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

EXPERIMENTAL PROCEDURE

A survey of hoists and rope sizes used in mines of the United States was used to select a size of rope for this investigation. Table 1 summarizes the information used to select 1-1/4-in-diam rope for study. Descriptions of ropes purchased for analysis are listed in table 2. All three ropes fall within a 6×19 classification and, therefore, have the same catalog breaking strength of 138,800 lb. As seen in table 1, the selected ropes are of popular diameter, construction, lay, and steel grade used in hoisting. The independent wire rope core (IWRC) was selected over a fiber core to include the metallic core in the analysis.

TABLE 1. Hoist rope installation data (7)

Rope parameter	Use, pct	
	Shaft	Slope
Construction:		
6×19	54	58
6×21	5	27
6×25	27	NA
Diameter, in:		
1	NA	18
1-1/4	17	52
1-3/8	7	9
1-1/2	19	NA
2	12	NA
Core:		
Fiber	89	87
Independent wire rope	11	13
Lay:		
Regular	54	66
Lang	46	34
Steel grade:		
Plow steel	11	24
Improved plow steel	85	76
Extra improved plow steel	4	NA

NA Not available.

A 75-ft length of each specific rope was purchased from local retailers. Letter identifications A, B, and C were substituted for manufacturer names. A leading end was designated to permit identification of rope strand and wire locations. Outer strands were labeled using a colored strand to index 1 through 6 numbering. Strand number was counted clockwise, viewing the leading end of the rope, starting with the colored strand as 1. The IWRC was labeled strand 7 in the tables. Fifteen feet of the rope was sent to the Bureau's Albany (OR) Research Center for independent wire evaluation, whereas the remaining 60 ft was held at the Bureau's Spokane (WA) Research Center to determine rope breaking strengths and conformance of rope construction to accepted specifications (4-6).

There are no specifications with which mine hoist wire rope must comply. The specifications referred to in this report delineate recognized principles and practices that are followed by the wire rope industry. For example, an inspection certificate for rope B stated that the rope conforms to Federal Specification RR-W-410C (6). In following wire rope terminology used in reference 6, this report uses the term strand pitch, which is the same as another commonly used term, lay length.

TABLE 2. - Description of purchased ropes, 1-1/4-in diam

Rope	Manufacturer	Description[1]	Strand construction[2]
A	Domestic	6×19 seale, IPS, RRL, IWRC	9-9-1
B	Foreign	6×19 flexible seale, IPS, RRL, IWRC	9-9-6-1
C	Domestic	6×25 filler wire, IPS, RRL, IWRC	12-6-6-1

[1]IPS, improved plow steel; RRL, right regular lay; IWRC, independent wire rope core.

[2]Wires per layer within the strand; numbering from the crown layer towards the strand core (see figs. 1-3).

ROPE MEASUREMENT AND TESTING

The 60-ft length of each rope tested at Spokane was seized to prevent loosening of the rope and was cut into ten 6-ft specimens. These specimens were used to make geometrical measurements, to perform failure load testing, and to obtain rope modulus of elasticity.

Geometrical Measurements

Rope and strand geometrical measurements are shown in table A-1 of the appendix. Wire diameters are shown in table 3.

Rope Tensile Failure Strengths

Rope tensile specimens were terminated with zinc sockets installed by a local wire rope vendor. Specimens were tested on a 400-kip hydraulic universal testing machine with the sockets inserted through the load platens and a load beam inserted through the loop of the sockets. This loading arrangement prevented termination rotation to give a fixed end test of the rope.

Rope diameter and strand pitch of each tensile specimen was measured at 0 and 10 pct of catalog rope strength. By API specification (5) a rope is acceptable if the diameter is within tolerance at 10 to 20 pct of nominal rope tensile strength, therefore, the 10 pct measurements were obtained for the test specimens. After the 10 pct measurements were obtained, the specimens were loaded to failure at a load rate of approximately 20,000 lb/min. Tensile test data are summarized in table 3, and detailed test data are provided in table A-2.

Rope Modulus of Elasticity

Rope specimens A-6, B-6, and C-7 were instrumented with brackets clamped on the rope and with an extensometer to give rope elongation versus load. Each specimen was cycled three times to 80,000-lb load with data recorded at each 10,000-lb increment. At the end of the third cycle, the instrumentation was removed and the rope was loaded to failure at a load rate of approximately 20,000 lb/min. The modulus of elasticity for the third load cycle and tensile failure data are shown in tables A-3 and A-4.

WIRE TESTING AND METALLURGICAL ANALYSIS

Each of the three ropes was fully coded for individual wire examination by preparing a drawing indexed to the aforementioned color-coded number 1 strand. Figures 1, 2, and 3 illustrate the alphanumerical sequenced location code used to identify wires from specific locations within the assembled ropes and show photograms of cross sections of the ropes. The first wire in the code for each strand was that wire touching a circumscribed circle around the entire rope. Figure 1, for example, shows the location of two wires. A3M0 is an inner wire at letter position M of strand 3 for rope A. The zero only fills out the fourth space. A7F3 is an IWRC wire (strand 7) at position F in core strand 3 of rope A, etc. The color-coded number 1 strands are labeled on the leading end views of the ropes in the drawings.

Ropes were disassembled by hand to obtain individual wires. These wires were labeled and then hand-straightened for ease of testing and sampling for analysis. The straightening was accomplished by passing the wires through a block of steel drilled with holes slightly larger than the wire diameters. The 1-in-thick block served to support the wires, while the helical bends were removed by hand. The straightened wires were then cut to obtain specimens for chemical, tension, torsion, and metallographic analysis and testing.

Mechanical Properties

The mechanical properties of strength and ductility were determined for all wires in each rope by tensile and torsion tests done in accordance with accepted specifications (6). The mechanical property data are concentrated in the appendix. Tables A-5 through A-7 summarize the breaking loads and tensile strengths

TABLE 3. - Wire rope test data and specifications

Rope	Rope: Diameter, in	Rope: Avg breaking strength, lb	Rope: Strand pitch, in	Wire: Diameter,[1] in: Size	Wire: Diameter,[1] in: Variation	Wire: Tensile strength, 10^3 psi	Wire: Torsions: Avg	Wire: Torsions: Min	Wire: Composition, wt pct: C	Wire: Composition, wt pct: Mn	Wire: Composition, wt pct: P	Wire: Composition, wt pct: S
A...	1.305	151,130	7.88	0.053	<0.002	284	58	40	0.73-0.82	0.42-0.58	<0.028	<0.030
				.057	<.002	278	51	37				
				.058	<.001	279	47	37				
				.063	<.001	270	44	34				
				.100	<.001	254	28	21				
				.115	<.001	229	26	18				
B...	1.313	149,050	7.75	.040	[2]<.001	285	77	54	.64- .74	.41- .77	<.032	<.019
				.043	<.001	277	69	50				
				.053	<.002	273	50	40				
				.058	[2]<.001	273	36-44	37				
				.065	<.001	276	33	33				
				.100	<.001	269	[3]18	21				
C...	1.307	149,292	8.05	.037	<.002	341	53	59	.69- .84	.59- .81	<.027	<.028
				.052	<.002	279	57	41				
				.056	<.002	280	57	38				
				.061	[4]<.003	280	42	35				
				.066	<.002	284	46	32				
				.081	<.002	260	29	25				
				.085	<.002	258	32	25				
				.091	<.001	252	33	23				
SPECIFICATIONS												
All.	1.250-1.313	138,800	8.44 max	0.028-0.059 .060- .092 .093- .141	0.002 .0025 .003	238 (0.031-0.060) 230 (.061- .100) 225 (.101- .140)	$\frac{29.5 - 25\ d}{12.5\ d}$		([5])			
REFERENCES												
All.	RR-W-410C, table IV; M11.1-1980, table 1.	RR-W-410C, table X.	RR-W-410C, table X.	RR-W-410C, table IV.		RR-W-410C, table I.	RR-W-410C, table III.		ASTM A510-75, table 6; or Fed. Std. 66, table III.			
COMMENTS												
A...	OK.........	8.9 pct over spec.	OK........	OK....................		OK...............	OK...........		Not applicable.			
B...	OK.........	7.4 pct over spec.	OK........	([2])...................		OK...............	0.100-in-diam wires below min.		Do.			
C...	OK.........	7.6 pct over spec.	OK........	[4]0.061................		OK...............	OK...........		Do.			

[1]Wires are listed in order of increasing diameter; location in rope is not indicated. See appendix tables.
[2]Wires of 0.040- and 0.058-in diam were interchanged in positions of construction. This amounted to excessive variation in diameter at those positions.
[3]Average value of torsional ductility for crown wires (see table A-9) was 18, whereas the minimum per quoted reference is 21.
[4]Oversized wire C7C7 caused excessive variation.
[5]Although no chemical composition specifications exist for ropes, the composition of ropes A and B corresponds to AISI 1070 and 1078 designations (8-9).

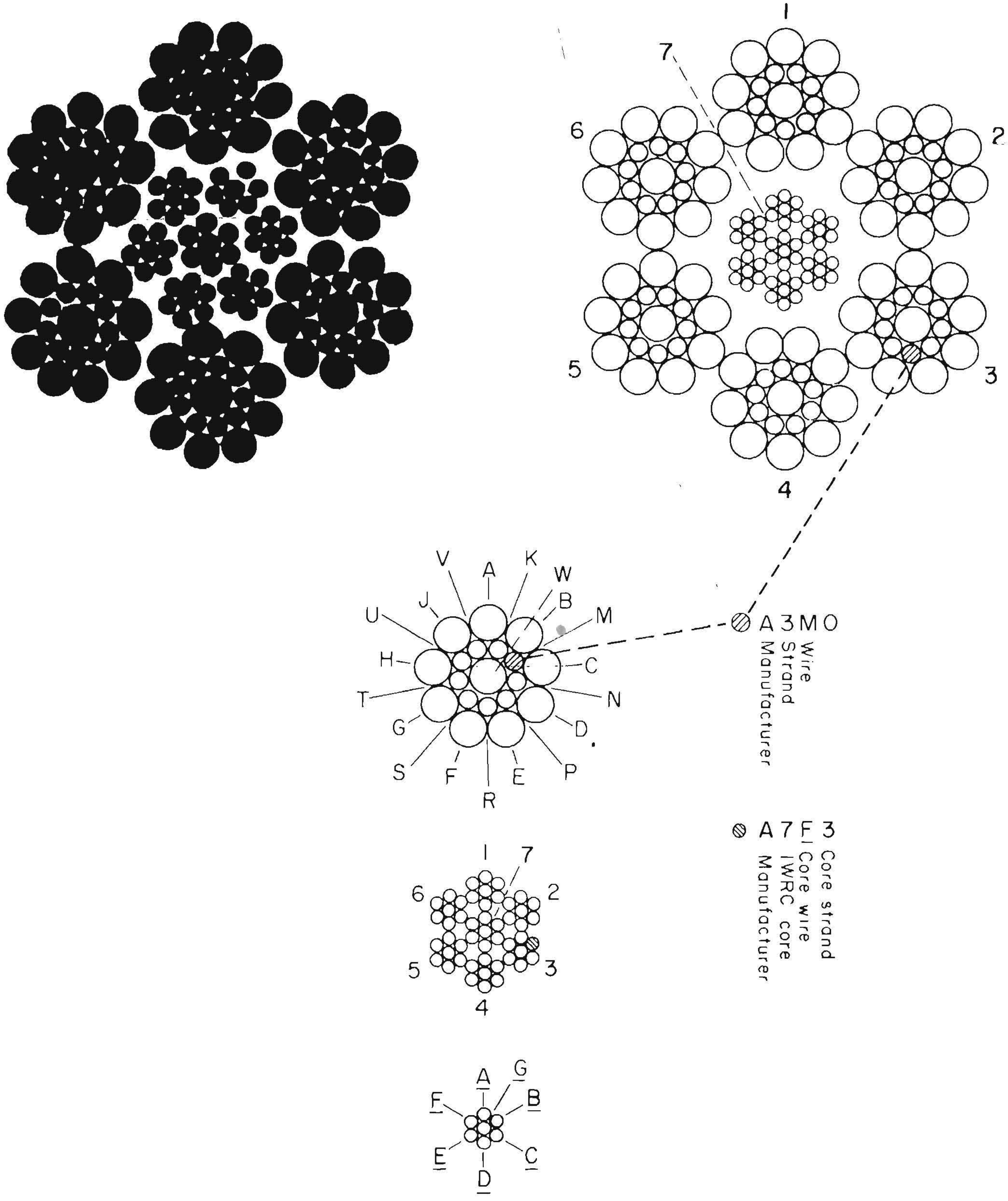


FIGURE 1. - Photogram and drawing of wire locations in rope A.

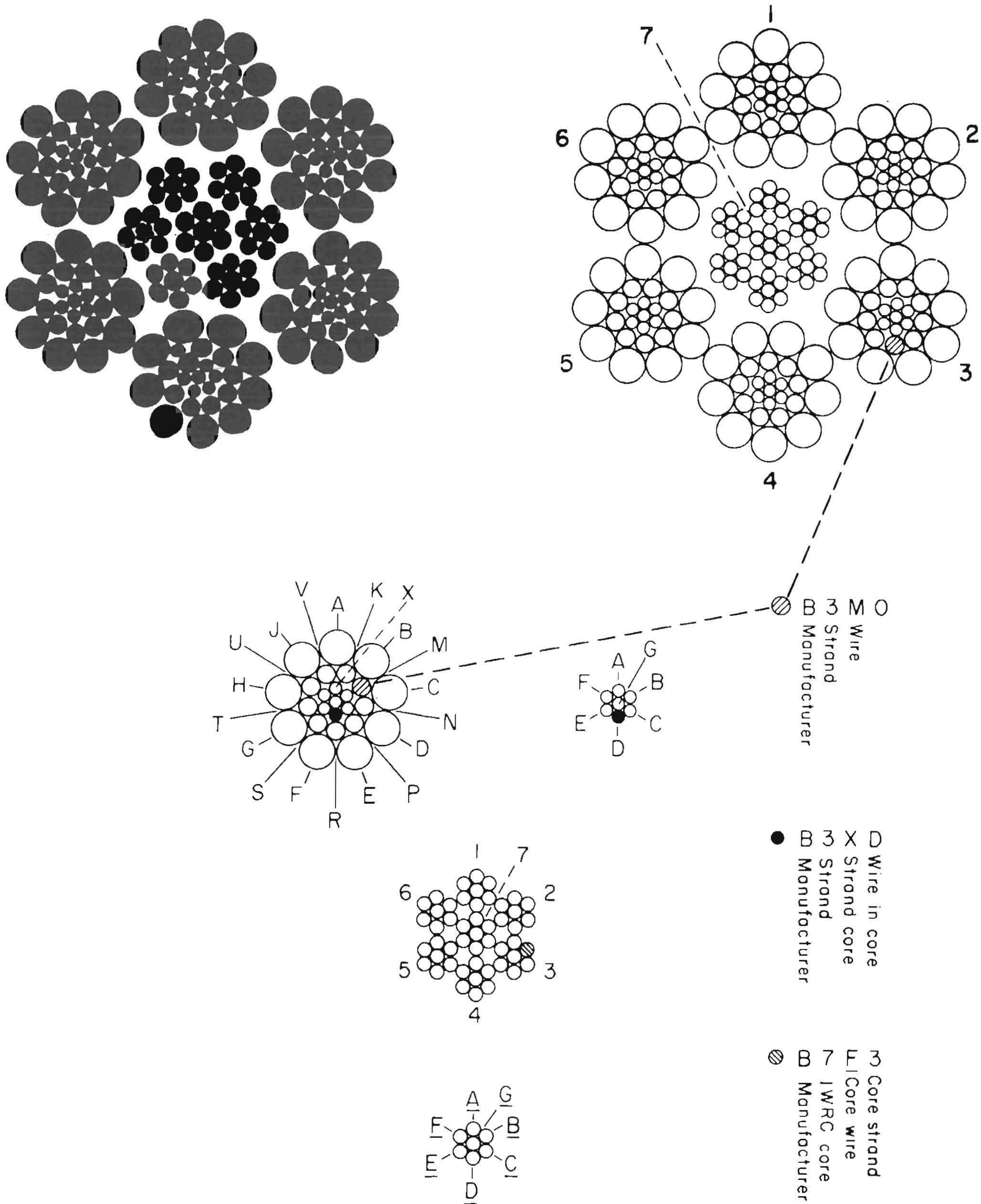


FIGURE 2. - Photogram and drawing of wire locations in rope B.

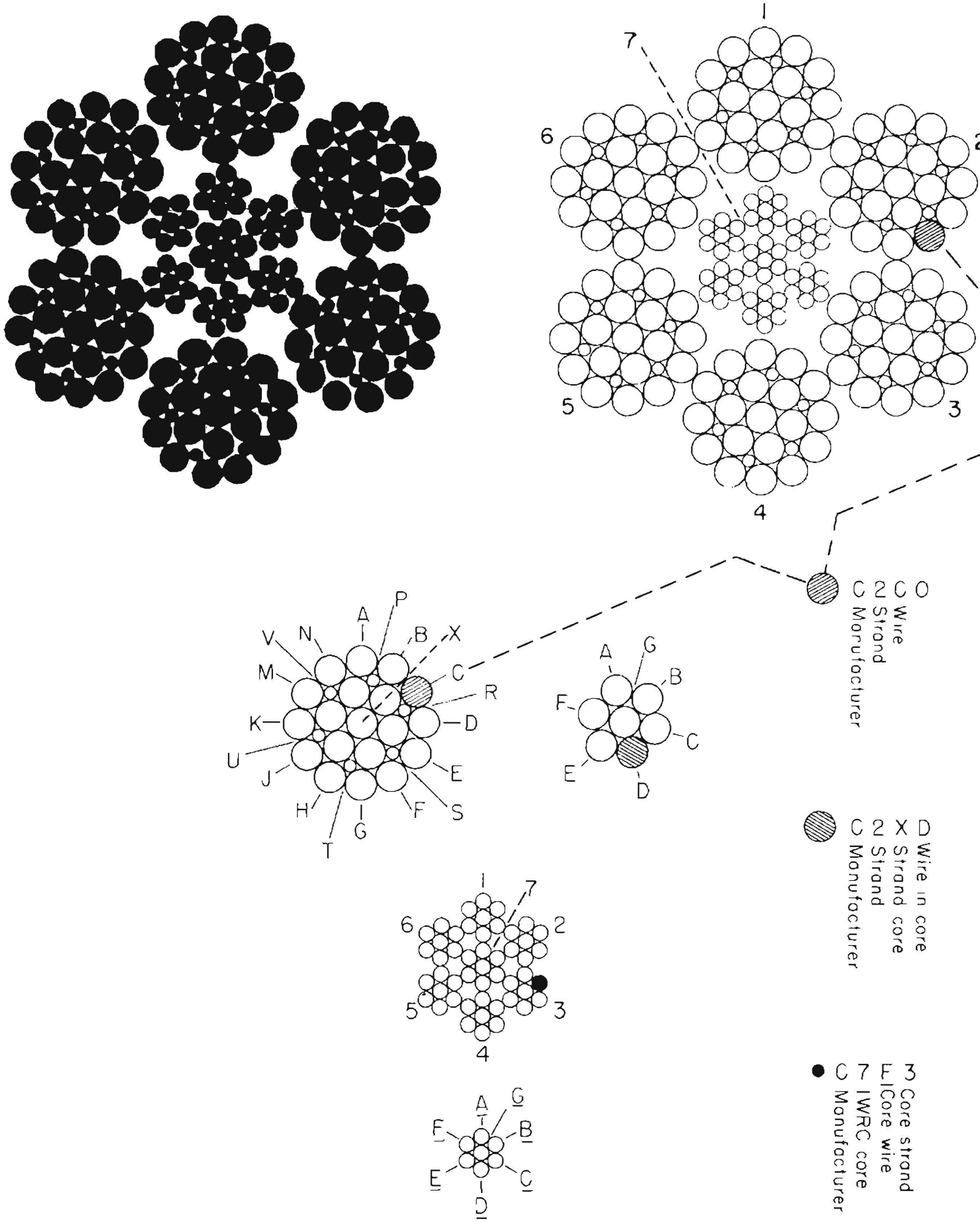


FIGURE 3. - Photogram and drawing of wire locations in rope C.

for individual wires and present the data by wire location. Similarly, tables A-8 through A-10 reflect the ductilities of the same wires in 360° torsions to failure.

Metallography

The microstructure of a typical wire from hoist rope is well known. It is a fibrous, heavily drawn pearlitic steel with the pearlitic structure being unresolvable by 1,000 magnifications of light microscopy. This fine microstructure is developed by a controlled heat treatment termed patenting and by subsequent cold work.

The heat treatment known as patenting dates back to 1854, when J. Horsfall of Birmingham patented his invention under the title of "Newly Invented Patent Steel Music Wire," which covered the process to manufacture wire for pianos and other musical instruments. The word "patenting" stayed with the process because the wire was marketed under the same title and eventually was used by competitor wire manufacturers. This patenting treatment is still one of the vital steps in the production of high-quality wire for hoist ropes.

The treatment involves steel of a hot-rolled or continuously cast (10) condition with near eutectoid composition of 0.8 wt pct C. The microstructure is usually a mixture of ferrite and coarse pearlite, which is unsuitable for extensive cold work. The steel is heated above the upper critical level, A_3, for a sufficient time to produce homogeneous austenite, and then control-cooled to produce fine lamellar pearlite, which is ferrite (essentially Fe) and cementite (Fe_3C). The resultant product is known as sorbitic pearlite to the wire drawing industry.

The as-drawn wire microstructure is shown in figure 4, resolved by a scanning electron microscope. The transverse direction of wire A1W0 from domestic rope A is shown in figure 4*A*, and the longitudinal direction of the same wire is shown in figure 4*B*. Note the deformed ferrite in figure 4*A* that results from the heavy deformation of cold drawing. Also, there is some porosity evident in figure 4*A*, probably resulting from included material being lost during metallographic preparation. Figure 4*B* shows the highly directional nature of the same deformed ferrite in the wire length direction.

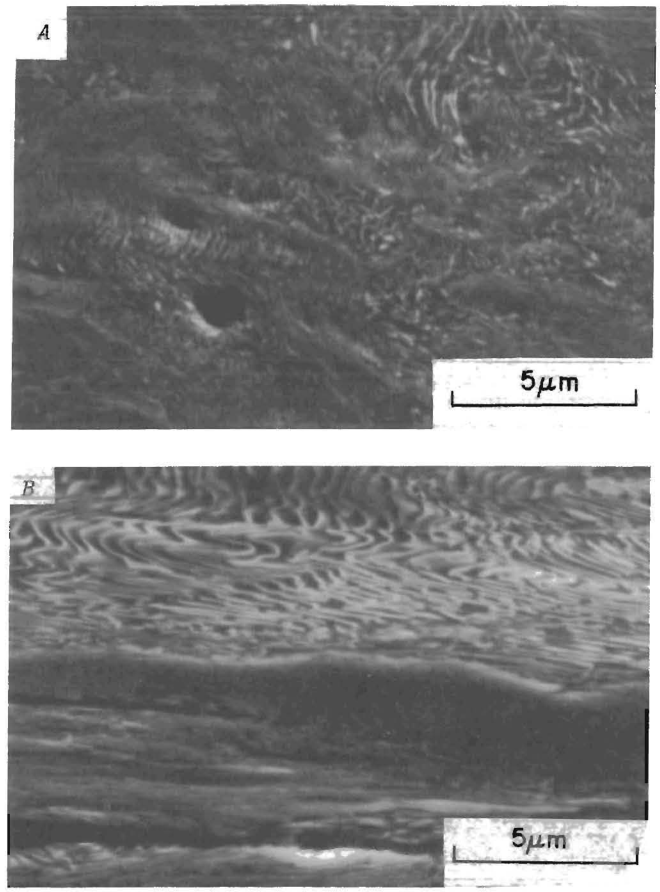


FIGURE 4. - Highly wrought, fine pearlitic structure of wire A1W0 (X 6,000). *A*, transverse; *B*, longitudinal.

A metallographic comparison of the wrought wires from the three ropes was done by looking at longitudinal sections of samples removed from selected wires of crown, inner, strand core, and IWRC positions. The wire positions are traceable to figures 1, 2, or 3.

Strand Crown Wires

Crown wires of ropes A, B, and C are represented by the selected wires A1A0, B1A0, and C1A0, respectively. Figure 5 shows photographs of those wire sections.

Strand Inner Wires

The next layer of wires below the crown was designated strand inner wires. Wires A1K0, B1K0, and C1XB were considered typical of those positions in ropes A, B, and C. Those samples are shown in figure 6.

Strand Core Wires

The center wire of each strand is called the strand core wire. The core wires from strand 1 of rope A, B, and C were selected: A1W0, B1XG, and C1XG. The structures are shown in figure 7.

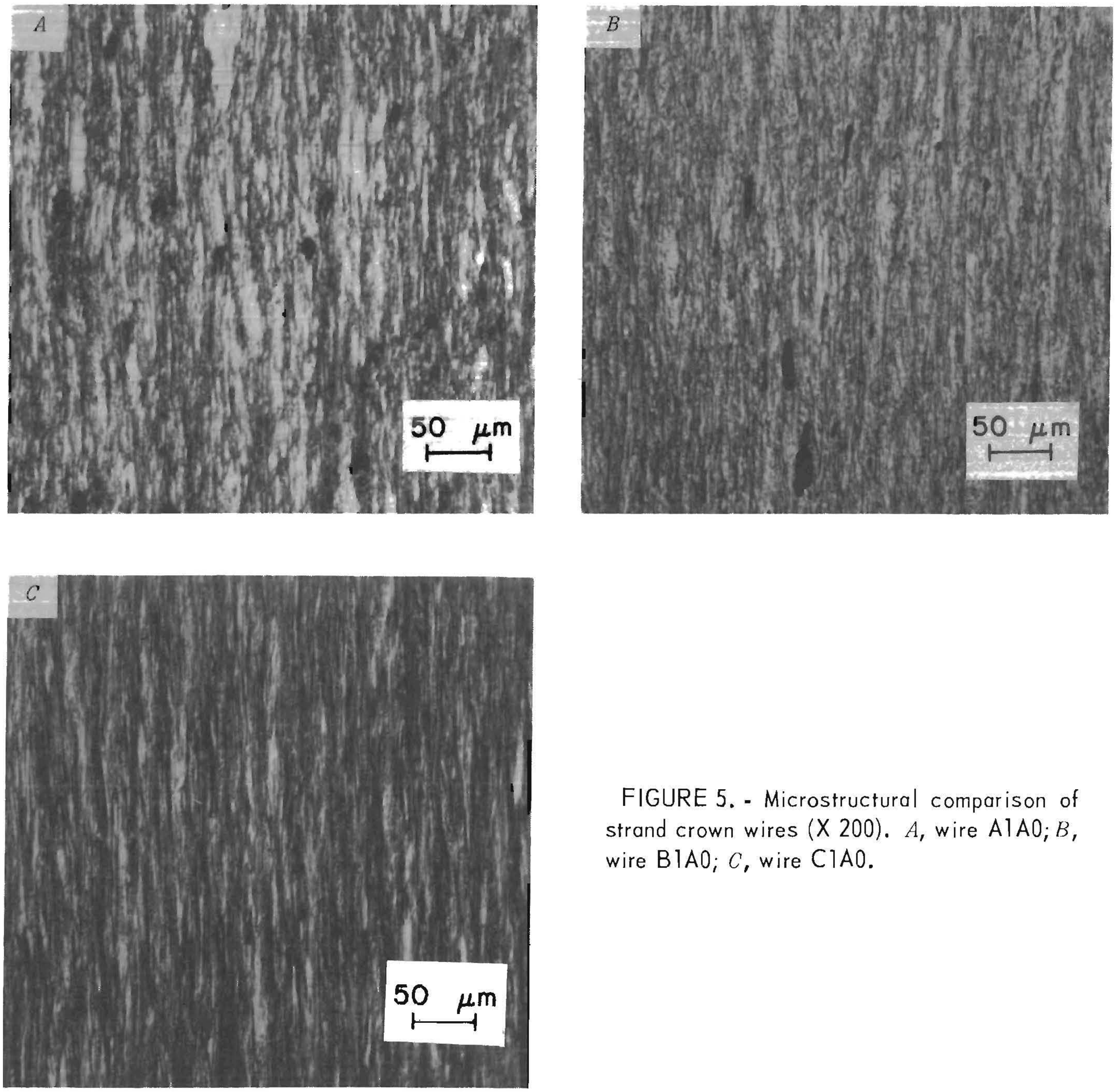


FIGURE 5. - Microstructural comparison of strand crown wires (X 200). *A*, wire A1A0; *B*, wire B1A0; *C*, wire C1A0.

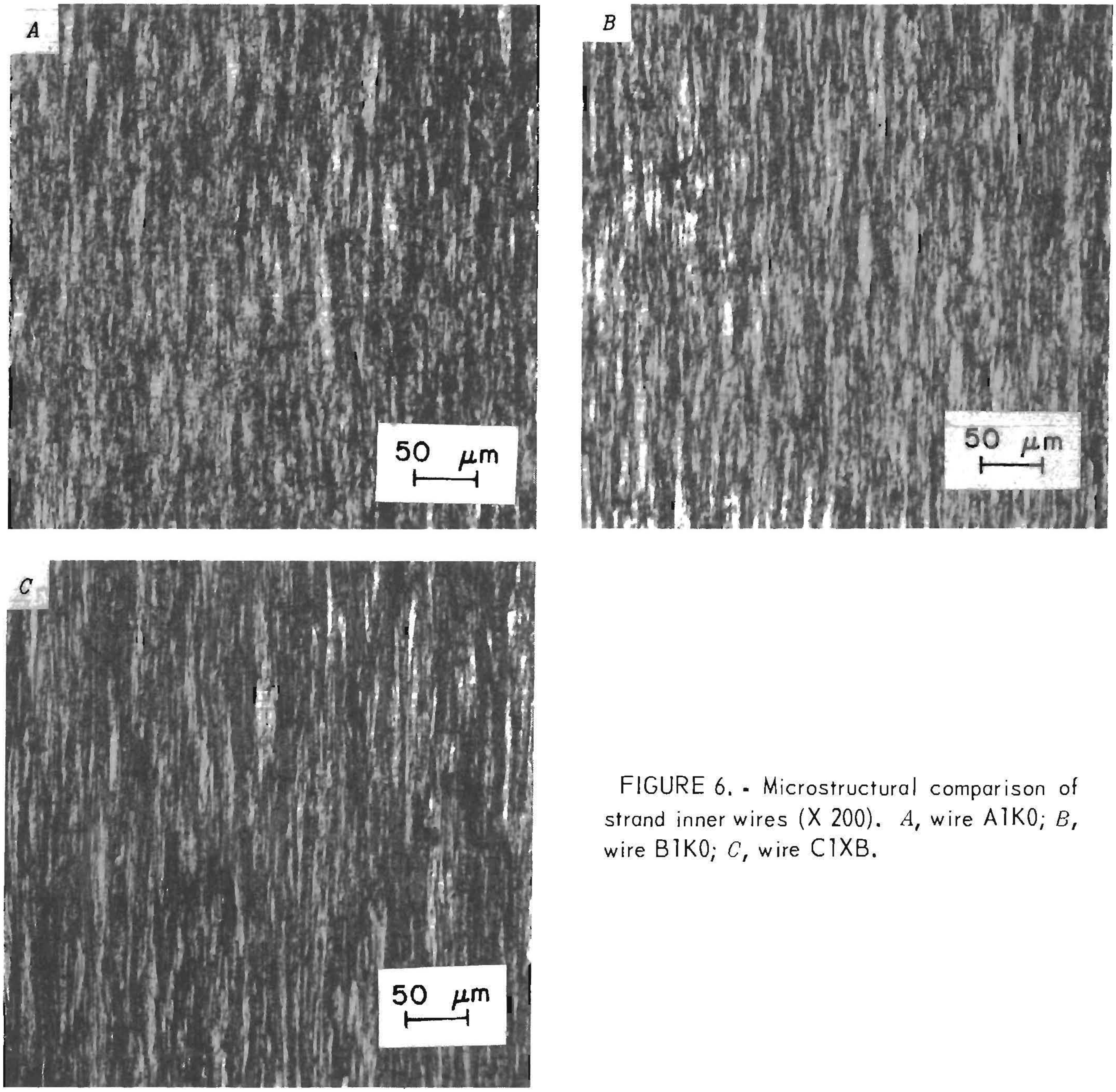


FIGURE 6. - Microstructural comparison of strand inner wires (X 200). *A*, wire A1K0; *B*, wire B1K0; *C*, wire C1XB.

IWRC Core Wires

Only 1 wire from the 49-wire IWRC was compared for longitudinal microstructure. The very center wire of each IWRC was labeled IWRC core wire. Figure 8 shows the structure of wires A7G7, B7G7, and C7G7.

Microhardness

If hardness is the resistance to permanent indentation by an indentor of fixed size and shape under a known load, then microhardness is merely hardness determined through low loads (1 to 1,000 g) and smaller indentation (10 to 1,000 μm). An excellent discussion has been set forth by Lysaght (11-12). A description of test technique, equipment, and calibration exists in ASTM standard E 384-73 (13). Hardness correlates with strength, and accumulated data for ferrous alloys make hardness testing a widely accepted evaluation procedure. Wright (14) only

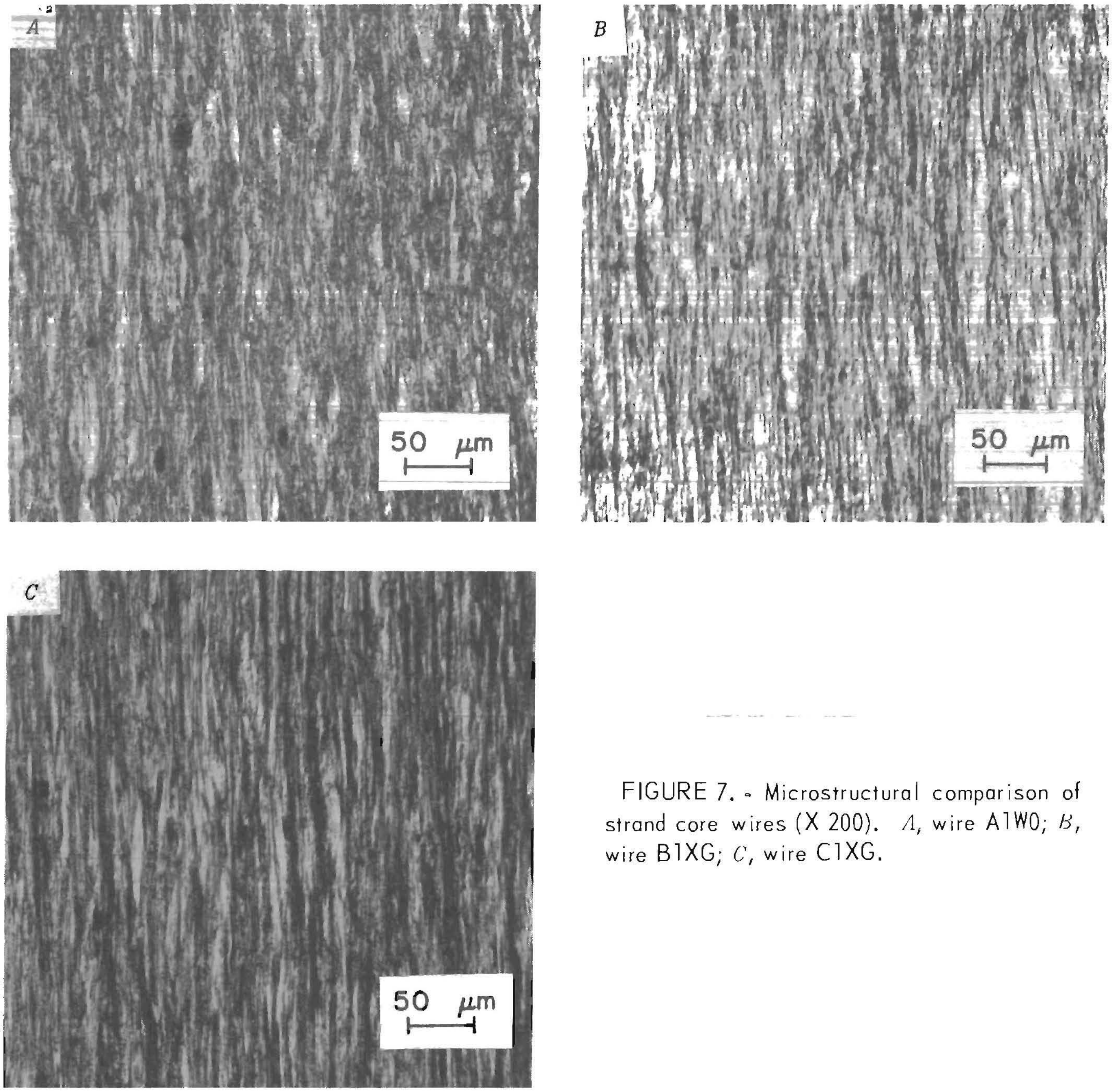
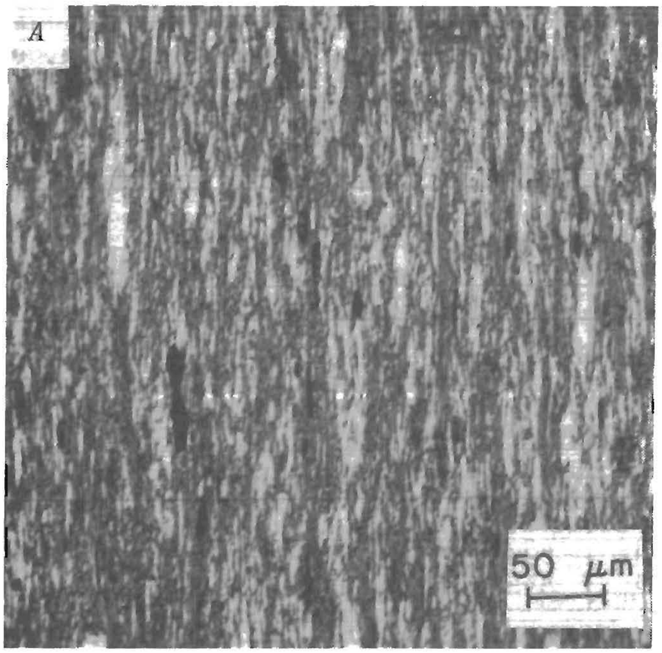


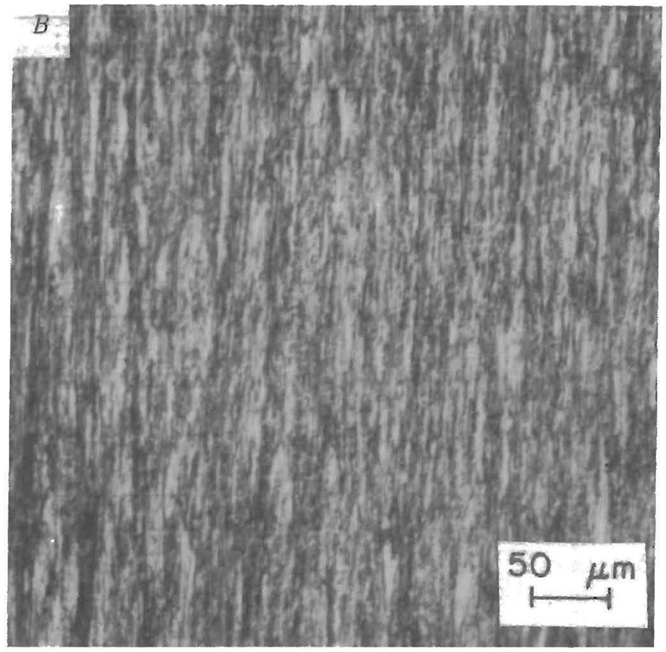
FIGURE 7. - Microstructural comparison of strand core wires (X 200). *A*, wire A1W0; *B*, wire B1XG; *C*, wire C1XG.

recently reviewed the use of microhardness in the analysis of wire products. Microhardness procedures were used to check for uniformity of hardness across the diameter of the heavily worked wires. Transverse sections of wires were obtained by metallographically mounting entire strands and IWRC's from each rope. Wires were located by placing copper tracer wires in the metallographic mounts. Indentations were made at edge, midradius, and center of the transverse sections of selected wires. Table 4 is a summary of the microhardness determinations.

Chemical Composition

There is presently no compositional specification for the steels used for wire rope construction. Instead, general grades of steel from pure iron through traction steel, cast steel, mild plow, plow, improved plow, to extra improved





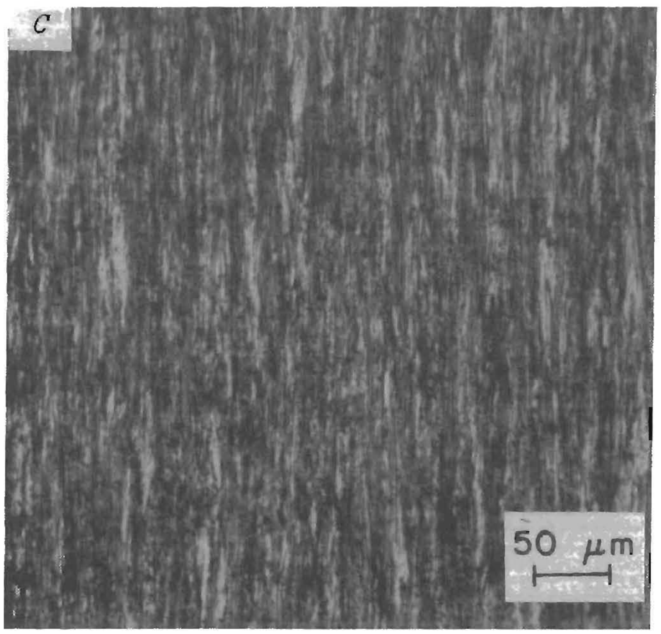


FIGURE 8. - Microstructural comparison of IWRC core wires (X 200). *A*, wire A7G7; *B*, wire B7G7; *C*, wire C7G7.

plow steel were developed over the years to obtain increasingly higher tensile strength wire to meet demanded breaking strengths.

A moderate investigation of chemical composition was made on wires from all three available ropes to check for consistency from wire to wire as well as adherence to standards for a given steel classification. Determinations of carbon content were made for every wire in the ropes because carbon is the most important element influencing strength of the cold-worked wires. Sulfur, phosphorus, manganese, and silicon content were determined for selected wires only. Analytical methods were combustion for carbon and sulfur, wet chemical for phosphorus, and atomic absorption for manganese and silicon.

Sulfur exists as an impurity in most steels and has an effect on final properties through the formation of undesirable FeS, which causes hot shortness during

TABLE 4. - Microhardness of transverse sections of selected wires[1]

Location	Wire	Diameter, in	Hardness, KHN		
			Edge[2]	Midradius	Center
		ROPE A			
A1A0....	Crown.........	0.100	466	483	457
A1K0....	Inner.........	.056	497	NM	476
A1W0....	Strand core...	.115	415	NM	419
A7B2....	IWRC strand...	.053	480	NM	498
A7G7....	IWRC core.....	.057	433	NM	466
		ROPE B			
B1A0....	Crown.........	0.100	494	538	441
B1K0....	1st inner.....	.058	453	NM	463
B1XC....	2d inner......	.040	476	NM	473
B1XG....	Strand core...	.042	451	NM	527
B7B2....	IWRC strand...	.053	432	NM	409
B7G7....	IWRC core.....	.058	464	NM	483
		ROPE C			
C1A0....	Crown.........	0.083	457	480	436
C1P0....	Filler........	.037	440	NM	552
C1XB....	Inner.........	.085	450	NM	512
C1XG....	Strand core...	.091	423	NM	420
C7B2....	IWRC strand...	.061	368	NM	515
C7G7....	IWRC core.....	.066	489	NM	558

NM Not measured.

[1]Knoop indentor, 500-g load, X 20 objective; calibration block was 734±16 KHN and test indentations were 733, 733, 727 KHN.

[2]Edge indentations taken 0.002 in. from wire surface.

hot working. Generally, sulfur should be held to less than 0.03 wt pct, and lower values would be wise for high-carbon steels in wire making.

Phosphorus is present as a residual impurity in steelmaking. It hardens ferrite by solid solution, and its solubility in ferrite is decreased by carbon. It is important then in these high-carbon pearlitic structures to keep phosporus to a minimum level. Sulfur and phosphorus combined do not usually exceed 0.05 wt pct.

As well as being a deoxidant, manganese reacts with sulfur to form MnS in preference to the less desirable FeS. It also serves as a strengthener through the formation of a carbide similar to cementite. It is usually present to the extent of 0.5 to 0.9 wt pct. Manganese refines the pearlite and lowers the M_s temperature, which makes the formation of unfavorable untempered martensite less likely.

Silicon is a strong deoxidant and is usually held to 0.2 wt pct or lower.

Tabulated chemical determination results are in the appendix. Tables A-11, A-12, and A-13 list the carbon contents of all individual wires by strand and location. Tables A-14, A-15, and A-16 show representative levels of C, S, Mn, P, and Si for selected wires from all ropes.

Qualitative spectrographic analyses were done on a limited but representative number of wires from each rope to determine other metallic elements. The only regularly occuring elements were Al, Cu, Cr, and Ni. Table A-17 values are the maximum content found of each element reported.

ANOMALIES

During rope examination, irregularities were found in rope construction and wire surface finish, breaks were found in wires, internal cracks were found in metallographic sections of wires, and differences were observed in lubrication coverage.

Rope A

Rope A was received with a good cover of lubricant as protection against deterioration by corrosion. The surfaces of the individual wires were smooth to visual examination.

Metallographic examinations of an arbitrary transverse section for microstructural detail showed two instances of cracking in individual wires. The first was within the interior of wire A4R0, an inner strand wire. The second, less severe crack, was on the surface of wire A1A0, a strand crown wire. Figure 9 illustrates the nature of the cracking.

Rope B

This rope was received in less than good condition. The lubricant covering was incomplete, and inner layer wires of the strand showed visible rust.

Examination of the photogram in figure 2 shows two strands, 3 and 4, have "closing" mistakes. Two wires are transposed between the second and third layer of those strands.

Two wire anomalies are shown in figure 10. Wire B1U0, from strand 1, contained a very rough lap-type spot weld. Wire

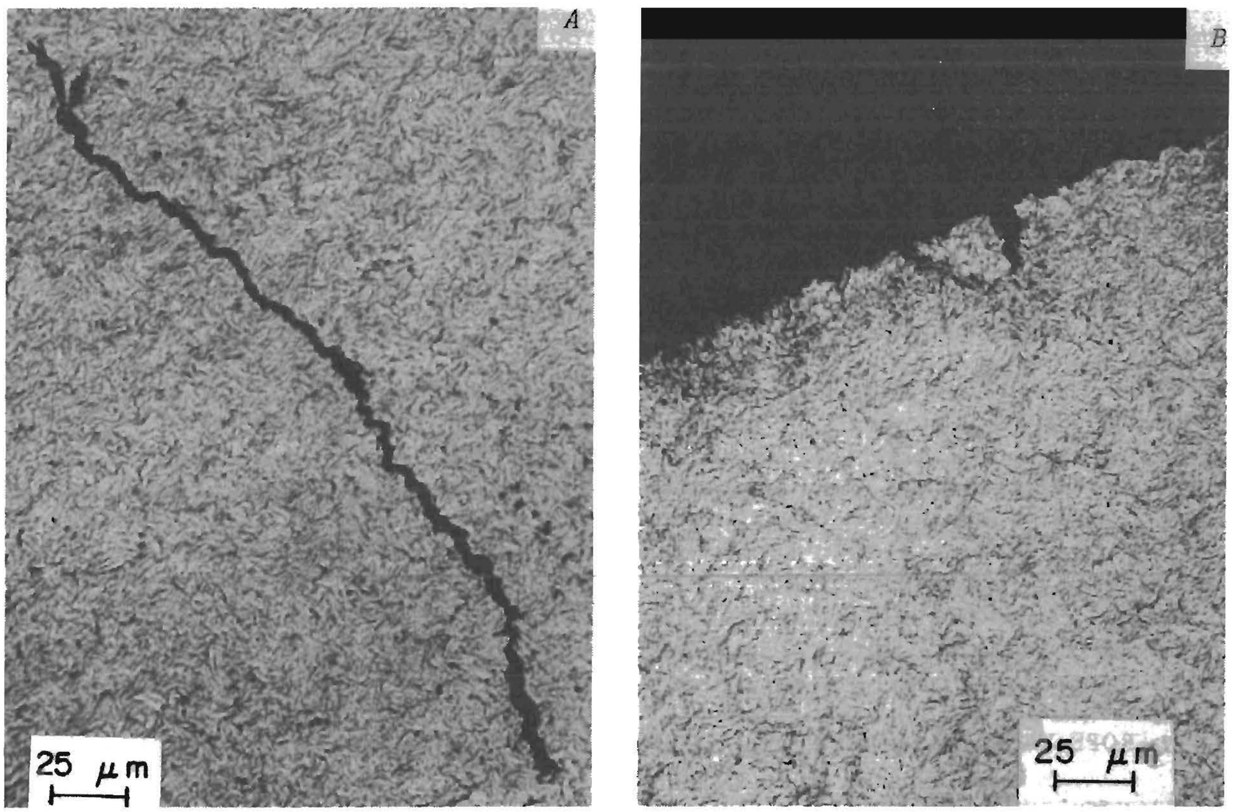


FIGURE 9. - Cracks in wires from rope A. *A*, wire A4R0; *B*, wire A1A0.

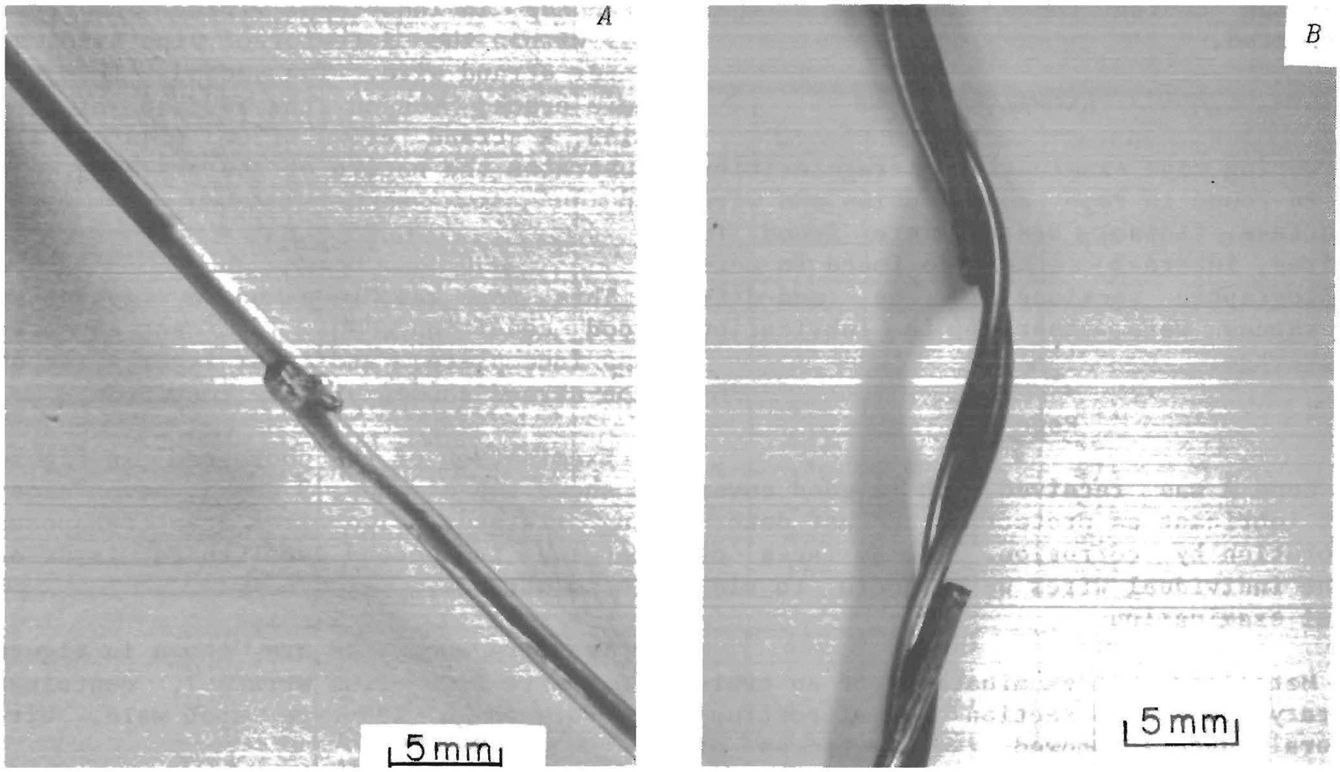


FIGURE 10. - *A*, spot weld (wire B1U0) and *B*, separation (wire B7G6) in rope B.

B7G6 from the IWRC exhibited a break or separation of a weld.

Drawing defects were found on the surfaces of several wires from rope B, but wire B6A0, a crown strand wire, suffered typical damage. That die damage is shown in figure 11.

Rope C

The lubrication penetration and amount were good on this rope. The surface of the wires was visually smooth.

Wire C7C7 was oversized.

RESULTS

An interpretation of the collected results of this analysis can only logically be made by comparing constructions, properties, and variations within the three examined ropes and suggesting significance of these results to retirement or life of rope in a hoisting application.

ROPE TENSILE FAILURE

The average rope failure loads were 7 to 9 pct above the nominal catalog strength of 138,800 lb for 1-1/4-in-diam, 6×19, IWRC, IPS wire rope. See tables 3 and A-3.

All specimens except C-1 failed more than three rope diameters from a socket; therefore, these tests were not influenced by the terminations. Specimen C-1 failure in the socket was caused by inadequate heating of the socket and zinc during installation of the termination; however, that failure occurred above the nominal catalog strength.

Failure of all specimens was by separation of three strands and the IWRC. Rope A specimens failed violently with no warning of impending separation. In ropes B and C, audible popping of

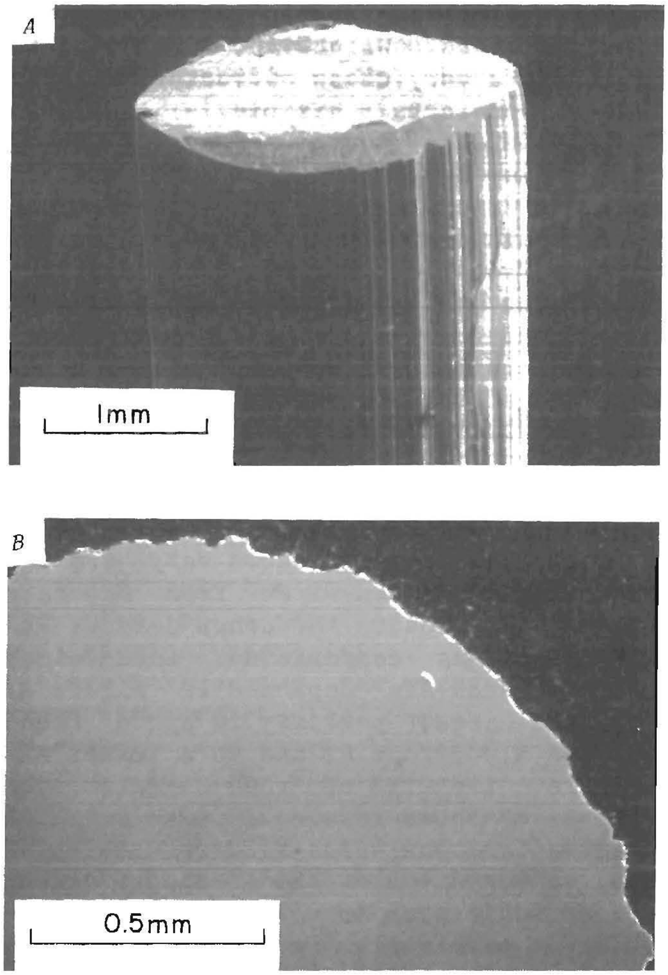


FIGURE 11. - Drawing defects on surface of wire B6A0. *A*, smooth and grooved surface areas (X 25); *B*, section of wire showing groove depth (X 65).

individual wires occurred just before the final violent rope failure.

Diameters of ropes A, B, and C were within the tolerance of 0 undersize to 1/16-in oversize as given in specifications of RR-W-410C (6). Rope strand pitches of the three ropes were also under the 8-7/16-in maximum given in the same specification.

ROPE MODULUS OF ELASTICITY

Average tangent modulus of elasticity for ropes A, B, and C is 13.4 million psi in the 17,350- to 34,700-lb load range, which corresponds to load levels for the mine hoist rope design factor range of 8 to 4 given in CFR 30 (3). This modulus compares closely to the 13.5-million-psi approximate modulus given by AISI in the Wire Rope Users Manual (4) for 6×19 IWRC rope at 0 to 20 pct loading.

Individual tangent modulus values given in table A-3 vary nonuniformly with load increase. These variations were likely caused by abrupt movement and adjustment of rope strands as the load increased.

ROPE LUBRICATION

Although visual examination for lubrication penetration and coverage is qualitative, rope B definitely exhibited poor lubrication. The lubrication was of high viscosity and seemed to be applied only to the exterior of the rope. Rust appeared on crown and first inner layer wires. Ropes A and C contained lubrication at all layers of the construction.

ROPE CONSTRUCTION CONFORMANCE

The construction of ropes A and C were in conformance with specifications, but rope B actually had wires misplaced or interchanged in strands 3 and 4. In addition, there was one instance of a lap weld. Figure 10*A* is assumed to be typical for wire joining by that manufacturer. The enlarged diameter generated by the lap type instead of butt joint type weld could cause wear on adjoining wires of the rope. Several separations or breaks also were found in rope B during the disassembly of the 120-in length of rope. Figure 10*B* shows the shortest separation, but the other was greater than 12 in.

The surface condition of individual wires was checked visually for each rope after disassembly and cleaning. Rope B was the only product exhibiting die marking on wire surfaces from the drawing procedures.

WIRE STRENGTH AND DUCTILITY

Individual wire strength and ductility combine to give a measure of wire toughness. Accurate measurements of breaking loads, calculations of wire tensile strengths, and determinations of torsional ductilities of wires resulted in the specific properties tabulated in the appendix for all wires of the three ropes. A summary of these wire strengths and ductilities by diameter is included in table 3 for the three ropes.

Close examination of table 3 shows that no test data fell below specification minimums for wire tensile strength. Ductility performance was not as straightforward. Although wires from the first rope, A, surpassed the minimum torsions in all diameters, rope B suffered serious shortcomings. In that rope, the 0.100-in-diam crown wires failed to meet the minimum. In fact, 47 of the 54 crown wires fell below the 21 torsions minimum. The petroleum industry specification (5) allows no more than 5 wires per strand or a total of 30 wires in this case to fall below. This is a critical property failure in that reduced ductility of that many crown wires might shorten the fatigue life of such a rope in hoisting. The significance of this loss of ductility on fatigue life could only be determined through controlled fatigue testing or hoist usage of rope from the same manufacturer lot. Critical wires of rope C surpassed the minimum torsions specification. Wires of 0.037-in diameter from rope C failed the torsional ductility minimum, but the reference does not hold such filler wires to the specification.

MICROSTRUCTURE OF WIRES

The heavily wrought microstructure is perhaps one of the most difficult to analyze because the wrought property masks many differences that would show in an unworked microstructure. Also, it is difficult to obtain uniform chemical etching of a polished specimen of wrought steel. Consequently, structures appear to have greater variations than actually exist. Figure 5 displays the structures of crown wires from ropes A, B, and C. Obviously, both wire A1A0 and B1A0 contain more included material or porosity than wire C1A0. Wire B1A0 shows that the defects are elongated from the deformation processes. Wire C1A0, from rope C, exhibits a very clean structure with no internal defects visible. The illustrated defects would serve as stress risers in developing internal fatigue cracks. Wire A1A0 has a coarser structure than equivalent wires in other ropes. The effect of this coarser structure upon the performance of the wire could only be determined through controlled single-wire mechanical tests coded to actual microstructures of tested wires.

Figure 6 represents the structures found in selected inner layer strand wires. This figure shows very similar structures between wires from separate ropes. No porosity or other defects exist to use as comparisons. Core wires from strands are depicted in figure 7. In these cases, porosity is again found in wire A1W0, rope A, and to a lesser extent in wire C1XG of rope C. Also, the wire A1W0 shows less cold work or total deformation than wires B1XG or C1XG. The very center wires of the respective IWRC strands of ropes A, B, and C are available for examination in figure 8. Porosity is again visible in the rope A product, A7G7. Also, wire A7G7 appears to have undergone less cold work than the wires B7G7 and C7G7 from ropes B and C.

The only flaws found by transverse sectioning and subsequent metallographic examination for all three ropes are shown in figure 9. In these micrographs, an internal crack is shown in wire A4R0 and a minor surface crack is visible in wire A1A0. Both of these flaws could lead to early crack growth in wires of rope A during use. Since the rope section from which these wires were removed saw no use history prior to this metallographic examination, the flaws are attributed to manufacturer processing for rope A.

Microhardness data taken from polished transverse sections are listed in table 4. These measurements were made to check for mechanical hardening across the cross section of selected wires for each rope.

In ropes A and B there is no significant difference in hardness between edge and center of specific wires, whereas in rope C, several wires have significantly harder centers. An unexplained higher midradius hardness was found for the few specimens tested. Hardness variations with wire diameter do not follow any predictable pattern. Actually, the microhardness data do not show differences sufficient to warrant concern for nonuniform cold work.

CHEMICAL COMPOSITION OF WIRES

Although no compositional specification is used for the sale of rope, the growing demands for higher tensile strength products can only be met by producing wire from steel of controlled microstructure and chemical composition. Three primary factors influencing the strength of cold drawn wire are chemical composition, heat treatment, and degree of cold work. In this evaluation the factors of heat treatment and degree of cold work are not specifically known, but the more important factor, chemical composition, was approximated by analysis.

Carbon has the dominant compositional effect upon the strength of wires. Carbon levels were determined for every wire to obtain a measure of consistency within a given rope and differences between ropes. The variation within any given rope was approximately ±0.05 wt pct C. Rope A exhibited the highest all-wire-average carbon content of 0.78 wt pct, with ropes C and B following with 0.75 and 0.70 wt pct, respectively. No significant parallel between these carbon levels and the individual wire tensile strengths was found. In fact, rope C, with the lowest carbon level, exhibited strengths as high as rope A with the highest carbon level. The Cr and Ni levels in rope C wires may account for the equal strength with lower amounts of carbon.

Sulfur, manganese, phosphorus, and silicon are shown with carbon for selected wires from strands and IWRC's for all three ropes in tables A-14, A-15, and A-16. These five elements are known to have effects upon properties, but seem to be within normal limits in wires sampled. The manganese level varies more than other listed elements. For example, the crown wires from rope B contain about 0.72 wt pct, whereas other wires in that rope average closer to 0.50 wt pct. Whether this difference relates to the lower ductility for the crown wires of B is unknown. All wires of rope C contain equally high contents of manganese with no loss of ductility.

Spectrographic analyses of filings from selected wires of the concerned ropes detected four additional metallic elements. The Al, Cu, Cr, and Ni levels found are listed in table A-17. The levels are minimal in all cases except rope C, where the Cr and Ni are approaching levels known to affect heat treatment and strength of pearlitic steels. Both elements can be significant in a normal patenting heat treatment by affecting the isothermal transformation of austenite to fine grained pearlite. Chromium, at a maximum content of 3 wt pct in rope C, would have the most effect, but nickel, at 1 wt pct, is also in significant composition range. These amounts of Cr and Ni did not adversely affect other properties determined for rope C.

Variations in composition are then only those of 0.05 wt pct C, 0.20 wt pct Mn, and 1 to 3 wt pct Ni and Cr.

SURFACE CONDITION OF WIRE

Although the experiments were not included to quantitatively measure the surface finish of individual wires, gross drawing die markings on wires from rope B were visible to the human eye. Figure 11 shows two scanning electron micrographs illustrating the nature of these longitudinal grooves.

DISCUSSION

Although performance of a hoist rope provides the only quantitative measure of life, this analysis identified the following new rope conditions that may influence this life.

LUBRICATION

Visual examination of the received ropes showed a difference in exterior condition of lubrication that was further confirmed during disassembly. Ropes A and C, the domestic products, were well covered and deeply penetrated with moderate viscosity lubricant. Rope B, the foreign product, was coated on the exterior with a higher viscosity, almost dry lubricant that did not penetrate thoroughly to the IWRC.

CONSTRUCTION

In rope B, wires of differing diameter were misplaced within two strands. Although no wire surface finish specification exists, die grooving occurred regularly on surfaces of wires from this same rope but did not occur on wires of ropes A and C.

MECHANICAL PROPERTIES

Tensile strengths of ropes and wires surpassed specifications as shown in table 3. The rope moduli of elasticity were near literature values (4). The crown wires of rope B did not meet quoted minimum ductility requirements, but all other wires did. Hardness determinations showed no gross change across wire diameters.

MICROSTRUCTURE

The microstructure of rope A was coarser in grain size than B and C, indicating a lower percentage of cold work. Rope C had the microstructure most free of voids and inclusions, whereas ropes A and B contained visible amounts of each. If internal voids and inclusions serve as stress risers in fatigue, then the cleaner microstructure would be related to longer life before internal fatigue crack initiation.

CHEMISTRY

No adverse effects associated with chemistry were shown from the comparisons of chemical compositions to resultant mechanical properties. Carbon content did vary from 0.78 wt pct for rope A to 0.70 wt pct for rope B. Rope C contained a maximum of 3 wt pct Cr and 1 wt pct Ni.

ANOMALIES

The following items were considered significant: (1) rope A showed internal and external wire cracks, and (2) rope B exhibited construction errors, breaks or separations, lap-joint welding techniques, and die-marked wire surface finishes.

RECOMMENDATIONS

FUTURE TESTING

Future laboratory or field testing should be done on ropes that have been examined for lubrication, construction conformance, chemical composition, microstructure, wire surface condition, initial rope strength, and individual wire torsional ductility. Otherwise, no control or reference condition is available for judgment of degradation after testing or retirement.

FUTURE QUALIFICATION

The authors feel, after this limited examination or analysis of three typical 6×19 classification hoist ropes, that some further qualification should be met than now exists when using these ropes for hoisting personnel. For example, rope B certification from the manufacturer met the minimum ductility for crown wires, whereas the authors' analysis showed less ductility.

Perhaps some qualification of cleanliness of microstructure is possible. This can be accomplished by inclusion or crack initiation site counting.

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APPENDIX.--WIRE ROPE ANALYSES AND TEST DATA

TABLE A-1. - Diameters and pitches of ropes and strands

Strand	1	2	3	4	5	6	7
DIAMETER,[1] in							
Rope A:							
Rope strand	0.407	0.405	0.406	0.405	0.407	0.407	[2]0.496
IWRC strand	.161	.161	.161	.160	.160	.161	.184
Rope B:							
Rope strand	.415	.415	.415	.415	.415	.415	[2].498
IWRC strand	.163	.161	.164	.167	.163	.163	.180
Rope C:							
Rope strand	.415	.416	.416	.415	.416	.415	[2].498
IWRC strand	.156	.157	.157	.156	.158	.156	.188
PITCH,[3] in							
Rope A:							
Rope strand	2.47	2.47	2.48	2.47	2.45	2.46	[2]3.05
IWRC strand	2.15	2.18	2.10	2.11	2.13	2.17	1.30
Rope B:							
Rope strand	2.34	2.35	2.35	2.35	2.31	2.32	[2]3.54
IWRC strand	1.54	1.55	1.54	1.55	1.57	1.55	1.22
Rope C:							
Rope strand	2.42	2.42	2.42	2.41	2.40	2.41	[2]3.60
IWRC strand	1.96	1.96	1.96	1.96	1.96	1.97	1.40

[1]Diameters--A, 1.305 in; B, 1.313 in; C, 1.307 in.
[2]Rope strand 7 is the IWRC. Values listed are the diameter and pitch of the IWRC.
[3]Pitches--A, 7.88 in; B, 7.75 in; C, 8.05 in.

TABLE A-2. - Tensile test data summary for wire ropes A, B, and C

Specimen	Failure load, lb	Diameter,[1] in		Strand pitch,[1] in		Failure distance from socket,[2] in
		0 pct	10 pct	0 pct	10 pct	
A-1.....	151,300	1.328	1.278	8.00	8.00	13
A-2.....	152,250	1.303	1.277	7.72	7.81	16
A-3.....	151,500	1.301	1.273	7.83	7.83	29
A-4.....	150,750	1.297	1.279	7.94	7.96	4
A-5.....	149,450	1.295	1.277	7.92	8.00	32
B-1.....	148,250	1.308	1.292	7.67	7.75	5
B-2.....	147,500	1.316	1.292	7.75	7.75	6
B-3.....	149,000	1.293	1.258	7.83	7.92	9
B-4.....	151,000	1.313	1.295	7.75	7.83	8
B-5.....	149,500	1.334	1.300	7.75	7.83	19
C-1.....	148,750	1.308	1.291	8.08	8.17	NAp
C-2.....	149,000	1.309	1.290	7.88	7.88	36
C-3.....	151,750	1.304	1.294	8.08	8.10	12
C-4.....	149,250	1.308	1.292	8.17	8.17	10
C-5.....	150,000	1.312	1.286	7.92	7.96	4.75
C-6.....	147,000	1.301	1.291	8.17	8.19	26

NAp Not applicable; failed in socket.
[1]Measurements at 0 and 10 pct of the catalog strength.
[2]All failures were 3 strands and IWRC.

TABLE A-3. - Wire rope tangent modulus of elasticity

Rope load, lb	Rope modulus, 10^6 psi				Rope load, lb	Rope modulus, 10^6 psi			
	A	B	C	Avg		A	B	C	Avg
10,000	13.6	13.1	15.0	13.9	50,000	14.0	14.8	15.5	14.8
20,000	13.1	13.3	13.9	13.4	60,000	14.0	15.8	16.0	15.3
30,000	13.5	11.6	15.2	13.4	70,000	13.3	15.3	16.5	15.0
40,000	15.2	12.7	13.2	13.7	80,000	13.7	15.0	15.6	14.8

TABLE A-4. - Tensile test data for ropes instrumented for elongation measurements

Specimen................	A-6	B-6	C-7
Failure load........lb..	148,900	147,500	148,800
Diameter,[1] in:			
0 pct..................	1.298	1.281	1.310
10 pct.................	1.252	1.273	1.291
Strand pitch,[1] in:			
0 pct..................	7.90	7.79	7.92
10 pct.................	7.92	7.83	7.92
Failure distance from socket[2]............in..	4	27.5	36

[1]Measurements at 0 and 10 pct of the catalog strength.
[2]All failures were 3 strands and IWRC.

TABLE A-5. - Individual wire breaking loads and strengths for rope A[1]

Wire location	Diameter,[2] in	Strand 1		Strand 2		Strand 3		Strand 4		Strand 5		Strand 6		Strand 7	
		Load, lb	Strength, 10^3 psi	Load, lb	Strength, 10^3 psi	Load, lb	Strength, 10^3 psi	Load, lb	Strength, 10^3 psi	Load, lb	Strength, 10^3 psi	Load, lb	Strength, 10^3 psi	Load, lb	Strength, 10^3 psi
Crown:															
A.....	0.100	1,958	254.2	1,929	250.0	1,978	256.8	1,928	250.3	2,005	260.4	1,940	252.0	NAp	NAp
B.....	.100	1,978	256.8	1,960	254.6	1,940	252.0	1,935	251.3	1,958	254.2	1,975	256.5	NAp	NAp
C.....	.100	1,965	255.2	1,934	250.7	1,960	254.6	1,943	252.3	1,950	253.3	1,955	254.0	NAp	NAp
D.....	.100	1,940	251.3	1,943	252.3	1,928	250.3	1,935	251.3	1,935	251.3	1,960	254.6	NAp	NAp
E.....	.100	1,988	258.1	1,968	255.5	1,963	254.9	1,965	255.2	1,985	257.8	1,993	258.8	NAp	NAp
F.....	.100	1,970	255.8	1,980	257.1	1,930	250.6	1,928	250.3	1,950	253.3	1,940	252.0	NAp	NAp
G.....	.100	1,915	248.7	2,000	259.7	1,908	247.7	1,938	251.6	1,933	251.0	1,945	252.6	NAp	NAp
H.....	.100	1,945	252.6	1,980	257.2	1,935	251.3	1,960	254.6	1,910	248.1	1,958	253.6	NAp	NAp
J.....	.100	1,975	256.5	1,940	251.3	1,950	253.3	1,980	257.1	1,968	255.5	1,988	258.1	NAp	NAp
Inner:															
K.....	.057	688	279.9	618	259.5	662	269.1	687	279.1	658	276.3	675	274.4	NAp	NAp
M.....	.057	684	278.1	699	284.2	673	273.4	684	281.5	676	280.5	699	285.3	NAp	NAp
N.....	.057	704	286.0	683	277.6	657	271.4	684	278.1	656	274.5	651	272.4	NAp	NAp
P.....	.057	705	286.4	674	273.8	649	272.5	704	286.0	651	273.3	685	278.3	NAp	NAp
R.....	.057	673	273.4	609	255.9	689	280.1	694	282.1	691	284.4	689	288.1	NAp	NAp
S.....	.057	661	268.7	643	268.8	691	286.6	679	277.0	704	295.8	711	298.5	NAp	NAp
T.....	.057	654	265.9	652	274.0	714	291.2	678	275.6	708	297.5	693	281.5	NAp	NAp
U.....	.057	655	266.1	655	275.0	702	293.5	674	283.0	700	289.3	679	280.4	NAp	NAp
V.....	.057	651	266.1	641	268.2	667	271.1	664	277.6	701	287.1	681	281.7	NAp	NAp
W.....	.115	2,340	229.2	2,328	228.0	2,308	226.0	2,335	228.7	2,433	238.3	2,305	225.8	NAp	NAp
IWRC:															
A.....	.053	606	287.2	595	280.7	608	284.6	611	299.5	586	276.2	598	293.1	714	278.3
B.....	.053	598	283.4	576	271.5	592	284.5	602	295.1	589	277.8	601	283.3	723	281.7
C.....	.053	588	277.1	584	275.5	583	285.8	605	290.7	599	293.9	594	288.8	717	273.2
D.....	.053	593	279.5	558	266.4	604	284.7	587	276.7	603	295.4	602	294.9	719	282.0
E.....	.053	601	283.3	584	276.6	601	294.6	572	274.1	581	275.1	596	280.9	714	279.8
F.....	.053	607	286.3	592	287.9	599	274.6	602	293.0	590	278.3	596	290.1	717	281.0
G.....	.057	687	286.3	636	285.5	642	269.5	659	276.9	664	269.9	641	269.3	838	269.7

NAp Not applicable; 7th strand exists only in IWRC.

[1]All values are averages of 2 tensile tests per wire location.

[2]For strand 7 (present only in the IWRC), wire diameters A through F are 0.058 in and G is 0.063 in.

TABLE A-6. - Individual wire breaking loads and strengths for rope B[1]

Wire location[2]	Diameter,[3] in	Strand 1		Strand 2		Strand 3		Strand 4		Strand 5		Strand 6		Strand 7	
		Load, lb	Strength, 10^3 psi	Load, lb	Strength, 10^3 psi	Load, lb	Strength, 10^3 psi	Load, lb	Strength, 10^3 psi	Load, lb	Strength, 10^3 psi	Load, lb	Strength, 10^3 psi	Load, lb	Strength, 10^3 psi
Crown:															
A.......	0.100	2,105	270.7	1,926	247.7	2,062	262.5	2,168	270.5	2,082	269.6	2,105	262.7	NAp	NAp
B.......	.100	2,086	268.2	2,142	271.0	1,939	246.9	2,180	275.5	2,176	278.9	2,166	271.2	NAp	NAp
C.......	.100	2,087	267.5	2,128	270.9	2,154	277.0	2,017	257.6	2,191	284.6	2,164	277.3	NAp	NAp
D.......	.100	2,067	263.2	2,105	272.5	2,020	254.6	2,197	276.9	2,049	261.8	2,074	266.7	NAp	NAp
E.......	.100	2,150	271.0	2,144	270.2	2,148	264.6	2,074	270.9	2,109	269.2	2,079	266.5	NAp	NAp
F.......	.100	2,241	284.3	2,206	275.3	2,154	267.1	2,107	264.7	2,098	268.0	2,055	264.3	NAp	NAp
G.......	.100	2,131	275.0	2,218	285.2	2,086	263.8	2,031	256.0	2,051	262.0	2,155	271.0	NAp	NAp
H.......	.100	2,098	267.1	2,145	272.1	2,161	266.2	2,063	262.6	1,973	251.2	2,164	276.4	NAp	NAp
J.......	.100	2,130	274.9	2,164	275.5	2,183	278.8	2,141	268.1	2,234	287.2	2,120	262.8	NAp	NAp
1st inner:															
K.......	.058	749	278.7	718	258.0	685	250.1	773	287.7	735	280.6	695	267.5	NAp	NAp
M.......	.058	716	271.1	717	262.2	[4]389	[4]294.3	756	284.7	714	279.8	780	296.7	NAp	NAp
N.......	.058	786	297.4	741	277.4	690	264.1	692	265.0	730	281.1	673	253.2	NAp	NAp
P.......	.058	696	266.4	775	296.9	671	251.1	717	269.9	728	275.4	707	269.0	NAp	NAp
R.......	.058	711	269.0	776	290.4	694	262.5	791	294.1	743	281.3	747	284.2	NAp	NAp
S.......	.058	774	294.6	743	279.4	738	274.4	766	284.8	737	278.9	721	277.5	NAp	NAp
T.......	.058	716	272.4	754	283.6	754	293.9	782	290.9	719	285.2	788	301.8	NAp	NAp
U.......	.058	660	245.4	711	265.9	697	266.9	[4]343	[4]275.2	738	289.1	721	277.8	NAp	NAp
V.......	.058	678	253.5	782	296.0	676	247.4	761	286.4	664	251.3	789	303.8	NAp	NAp
2d inner:															
XA......	.040	337	275.3	390	302.9	340	270.2	363	288.7	348	276.7	350	285.6	NAp	NAp
XB......	.040	360	286.3	367	295.0	[4]706	[4]267.1	380	302.6	386	295.0	388	309.0	NAp	NAp
XC......	.040	370	294.3	338	269.0	369	291.4	351	274.7	366	291.3	385	306.2	NAp	NAp
XD......	.040	373	287.0	380	299.9	355	282.1	341	278.3	336	269.5	359	293.2	NAp	NAp
XE......	.040	342	274.6	368	292.4	352	275.5	344	273.5	338	266.5	344	280.5	NAp	NAp
XF......	.040	365	290.3	339	262.8	360	281.4	751	[4]284.3	356	290.2	375	298.4	NAp	NAp
XG......	.043	432	304.2	372	268.1	373	265.0	368	265.4	367	264.5	406	293.0	NAp	NAp
IWRC:															
A.......	.053	552	253.2	566	259.7	644	294.7	629	289.0	669	304.9	636	286.3	715	266.1
B.......	.053	553	261.8	580	262.7	615	282.5	569	257.9	585	270.0	549	259.9	723	273.6
C.......	.053	559	253.4	579	262.5	583	264.0	629	285.1	569	259.6	633	286.9	700	258.9
D.......	.053	630	285.6	591	274.8	640	291.9	662	301.5	572	264.2	551	260.9	703	261.4
E.......	.053	571	256.3	562	258.1	642	290.8	672	304.4	665	303.3	563	265.1	699	260.0
F.......	.053	562	254.6	556	252.0	582	263.8	663	304.5	562	254.6	578	261.8	731	280.0
G.......	.058	742	271.2	727	268.1	725	268.0	722	270.3	528	254.5	711	278.5	918	276.6

NAp Not applicable; 7th strand exists only in the IWRC.

[1] All values are averages of 2 tensile tests per wire location.

[2] Locations A through XG are in the outer 6 strands of the rope; locations A through G are within the 7th strand (IWRC).

[3] For strand 7 (present only in the IWRC), wire diameters A through F are 0.058 in and G is 0.065 in.

[4] Misplaced wires during construction.

TABLE A-7. - Individual wire breaking loads and strengths for rope C[1]

Wire location[2]	Diameter,[3] in	Strand 1		Strand 2		Strand 3		Strand 4		Strand 5		Strand 6		Strand 7	
		Load, lb	Strength, 10^3 psi	Load, lb	Strength, 10^3 psi	Load, lb	Strength, 10^3 psi	Load, lb	Strength, 10^3 psi	Load, lb	Strength, 10^3 psi	Load, lb	Strength, 10^3 psi	Load, lb	Strength, 10^3 psi
Crown:															
A......	0.081	1,342	260.6	1,345	261.0	1,345	260.0	1,295	254.4	1,305	256.5	1,354	256.9	NAp	NAp
B......	.081	1,310	254.2	1,293	254.0	1,328	261.0	1,309	258.3	1,380	272.7	1,393	270.5	NAp	NAp
C......	.081	1,335	259.1	1,282	255.0	1,380	267.8	1,352	262.5	1,292	255.2	1,315	253.8	NAp	NAp
D......	.081	1,312	254.5	1,303	252.9	1,300	252.3	1,304	256.6	1,269	252.3	1,372	266.3	NAp	NAp
E......	.081	1,340	260.0	1,318	255.8	1,428	277.0	1,331	260.5	1,398	273.6	1,406	264.7	NAp	NAp
F......	.081	1,280	248.4	1,340	254.8	1,373	266.4	1,315	256.8	1,295	255.4	1,348	264.7	NAp	NAp
G......	.081	1,312	254.5	1,358	263.4	1,338	262.8	1,329	258.1	1,412	277.4	1,301	255.6	NAp	NAp
H......	.081	1,308	253.7	1,273	246.9	1,320	259.4	1,330	262.9	1,284	251.3	1,321	257.9	NAp	NAp
J......	.081	1,298	251.8	1,423	276.1	1,313	257.9	1,367	265.4	1,279	252.3	1,273	249.6	NAp	NAp
K......	.081	1,477	260.2	1,435	278.5	1,317	257.6	1,349	269.8	1,280	251.5	1,297	254.9	NAp	NAp
M......	.081	1,355	238.8	1,380	267.8	1,307	256.7	1,300	255.4	1,313	258.0	1,406	264.7	NAp	NAp
N......	.081	1,590	280.2	1,333	258.6	1,368	262.1	1,329	258.1	1,316	258.6	1,380	261.4	NAp	NAp
Filler:															
P......	.037	368	342.3	373	346.9	358	332.9	371	345.1	367	341.3	366	335.8	NAp	NAp
R......	.037	375	348.8	353	328.3	376	349.7	370	344.1	368	334.6	372	341.3	NAp	NAp
S......	.037	369	343.2	373	346.9	366	340.4	363	337.6	372	344.4	360	330.6	NAp	NAp
T......	.037	351	326.4	369	343.2	353	328.3	371	345.1	373	346.9	353	326.9	NAp	NAp
U......	.037	369	343.2	366	340.4	374	347.8	369	343.2	369	343.2	377	345.4	NAp	NAp
V......	.037	363	320.0	375	348.8	369	343.2	366	340.4	375	348.8	372	350.5	NAp	NAp
Inner:															
XA.....	.085	1,483	261.3	1,421	250.4	1,439	253.6	1,609	277.0	1,420	250.2	1,481	261.2	NAp	NAp
XB.....	.085	1,389	244.8	1,519	258.5	1,518	261.3	1,361	239.8	1,487	262.0	1,391	246.3	NAp	NAp
XC.....	.085	1,625	279.8	1,408	248.1	1,419	250.1	1,481	261.0	1,543	262.5	1,449	249.5	NAp	NAp
XD.....	.085	1,384	268.7	1,456	259.5	1,432	252.3	1,503	258.7	1,492	250.9	1,507	253.5	NAp	NAp
XE.....	.085	1,340	260.0	1,560	268.6	1,524	262.4	1,337	235.6	1,406	247.8	1,615	276.3	NAp	NAp
XF.....	.085	1,370	265.9	1,460	251.3	1,400	246.7	1,639	282.2	1,496	254.5	1,468	258.7	NAp	NAp
XG.....	.091	1,649	259.2	1,647	253.2	1,629	250.5	1,629	250.5	1,624	249.7	1,652	251.2	NAp	NAp
IWRC:															
A......	.052	585	275.5	575	275.8	611	282.3	574	273.1	626	295.3	557	259.7	805	270.9
B......	.052	576	276.3	586	286.9	613	288.6	566	266.8	596	281.0	554	255.8	846	289.7
C......	.052	594	282.4	581	268.4	607	280.2	577	277.2	632	297.9	622	283.6	953	278.7
D......	.052	593	279.0	573	274.8	611	282.3	557	262.5	625	294.6	573	267.4	861	284.9
E......	.052	609	286.5	632	292.0	627	289.6	589	277.8	621	292.2	522	238.6	817	279.8
F......	.052	625	294.1	630	294.8	630	290.8	604	284.9	592	278.9	584	269.8	803	274.8
G......	.056	667	275.5	722	298.3	712	294.1	645	271.2	650	273.4	662	269.1	971	283.8

NAp Not applicable; 7th strand exists only in the IWRC.

[1] All values are averages of 2 tensile tests per wire location.

[2] Locations A through XG are in the outer 6 strands of the rope; locations A through G are within the 7th strand (IWRC).

[3] For strand 7 (present only in the IWRC), wire diameters A through F are 0.061 in and G is 0.066 in.

TABLE A-8. - Individual wire torsional ductility for rope A[1]

Wire location[2]	Diameter,[3] in	Strand 1	2	3	4	5	6	7
Crown:								
A......	0.100	27	30	26	27	32	28	NAp
B......	.100	27	28	28	26	26	28	NAp
C......	.100	27	29	26	27	23	24	NAp
D......	.100	29	25	30	27	25	27	NAp
E......	.100	28	29	28	28	26	25	NAp
F......	.100	31	28	25	31	31	27	NAp
G......	.100	27	29	27	27	28	27	NAp
H......	.100	29	28	29	26	25	25	NAp
J......	.100	33	27	30	26	30	27	NAp
Inner:								
K......	.057	60	46	50	53	59	47	NAp
M......	.057	45	58	49	55	63	49	NAp
N......	.057	63	52	42	47	50	53	NAp
P......	.057	54	47	52	51	47	50	NAp
R......	.057	53	48	53	48	47	58	NAp
S......	.057	50	44	55	52	57	51	NAp
T......	.057	46	50	43	53	59	45	NAp
U......	.057	48	54	43	48	45	54	NAp
V......	.057	54	52	57	50	43	49	NAp
W......	.115	27	27	26	24	26	26	NAp
IWRC:								
A......	.053	54	58	57	59	53	51	44
B......	.053	60	52	60	57	63	51	47
C......	.053	57	59	53	58	59	50	47
D......	.053	57	63	56	62	68	59	50
E......	.053	60	70	55	59	52	60	45
F......	.053	60	66	52	53	56	63	49
G......	.057	47	52	52	52	67	49	44

NAp Not applicable; 7th strand exists only in the IWRC.

[1]Listed values are averages of 3 torsion tests done in accordance with Federal Specification RR-W-410C, Sept. 18, 1968. Each value represents the number of 360° torsions at 30 rpm to failure for an 8-in specimen length.

[2]Location A through W are in the outer 6 strands of the rope; location A through G are within the 7th strand (IWRC).

[3]For strand 7 (present only in the IWRC), wire diameters A through F are 0.058 in and G is 0.063 in.

TABLE A-9. - Individual wire torsional ductility for rope B[1]

Wire location[2]	Diameter,[3] in	Strand 1	2	3	4	5	6	7
Crown:								
A.......	0.100	18	19	20	16	20	12	NAp
B.......	.100	16	15	30	20	20	19	NAp
C.......	.100	18	16	18	23	20	11	NAp
D.......	.100	21	19	26	16	20	15	NAp
E.......	.100	14	10	17	18	17	20	NAp
F.......	.100	17	10	15	17	15	26	NAp
G.......	.100	17	18	20	26	22	18	NAp
H.......	.100	18	17	18	19	17	19	NAp
J.......	.100	18	17	19	17	18	16	NAp
1st inner:								
K.......	.058	38	42	54	42	40	45	NAp
M.......	.058	37	47	[4]58	41	41	34	NAp
N.......	.058	38	44	52	54	47	52	NAp
P.......	.058	53	32	51	43	44	41	NAp
R.......	.058	44	38	45	43	37	37	NAp
S.......	.058	39	44	47	40	41	34	NAp
T.......	.058	45	40	37	41	46	44	NAp
U.......	.058	43	51	49	[4]78	43	45	NAp
V.......	.058	49	40	52	38	50	45	NAp
2d inner:								
XA......	.040	72	68	90	72	84	83	NAp
XB......	.040	80	92	[4]47	81	60	62	NAp
XC......	.040	80	83	73	79	70	59	NAp
XD......	.040	63	73	85	90	100	78	NAp
XE......	.040	76	46	84	83	72	78	NAp
XF......	.040	67	83	80	[4]44	82	71	NAp
XG......	.043	63	67	69	66	77	73	NAp
IWRC:								
A.......	.053	56	59	38	35	36	49	42
B.......	.053	57	52	44	58	44	52	48
C.......	.053	56	55	52	44	57	50	52
D.......	.053	52	56	44	32	55	51	43
E.......	.053	56	61	40	34	41	55	41
F.......	.053	59	52	51	41	54	51	40
G.......	.058	41	39	37	33	19	48	33

NAp Not applicable; 7th strand exists only in the IWRC.

[1]Listed values are averages of 3 torsion tests done in accordance with Federal Specification RR-W-410C, Sept. 18, 1968. Each value represents the number of 360° torsions at 30 rpm to failure for an 8-in specimen length.

[2]Locations A through XG are in the outer 6 strands of the rope; locations A through G are within the 7th strand (IWRC).

[3]For strand 7 (present only in the IWRC), wire diameters A through F are 0.058 in and G is 0.065 in.

[4]Misplaced wires during construction.

TABLE A-10. -Individual wire torsional ductility for rope C[1]

Wire location[2]	Diameter,[3] in	Strand 1	2	3	4	5	6	7
Crown:								
A......	0.081	10	36	21	28	29	37	NAp
B......	.081	30	30	35	35	23	28	NAp
C......	.081	35	28	12	24	26	35	NAp
D......	.081	34	33	36	28	35	9	NAp
E......	.081	34	32	17	14	16	32	NAp
F......	.081	36	32	34	35	31	28	NAp
G......	.081	33	35	27	27	25	18	NAp
H......	.081	36	23	25	36	35	29	NAp
J......	.081	21	20	34	22	33	37	NAp
K......	.081	33	12	30	26	21	37	NAp
M......	.081	36	11	33	24	27	35	NAp
N......	.081	29	35	31	33	26	33	NAp
Filler:								
P......	.037	32	47	80	53	51	32	NAp
R......	.037	43	79	37	47	45	24	NAp
S......	.037	41	44	49	80	45	59	NAp
T......	.037	72	64	73	46	43	76	NAp
U......	.037	63	44	39	59	47	39	NAp
V......	.037	79	43	52	78	33	49	NAp
Inner:								
XA.....	.085	32	27	35	26	37	36	NAp
XB.....	.085	39	34	33	38	17	35	NAp
XC.....	.085	31	36	21	24	31	35	NAp
XD.....	.085	32	34	33	27	34	34	NAp
XE.....	.085	35	33	31	36	36	32	NAp
XF.....	.085	30	35	36	32	31	28	NAp
XG.....	.091	33	33	32	35	33	33	NAp
A......	.052	62	59	54	57	51	57	44
B......	.052	60	55	57	61	55	64	39
C......	.052	59	52	55	60	50	55	43
D......	.052	67	56	53	63	55	49	43
E......	.052	62	53	54	62	55	64	40
F......	.052	59	56	54	56	54	52	45
G......	.056	59	55	51	55	62	62	46

NAp Not applicable; 7th strand exists only in the IWRC.

[1]Listed values are averages of 3 torsion tests done in accordance with Federal Specification RR-W-410C, Sept. 18, 1968. Each value represents the number of 360° torsions at 30 rpm to failure for an 8-in specimen length.

[2]Locations A through XG are in the outer 6 strands of the rope; locations A through G are within the 7th strand (IWRC).

[3]For strand 7 (present only in the IWRC), wire diameters A through F are 0.061 and .

TABLE A-11. - Carbon contents of individual wires from rope A, weight percent

Wire location[1]	Strand 1	2	3	4	5	6	7
Crown:							
A....	0.81	0.77	0.77	0.76	0.78	0.77	NAp
B....	.76	.77	.77	.75	.79	.78	NAp
C....	.75	.79	.77	.77	.80	.79	NAp
D....	.82	.79	.76	.78	.81	.80	NAp
E....	.82	.80	.78	.76	.79	.79	NAp
F....	.76	.79	.79	.79	.80	.77	NAp
G....	.81	.79	.79	.76	.76	.79	NAp
H....	.78	.79	.77	.76	.77	.78	NAp
J....	.83	.79	.77	.78	.75	.80	NAp
Inner:							
K....	.79	.80	.78	.79	.77	.79	NAp
M....	.77	.81	.78	.79	.79	.84	NAp
N....	.77	.76	.77	.79	.76	.80	NAp
P....	.82	.77	.78	.82	.79	.82	NAp
R....	.80	.76	.81	.79	.77	.78	NAp
S....	.79	.76	.81	.80	.77	.77	NAp
T....	.75	.79	.75	.79	.77	.78	NAp
U....	.78	.79	.80	.78	.80	.77	NAp
V....	.77	.77	.76	.78	.80	.76	NAp
W....	.81	.78	.81	.79	.78	.77	NAp
IWRC:							
A....	.78	.80	.81	.80	.79	.79	0.81
B....	.77	.75	.81	.78	.79	.79	.81
C....	.75	.78	.78	.78	.78	.78	.75
D....	.77	.75	.79	.75	.80	.81	.80
E....	.78	.76	.78	.76	.76	.80	.80
F....	.80	.80	.77	.73	.79	.79	.77
G....	.77	.77	.78	.79	.76	.80	.75

NAp Not applicable; 7th strand exists only in the IWRC.

[1]Locations A through W are in the outer 6 strands of the rope; locations A through G are within the 7th strand (IWRC).

TABLE A-12. - Carbon contents of individual wires from rope B, weight percent

Wire location[1]	Strand 1	2	3	4	5	6	7
Crown:							
A....	0.71	0.72	0.72	0.73	0.71	0.72	NAp
B....	.74	.73	.72	.73	.73	.71	NAp
C....	.73	.72	.73	.71	.73	.72	NAp
D....	.71	.72	.75	.73	.71	.73	NAp
E....	.73	.73	.73	.73	.73	.72	NAp
F....	.73	.72	.72	.72	.71	.73	NAp
G....	.73	.72	.71	.72	.71	.73	NAp
H....	.73	.73	.73	.73	.72	.73	NAp
J....	.73	.74	.72	.73	.72	.71	NAp
1st inner:							
K....	.72	.71	.67	.71	.66	.72	NAp
M....	.67	.71	.67	.66	.65	.72	NAp
N....	.73	.72	.73	.72	.66	.67	NAp
P....	.72	.72	.67	.70	.69	.65	NAp
R....	.69	.72	.71	.72	.66	.64	NAp
S....	.71	.72	.67	.72	.65	.66	NAp
T....	.66	.72	.72	.73	.73	.71	NAp
U....	.68	.68	.72	.67	.72	.66	NAp
V....	.68	.72	.67	.73	.67	.72	NAp
2d inner:							
XA...	.67	.66	.70	.66	.70	.69	NAp
XB...	.66	.67	.72	.67	.66	.67	NAp
XC...	.66	.68	.66	.67	.66	.66	NAp
XD...	.67	.66	.69	.67	.68	.69	NAp
XE...	.68	.68	.67	.66	.66	.67	NAp
XF...	.67	.66	.67	.73	.67	.66	NAp
XG...	.68	.68	.69	.69	.68	.68	NAp
IWRC:							
A....	.66	.69	.73	.72	.73	.72	0.71
B....	.66	.69	.72	.66	.66	.65	.72
C....	.67	.69	.68	.71	.69	.72	.71
D....	.72	.72	.72	.72	.66	.65	.70
E....	.66	.66	.71	.72	.73	.69	.71
F....	.68	.65	.68	.72	.66	.69	.72
G....	.73	.72	.72	.72	.73	.71	.70

NAp Not applicable; 7th strand exists only in the IWRC.

[1]Locations A through XG are in the outer 6 strands of the rope; locations A through G are within the 7th strand (IWRC).

TABLE A-13. - Carbon contents of individual wires from rope C, weight percent

Wire location[1]	Strand 1	2	3	4	5	6	7
Crown:							
A....	0.72	0.72	0.73	0.73	0.72	0.75	NAp
B....	.73	.72	.72	.73	.72	.75	NAp
C....	.72	.73	.75	.73	.71	.72	NAp
D....	.73	.73	.72	.73	.72	.76	NAp
E....	.72	.72	.76	.73	.74	.77	NAp
F....	.73	.76	.71	.72	.72	.73	NAp
G....	.73	.73	.72	.73	.75	.72	NAp
H....	.72	.73	.72	.73	.71	.73	NAp
J....	.72	.75	.73	.73	.72	.73	NAp
K....	.75	.76	.72	.73	.71	.73	NAp
M....	.72	.76	.72	.73	.72	.75	NAp
N....	.82	.72	.75	.72	.72	.75	NAp
Filler:							
P....	.76	.75	.73	.75	.78	.75	NAp
R....	.76	.71	.77	.76	.76	.76	NAp
S....	.76	.75	.76	.74	.76	.76	NAp
T....	.71	.76	.72	.76	.76	.71	NAp
U....	.76	.75	.76	.76	.77	.76	NAp
V....	.74	.76	.75	.75	.76	.76	NAp
Inner:							
XA...	.75	.72	.73	.82	.72	.74	NAp
XB...	.71	.74	.75	.71	.75	.73	NAp
XC...	.82	.71	.74	.76	.77	.75	NAp
XD...	.73	.74	.72	.75	.73	.76	NAp
XE...	.73	.76	.74	.71	.73	.82	NAp
XF...	.73	.73	.71	.81	.75	.74	NAp
XG...	.72	.72	.72	.71	.71	.72	NAp
IWRC:							
A....	.77	.74	.73	.73	.76	.69	0.74
B....	.75	.73	.83	.73	.73	.69	.77
C....	.77	.83	.84	.76	.77	.77	.72
D....	.77	.74	.76	.75	.76	.84	.76
E....	.77	.83	.77	.76	.84	.60	.74
F....	.77	.76	.77	.76	.73	.84	.75
G....	.71	.75	.74	.74	.73	.76	.71

NAp Not applicable; 7th strand exists only in the IWRC.

[1]Locations A through XG are in the outer 6 strands of the rope; locations A through G are within the 7th strand (IWRC).

TABLE A-14. - Major chemical constitutents of selected wires from rope A

Wire	Location	Measured content of element, wt pct				
		C	S	Mn	P	Si
	STRAND 1					
Crown.................	A1A0............	0.81	0.021	0.45	0.010	0.25
	A1G0............	.81	.020	.45	.009	.21
Inner.................	A1K0............	.79	.013	.51	.017	.51
	A1T0............	.75	.017	.54	.015	.25
Strand core...........	A1W0............	.81	.018	.52	.015	.24
	STRAND 2					
Crown.................	A2B0............	0.77	0.030	0.46	0.010	0.20
	A2H0............	.79	.020	.43	.018	.20
Inner.................	A2M0............	.81	.010	.58	.014	.24
	A2U0............	.79	.018	.52	.018	.23
	STRAND 3					
Crown.................	A3C0............	0.77	0.019	0.48	0.011	0.22
	A3J0............	.77	.020	.44	.011	.19
Inner.................	A3N0............	.77	.017	.51	.014	.23
	A3V0............	.76	.018	.51	.015	.23
	STRAND 4					
Crown.................	A4D0............	0.78	0.018	0.43	0.008	0.21
Inner.................	A4P0............	.82	.011	.56	.011	.22
Strand core...........	A4W0............	.79	.011	.54	.028	.21
	STRAND 5					
Crown.................	A5E0............	0.79	0.020	0.45	0.007	0.19
Inner.................	A5R0............	.77	.012	.51	.018	.20
	STRAND 6					
Crown.................	A6F0............	0.77	0.020	0.42	0.009	0.18
Inner.................	A6S0............	.77	.013	.52	.011	.20
	STRAND 7					
IWRC..................	A7$\underline{A}$1............	0.78	0.011	0.58	0.021	0.18
	A7$\underline{G}$1............	.77	.016	.52	.015	.20
	A7$\underline{B}$2............	.75	.010	.55	.018	.36
	A7$\underline{C}$3............	.78	.008	.57	.019	.21
	A7$\underline{D}$4............	.75	.011	.52	.014	.20
	A7$\underline{G}$4............	.79	.017	.54	.017	.20
	A7$\underline{E}$5............	.76	.019	.55	.011	.23
	A7$\underline{F}$6............	.79	.013	.55	.019	.21
	A7$\underline{A}$7............	.81	.017	.49	.016	.20
	A7$\underline{G}$7............	.75	.013	.58	.020	.19

TABLE A-15. - Major chemical constitutents of selected wires from rope B

Wire	Location	Measured content of element, wt pct				
		C	S	Mn	P	Si
STRAND 1						
Crown	B1A0	0.71	0.014	0.72	0.025	0.28
	B1G0	.73	.015	.77	.021	.28
1st inner	B1K0	.72	.012	.48	.027	.29
	B1T0	.66	.007	.47	.023	.26
2d inner	B1XC	.66	.015	.46	.024	.26
	B1XG	.68	.006	.47	.029	.26
STRAND 2						
Crown	B2B0	0.73	0.015	0.72	0.025	0.28
	B2H0	.73	.015	.72	.023	.29
1st inner	B2M0	.71	.011	.47	.014	.28
	B2U0	.68	.015	.50	.024	.27
STRAND 3						
Crown	B3C0	0.73	0.014	0.69	0.030	0.26
	B3J0	.72	.013	.69	.020	.28
1st inner	B3N0	.73	.019	.48	.020	.26
	B3V0	.67	.011	.48	.023	.26
STRAND 4						
Crown	B4D0	0.73	0.017	0.72	0.031	0.28
1st inner	B4P0	.70	.006	.47	.022	.24
2d inner	B4XA	.66	.007	.45	.021	.26
	B4XG	.68	.015	.46	.032	.23
STRAND 5						
Crown	B5E0	0.73	0.015	0.72	0.028	0.30
First inner	B5R0	.66	.006	.44	.026	.25
STRAND 6						
Crown	B6F0	0.73	0.013	0.74	0.020	0.29
First inner	B6S0	.66	.006	.41	.025	.26
STRAND 7						
IWRC	B7A1	0.66	0.006	0.44	0.023	0.26
	B7$\overline{G}$1	.73	.018	.47	.028	.27
	B7$\overline{B}$2	.69	.006	.48	.029	.25
	B7$\overline{C}$3	.68	.010	.52	.028	.23
	B7$\overline{D}$4	.72	.016	.51	.020	.28
	B7$\overline{G}$4	.72	.017	.45	.031	.24
	B7$\overline{E}$5	.73	.016	.46	.024	.27
	B7$\overline{F}$6	.69	.006	.46	.031	.25
	B7$\overline{A}$7	.71	.014	.48	.030	.24
	B7$\overline{G}$7	.70	.012	.47	.024	.27

TABLE A-16. - Major chemical constitutents of selected wires from rope C

Wire	Location	Measured content of element, wt pct				
		C	S	Mn	P	Si
STRAND 1						
Crown..................	C1A0..............	0.72	0.021	0.81	0.013	0.23
Filler.................	A1P0..............	.76	.019	.77	.026	.32
Inner..................	C1XB..............	.71	.020	.75	.024	.30
STRAND 2						
Crown..................	C2B0..............	0.72	0.013	0.69	0.014	0.23
Filler.................	C2P0..............	.75	.019	.79	.025	.37
Inner..................	C2XB..............	.74	.020	.67	.015	.40
STRAND 3						
Crown..................	C3C0..............	0.75	0.020	0.79	0.027	0.33
Filler.................	C3S0..............	.76	.019	.75	.027	.37
Inner..................	C3XC..............	.74	.017	.79	.024	.28
STRAND 4						
Crown..................	C4D0..............	0.73	0.014	0.72	0.018	0.21
Inner..................	C4XD..............	.75	.025	.66	.013	.22
STRAND 5						
Crown..................	C5E0..............	0.74	0.019	0.76	0.022	0.16
Inner..................	C5XE..............	.73	.013	.68	.015	.20
STRAND 6						
Crown..................	C6F0..............	0.73	0.014	0.72	0.017	0.16
Inner..................	C6XE..............	.82	.020	.59	.025	.23
	C6XF..............	.74	.015	.78	.025	.25
Strand core............	C6XG..............	.72	.014	.74	.019	.20
STRAND 7						
IWRC...................	C7A1..............	0.77	0.013	0.62	0.020	0.20
	C7G1..............	.71	.016	.73	.024	.23
	C7B2..............	.73	.016	.78	.022	.37
	C7C3..............	.84	.020	.77	.014	.23
	C7D4..............	.75	.016	.61	.017	.21
	C7G4..............	.74	.028	.25	.019	.24
	C7E5..............	.84	.020	.69	.026	.23
	C7F6..............	.84	.021	.70	.026	.25
	C7A7..............	.74	.029	.59	.021	.31
	C7G7..............	.71	.014	.70	.023	.22

TABLE A-17. - Qualitative spectrographic analysis of selected wires

Wire	Location	Maximum content of element, wt pct			
		Al	Cu	Cr	Ni
	ROPE A				
Crown	A1A0	0.03	0.01	0.03	0.3
Strand core	A1W0	.03	.001	.1	.1
Inner	A1K0	.03	.003	.1	.1
IWRC	A7A1	.03	.003	.1	.1
	A7$\overline{G}$7	.03	.003	.1	.1
	ROPE B				
Crown	B1A0	0.03	0.001	0.1	0.1
Inner	B1K0	.01	.001	.1	.1
Strand core	B1XC	.005	.001	.1	.1
	B1XG	.005	.001	.1	.1
IWRC	B7A1	.005	.001	.1	.1
	B7$\overline{G}$7	.005	.001	.1	.1
	ROPE C				
Crown	C1A0	0.03	0.03	1.0	0.3
Inner	C1P0	ND	.03	.3	.3
Strand core	C1XB	.03	.03	3.0	1.0
	C6XG	ND	.01	3.0	1.0
IWRC	C7A1	ND	.01	3.0	1.0
	C7$\overline{G}$7	.005	.03	3.0	.3

ND Not detected.

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