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HAWAII DEEP WATER CABLE PROGRAM

PHASE II

CABLE CONSTRUCTION SPECIFICATION

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CABLE CONSTRUCTION SPECIFICATION

Prepared by

Pirelli Cable Corporation

Prepared for

The Ralph M. Parsons Company
Hawaiian Electric Co., Inc.
and the
U.S. Department of Energy

SEPTEMBER 1985

HAWAII DEEP WATER CABLE (HDWC) PROGRAM

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TABLE OF CONTENTS

	PAGE NO.
ABSTRACT	i
KEY WORD LIST	ii
LIST OF ABBREVIATIONS	iii
EXECUTIVE SUMMARY	iv
1. GENERAL	1
2. SYSTEM, CABLE AND ENVIRONMENTAL DATA	2
2.1 System Characteristics	2
2.2 Individual Cable Characteristics	2
2.3 Environmental Conditions	2
2.4 Thermal, Mechanical and Hydraulic Design Characteristics	3
3. GENERAL CABLE CONSTRUCTION	4-5
4. CABLE DRAWING	5
5. CABLE DIMENSIONS AND WEIGHTS	7
5.1 Dimensions	7
5.2 Overall Diameter of Finished Cable	8
5.3 Cable Weights	8
6. DETAILED CABLE CONSTRUCTION	9
6.1 Conductor	9
6.1.1 Chemical Requirements of the Material	9
6.1.2 Physical and Electrical Requirements	9
6.1.3 Conductor Design	9
6.1.4 Conductor Resistance	10
6.1.5 Bending Diameter	10
6.2 Conductor Shield	10
6.2.1 Conductor Shield Design	10
6.2.2 Chemical and Physical Properties of the Materials	10
6.2.3 Conductor Shield Tape Requirements	10-11
6.2.4 Dimensions	11
6.3 Insulation	11
6.3.1 General	11
6.3.2 Chemical and Physical Properties of the Material	11
6.3.3 Insulating Tape Requirements	12
6.3.4 Dimensions	12
6.4 Insulation Shield	12
6.4.1 Insulation Shield Design	12
6.4.2 Chemical and Physical Properties of the Material	12
6.4.3 Insulation Shield Tape Requirements	12
6.4.4 Dimensions	12

6.5 Protective Layer 13
6.5.1 Description of Protective Tape 13
6.5.2 Dimensions 13
6.6 Impregnant and Filling Fluid 13
6.6.1 General 13
6.6.2 Chemical and Physical Requirements 13
6.7 Lead Alloy Sheath 14
6.7.1 General 14
6.7.2 Chemical Requirements of the Material 14
6.7.3 Dimensions 14
6.8 Reinforcement and Anticorrosion Protection 14
6.8.1 Reinforcement and Anticorrosion Design 14
6.8.2 Chemical and Physical Properties 15
6.8.3 Dimensions 16
6.9 Polyethylene Jacket 16
6.9.1 General 16
6.9.2 Chemical and Physical Properties 16
6.9.3 Test Requirements 16
6.9.4 Compound Packaging and Handling 17
6.9.5 Dimensions 17
6.10 Antiteredo Tape Structure 17
6.10.1 Description 17
6.10.2 Chemical & Physical Properties 17
6.10.3 Dimensions 18
6.11 Bedding-Armor-Serving 18
6.11.1 Bedding-Armor-Serving Design 18
6.11.2 Chemical and Physical Properties of Polypropylene Yarn 19
6.11.3 Chemical and Physical Properties of Galvanized Steel Flat wire 19-20
6.11.4 Bitumen 20
6.12 Bending Diameter of Finished Cable 20
6.13 Residual Torque of Finished Cable 20

7. QUALITY ASSURANCE/QUALITY CONTROL 20
7.1 General 20
7.2 QA/QC Program 21
7.2.1 Quality Assurance and Quality Control Procedures 21
7.2.2 Acceptance and In-Process Tests 21-29

ABSTRACT

This document constitutes a detailed construction specification covering the design, fabrication and testing of the preferred 250 MW dc self contained oil filled (SCOF) cable to be used for the laboratory and possibly at-sea portions of the U.S. Department of Energy Hawaii Deep Water Cable (HDWC) Program. All cable materials, components, details of cable fabrication and test requirements are fully described. This specification incorporates a level of technical detail sufficient to permit an experienced cable manufacturer to produce a length of cable.

KEY WORD LIST

HAWAII HVDC SYSTEM
DC SUBMARINE CABLE
HAWAII DEEP WATER CABLE PROGRAM
HDWC PROGRAM
CABLE CONSTRUCTION SPECIFICATION
HAWAII DEEP WATER CABLE SPECIFICATION
CABLE CONSTRUCTION SPECIFICATION FOR LABORATORY TEST CABLE

LIST OF ABBREVIATIONS

ac - Alternating Current
Al - Aluminum
AEIC - Association of Edison Illuminating Companies
ASTM - American Society of Testing Materials
atm - Atmospheres
BTU - British Thermal Unit
BS - British Standard
Cu - Copper
CIGRE - Conference Internationale des Grands Reseaux Electriques a Haute Tension
^{o}C - Degree Centigrade
^{o}F - Degree Fahrenheit
dm - Dekameter
DIN - Deutsch International Normen
dc - Direct current
ft - Feet
HDWC - Hawaii Deep Water Cable
HVDC - High voltage, direct current
in - Inch
IEC - International Electrotechnical Commission
ISO - International Standards Organization
km - Kilometer
kV - Kilovolt
KW - Kilowatt
MW - Megawatt
m - Meter
us - Microsecond
mi - Mile
mm - Millimeter
N - Newton
oz - Ounce
P.U. - Per unit
psi - Pounds per square inch
s - Second
SCOF - Self-contained oil filled
sq cm - Square centimeter
sq ft - Square feet
sq in - Square inch
sq mm - Square millimeter
sq yd - Square yard
V - Volt
W - Watt

EXECUTIVE SUMMARY

This document constitues a detailed construction specification covering the design, fabrication and testing requirements for the preferred 250 MW dc self contained oil filled (SCOF) cable to be used for the laboratory and possibly the at-sea segments of the U.S. Department of Energy sponsored Hawaii Deep Water Cable (HDWC) Program. The design of this full scale prototype cable was selected based on a parametric study which was performed to identify deep water submarine cable designs capable of satisfying the stringent requirements of the HDWC Program including the transmission of power over a distance of more than 240 km (150 mi) in water having a maximum depth of 2134 m (7000 ft). The basis for selection of this cable design is included in the Selection Methodology Memorandum and the Cable Selection Report, both based on information contained in the final report of the Cable Design Parametric Study.

The preferred cable is a single conductor, paper insulated, lead alloy sheathed bronze tape reinforced polyethylene jacketed, teredo resistant tape protected, double galvanized steel flat wire armored self contained (SCOF) design. The dc maximum operating stress for the cable was selected as 35 kV/mm (889 V/mil) considered as the standard electric design stress for high voltage dc SCOF transmission cables.

This cable construction specification identifies all cable materials, components, details of fabrication and test requirements, in addition to providing a Quality Assurance/Quality Control (QA/QC) Program. The level of detail incorporated in this specification is sufficient to permit an experienced cable manufacturer to manufacture a length of cable. This cable construction specification is in sufficient detail to be utilized as a purchasing guideline for the preferred cable.

1. GENERAL

This construction specification covers the design and fabrication requirements for a 250 MW dc self contained oil filled (SCOF) cable to be used for the manufacture of test lengths for the U.S. Department of Energy sponsored Hawaii Deep Water Cable (HDWC) Program. The design of this full scale prototype cable was selected based on a parametric study which was performed to identify deep water submarine cable designs capable of satisfying the stringent requirements of the HDWC Program including the transmission of power over a distance of more than 240 km (150 mi) in water having a maximum depth of 2134 m (7000 ft).

The cable system nominal electrical characteristics, environmental conditions and the basis and constraints for the thermal and hydraulic calculations are discussed in this specification. The basis of selection of this cable design is included in the Selection Methodology Memorandum and the Cable Selection Report based on information contained in the final report of the Cable Design Parametric Study.

The design principles, formulae and test procedures used in the design of this cable are in accordance with recognized international standards and/or acceptable worldwide experience. The basic cable structure and manufacturing requirements set forth herein are based on standard Pirelli cable design and manufacturing practices. Proprietary material, design and manufacturing information have been excluded from this document.

This construction specification covers only the cable design and fabrication requirements. Specifications for cable splices, terminations and other accessories will be presented in separate documents.

2. SYSTEM, CABLE AND ENVIRONMENTAL DATA

2.1 System Characteristics

The cable covered by this specification has been designed to be used in a HVDC transmission system of the following system characteristics:

Voltage	± 300 kV
B.I.L.	775 kV
S.I.L.	580 kV
Total Transmission Load, Bipolar	500 MW
Transmission Load per Cable	250 MW (833A)
Daily Load Swing:	
- normal	200 - 500 MW
- during emergencies	0 - 500 MW
Short Circuit Current	50 kA
Duration	1 s
Reverse Polarity Lightning Impulse	- Uo + 2.15 Uo
(Cigre-Electra #72)	+ Uo - 2.15 Uo

2.2 Individual Cable Characteristics

An individual cable shall satisfy the following characteristics:

Transmission load	250 MW (833A)
Daily Load Factor	100%
Permissable Daily Load Swing	0 to 250 MW

2.3 Environmental Conditions

The following route lengths and maximum water depths were employed in the design of the cable system.

Section	Route length	Max. water depth
HAWAII-MAUI	100 km (60 mi)	2134 m (7000 ft)
MAUI - OAHU	153 km (95 mi)	900 m (2953 ft)

The cable spacing will depend on water depth.
Reference value for thermal calculation .. 60 m (200 ft)

The assumed thermal conditions for the design of the cable are as follows:

Cable Location	Thermal Resistivity (°C m/W)	Ambient Temperature (°C)	Cover Depth (m)
Sea bottom	1.5	3	100
Intermediate	1.5	14	10
Shallow water	1.5	25	3

The design installation weather/sea conditions are as follows:

wind speed	18 m/s (35 knots)
wave height	2.4 m (8 ft)
surface current speed	1.5 m/s (2.9 knots)

2.4 Thermal, Mechanical and Hydraulic Design Characteristics

Thermal and hydraulic calculations for the cable covered by this specification were based on the following conditions and constraints:

Maximum conductor temperature 85°C (185°F)

Maximum temperature difference between conductor and ambient 60°C (140°F)

Calculations of the thermal losses and hydraulic transients in normal operation and in the case of cable severance were based on an average conductor temperature along the cable route. The cable route may include naturally or artificially embedded sections as well as sections where the cables are not embedded. The conductor temperature will change depending on the embedment.

In order to establish an average conductor temperature along the entire route for calculation of losses and hydraulic transients, the following average installation conditions were assumed:

Cover Depth	-	.3 m (1 ft)
Thermal Resistivity	-	0.7°C m/W
Seabed Ambient Temperature	-	3°C

The average conductor temperature calculated under these conditions is 12°C (54°F).

Design oil feeding pressure of the cable is 30 atm (440 psi)

Mechanical design of the cable was based on a maximum expected static and dynamic loading on the cable of 80 metric tons. This value has been calculated in accordance with CIGRE Publication No. 68.

3. GENERAL CABLE CONSTRUCTION

Based on the cable design alternatives identified in the cable design parametric study for the Hawaii Deep Water Cable (HDWC) Program, a preferred cable design was selected, from several hundred designs, for full scale laboratory testing.

The preferred cable is a single conductor paper insulated, lead alloy sheathed, bronze tape reinforced, polyethylene jacketed, teredo resistant tape protected, double galvanized steel flat wire armored self contained oil filled (SCOF) design. The dc maximum operating stress for the cable was selected as 35 kV/mm (889 V/mil) considered as the standard electric design stress for high voltage dc SCOF transmission cables.

The basic construction of the cable is as follows:

Conductor
Hollow core segmental strip (keystone type) aluminum conductor comprised of three layers of strips assembled together with suitable pitch. The annular oil duct in the center of the conductor shall have a diameter of 25 mm (1 in).

Conductor Shield
Carbon black paper tapes and a carbon black duplex paper tape.

Insulation
Deionized water washed wood pulp paper tapes suitably graded in thickness and width applied with predetermined lapping tensions in a controlled environment room. The insulation is mass impregnated with high density, synthetic, low viscosity oil (highly aromatic hydrocarbon).

Insulation Shield
Carbon black duplex type paper tape and carbon black paper tapes.

Insulated Core Protection
Rayon/copper woven fabric binder tape.

Lead Sheath
Seamless tube of lead alloy "E".

Bituminous Compound
Anticorrosion bituminous compound.

Semiconducting Textile Tape Binder
Semiconducting rubberized cotton tape.

Bituminous Compound
Anticorrosion bituminous compound.

Bronze Reinforcement Tapes
Multiple layers of bronze tapes.

Bituminous Compound
Anticorrosion bituminous compound.

Semiconducting Textile Tape Binder
Semiconducting rubberized cotton tape helically applied.

Polyethylene Jacket
Extruded semiconducting, waterproof, anticorrosion polyethylene jacket.

Textile Tape
Bedding layer of treated cotton tape.

Antiteredo Copper Tape
Tinned annealed copper tapes.

Bedding
Carbon black loaded polypropylene yarn.

First Armor
One layer of galvanized high strength steel flat wires with a suitable laying pitch.

Bituminous Compound
Anticorrosion bituminous compound.

Binding
Carbon black loaded polypropylene yarn.

Second Counterhelical Armor
One layer of galvanized high strength steel flat wires.

Bituminous Compound
Anticorrosion bituminous compound.

Outer Serving
Carbon black loaded polypropylene yarn.

4. CABLE DRAWING

A cross sectional drawing of the the cable is shown in Figure 1.

FIGURE 1

WEIGHT OF CABLE IN AIR: 37kg/m (24.9 lb/ft)
WEIGHT OF CABLE IN WATER: 27kg/m (18.2 lb/ft)

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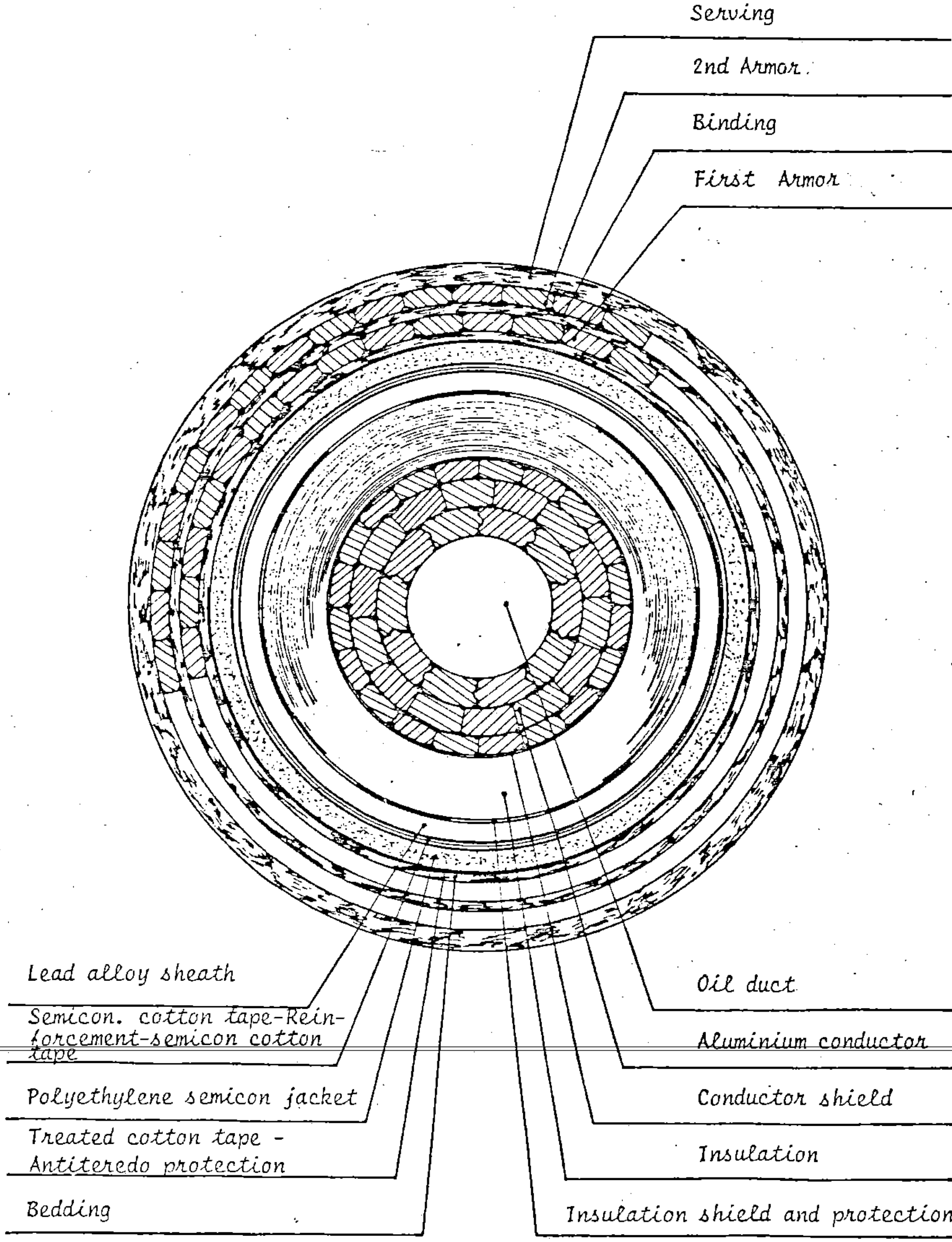

SCALE NTS	DRAWN BY SC/pb	Self Contained Oil Filled Cable $1x1600\ mm^2$ - 300 kV d.c.	B/M
DATE 3/85	APPRD BY LB	HAWAII DEEP WATER CABLE PROGRAM	DRAWING NO. 2

5. CABLE DIMENSIONS AND WEIGHTS

5.1 Dimensions

The nominal thicknesses of the various layers and corresponding diameters are as follows:

Component	Layer Thickness	Diameter
Conductor	-	51.9mm (2.043in)
Conductor Shield	0.6mm (0.024in)	53.2mm (2.094in)
Insulation	10.9mm (0.429in)	75.0mm (2.953in)
Insulation Shield	0.2mm (0.008in)	75.5mm (2.972in)
Core Protection	0.3mm (0.012in)	76.2mm (3.000in)
Lead Sheath	3.3mm (0.130in)	82.8mm (3.260in)
Bitumen	-	-
Semiconducting cotton binder tape	0.3mm (0.012in)	83.4mm (3.283in)
Bitumen	-	-
Bronze Tapes	0.6mm (0.024in)	84.6mm (3.331in)
Bitumen	-	-
Semiconducting cotton binder tape	0.45mm (0.018in)	85.5mm (3.366in)
Polyethylene Jacket	4.0mm (0.157in)	93.5mm (3.681in)
Treated Cotton Bedding Tape	0.34mm (0.013in)	94.2mm (3.709in)
Antiteredo Tinned Copper Tapes	0.1mm (0.004in)	94.4mm (3.717in)
Polypropylene Yarn Bedding	1.1mm (0.043 in)	96.6mm (3.803in)
First Flat Steel Armor	3.0mm (0.118in)	102.6mm (4.039in)
Bitumen	-	-
Polypropylene Yarn Binder	1.6mm (0.063in)	105.8mm (4.165in)
Second Counterhelical Armor	3.0mm (0.118in)	111.8mm (4.402in)
Bitumen	-	-
Polypropylene Yarn Serving	3.3mm (0.130 in)	118.4mm (4.661in)

5.2 Overall Diameter of Finished Cable

The nominal overall diameter of the finished cable is 118.4 mm (4.66 in.)

5.3 Cable Weights

The nominal weights of the cable are as follows:

In air: 37 kg/m (24.9 lb/ft)
In water: 27 kg/m (18.2 lb/ft)

NOTE:

The above dimensions and weights are manufacturing design values and differ slightly from the preliminary design values indicated in the Cable Design Parametric Study for cable No. 116. These dimensions are subject to production tolerances which shall be in accordance with good manufacturing standards e.g. see AEIC CS 4-79, 7th Edition.

6. DETAILED CABLE CONSTRUCTION

6.1 Conductor

6.1.1 Chemical Requirements of the Material

The conductor shall be made of high conductivity Alloy 1350 aluminum complying with the requirements of ASTM Standard B233.

6.1.2 Physical and Electrical Requirements

Aluminum Wire Rod

Tensile Strength, N/mm^2 87-117 (12,000-17,000 psi)
Elongation at Rupture, % min. 15
Electrical Resistivity at 20^oC, $\frac{ohm\text{-}mm^2}{m}$, max. 0.0282

Annealed Aluminum Wire

Tensile Strength N/mm^2 78 to 107 (11,300-15,500 psi)
Elongation at Rupture, % min. 15
Electrical Resistivity at 20^oC, $\frac{ohm\text{-}mm^2}{m}$, max. 0.0282

6.1.3 Conductor Design

The conductor shall be formed by the assembly of three layers of segmental strips. The lay angle of the assembled strips shall be such as to insure the integrity of the conductor in manufacturing operations and subsequent handling of the cable. The detail design of the conductor shall be as indicated below:

Layer Number*	Number of Strips Per Layer	Cross-sectional Area of Each Strip	Cross-sectional Area of Layer	Diameter of Layer
1	10	50 mm2	500 mm2	35.5 mm (1.398in)
2	14	42.86 mm2	600 mm2	45.3 mm (1.783in)
3	20	25 mm2	500 mm2	51.9 mm (2.043in)

* Counted from inside towards the insulation structure

The inside diameter of the conductor, constituting the oil duct, shall have a nominal diameter of 25.0 mm (1.0 in). The cross sectional area of the conductor is 1600 mm2 and the outer diameter of the conductor is 51.9 mm (2.043 in).

6.1.4 Conductor Resistance

The dc resistance of the conductor at 20°C shall not be greater than 0.0186 ohms per kilometer (0.03 ohms/mile).

6.1.5 Bending Diameter

The conductor shall not be bent to a diameter less than 3 m (9.8 ft)

6.2 Conductor Shield

6.2.1 Conductor Shield Design

The conductor shield shall comprise four layers of carbon black paper tape and one layer of duplex paper tape. The tapes are applied lapped as follows:

2 tapes with an overlap of 1/16 of the tape width
2 tapes with a gap of 1 mm (0.04 in.)
Duplex tape with a gap of 1 mm (0.04 in.)

The duplex paper tape, comprising a laminate of carbon black and insulating papers, shall be applied with the insulating side facing outward.

6.2.2 Chemical and Physical Properties of the Materials

The paper tapes shall be prepared with 100% wood pulp which shall not contain gelatin, albumen, resin size and mineral loading materials. A suitable grade of carbon black shall be employed to render the tapes conducting.

The paper tapes shall have a uniform texture with long and well distributed fibers and shall exhibit no evidence of manufacturing defects such as holes, imperfectly pulped materials, wood particles, slime spots, metallic particles or other deleterious substances. Chemicals or other deleterious processing materials used in the pulping or bleaching operations shall be removed.

6.2.3 Conductor Shield Tape Requirements

Conductor shield tape requirements after conditioning at 23 ± 1°C and 50 ± 2% relative humidity (R.H) for 16 hours shall be as follows:

	Carbon Black Tape	Duplex Tape
Electrical Resistance, M , max	0.5-1.7	0.5-1.7
Air Resistance, Gurley-sec.,max.	790	12,000
Moisture Content, %, max.	4	5
Ash Content, %, max.	1	1
Alkalinity, NaOH %, max.	0.05	0.05
Surface Friction Angle, deg,max.	25	25
Tensile Strength: MD, N, min.	100(22.5 lb)	135(30.3 lb)
:CMD, N, min.	40(9 lb)	45(10.1 lb)
Elongation at Rupture:MD, %, min.	1.7	2
:CMD, %, min.	3	4
Folding Endurance, min.	1000	600

Note: Test sample dimensions - 180 x 15 x 0.12 mm (7.1 x 0.59 x 0.0047 in)

MD - machine direction

CMD - cross machine direction

6.2.4 Dimensions

The dimensions of the carbon black paper tapes shall be 0.12 mm (0.0047 in) in thickness and not less than 18 mm (0.71 inches) in width.

The dimensions of the duplex tape shall be 0.11 mm (0.0043in) in thickness and not less than 18 mm (0.71 in) width.

The total thickness of the conductor shield shall be approximately 0.6 mm (0.024 in).

6.3 Insulation

6.3.1 General

The insulating tapes shall be made from 100% pulp paper washed with deionized water.

6.3.2 Chemical and Physical Properties of the Material

The paper shall be manufactured with 100% wood pulp free from gelatin, albumen, resin size and loading materials.

The paper shall be uniform in texture with long, well distributed fibers. It shall not show evidence of manufacturing defects such as holes, imperfectly pulped materials, wood particles, slime spots, metallic particles or other deleterious substances. Chemicals or other deleterious processing materials used in the pulping or bleaching operations shall be removed.

6.3.3 Insulating Tape Requirements

Insulating tape requirements after conditioning at 23 ± 1°C and 50% + 2% R.H. for 16 hours shall be as follows:

Tensile strength: MD, N, min.	95 (21.3 lb)
: CMD, N, min.	35 (7.86 lb)
Elongation at Rupture: MD, %, min.	2
: CMD, %, min.	5
Apparent Density kg/dm^3 (g/cm^3)	0.84 ± 0.04
Air Resistance, Gurley-sec.	1400 min. 3150 max.
Moisture Content, %, max.	4
Ash Content, %, max.	0.5
Surface Friction Angle, Deg., max.	20
Conductivity of the Aqueous Extract, micro mho/cm, max.	5
Ohm x F (Product of Insulation Resistance times Capacitance) at 100°C, sec., min.	300
DC Breakdown Strength Impregnated Paper kV/mm, min.	100 (2500 V/mil)
Loss Factor at 100°C, max.	0.002

Note: (Test sample dimensions: 180 x 15 x 0.08 mm (7.1 x 0.59 x 0.0031 in)

6.3.4 Dimensions

The paper tape thicknesses shall range from 0.08 mm (0.0031 in) to 0.20 mm (0.008 in). The tape widths shall range from 18 mm (0.71 in) to 38 mm (1.5 in). The nominal thickness of the insulation wall shall be 10.9 mm (0.43 in).

6.4 Insulation Shield

6.4.1 Insulation Shield Design

The insulation shield shall comprise one layer of duplex tape, applied with the insulating sides facing the insulation, and one layer of carbon black paper tape. The duplex tape and the carbon black paper tapes shall be applied with a gap of 2 mm (0.08 in)

6.4.2 Chemical and Physical Properties of the Material

Refer to 6.2.2 for the conductor shield.

6.4.3 Insulation Shield Tape Requirements

Refer to 6.2.3 for the conductor shield.

6.4.4. Dimensions

The total thickness of the insulation shield shall be approximately 0.2 mm (0.008 in).

6.5. Protective Layer

6.5.1 Description of Protective Tape

A protective tape shall be applied over the insulation shield to protect the cable core during the subsequent leading operation. The tape shall consist of a woven rayon tape with copper wires incorporated in the tape. The tape shall be uniform, free of imperfections and shall have a uniform thickness throughout the roll.

The tape shall include four pairs of tinned copper wires each wire having a diameter of 0.15 mm (0.006 in) along the entire length of the tape and spaced from each other at regular intervals.

6.5.2 Dimensions

The thickness and width of the protective tape are 0.3 mm (0.012 in) and 50 mm (1.97 in), respectively.

The outer nominal diameter of the finished core shall be 76.2 mm (3.00 in).

The bending diameter of the core shall be not less than 6 m (19.7 ft.).

6.6 Impregnant and Filling Fluid

6.6.1 General

The impregnant and filling fluid shall be a high density low viscosity synthetic fluid consisting of a highly aromatic hydrocarbon suitable for great depth long distance submarine cable applications.

6.6.2 Chemical and Physical Requirements

The synthetic fluid shall comply with the following chemical and physical requirements:

Specific Gravity	0.984
Viscosity at 20°C, cSt	8-11 (52-62 SUS)
at 50°C, cSt	3-4 (36-39 SUS)
Specific heat at 20°C, cal/gm°C	0.381 (0.381 BTU/lb°F)
Pour point, °C	-40 to -60 (-40 to -76°F)
Flash point, °C	140-160 (284 - 320°F)
Dissipation Factor at 100°C, %	0.05 - 0.17
Permittivity at 100°C	2.4 - 2.5
Ohm x F at 100°C, sec.	6 - 9
DC Dielectric Strength at 20°C, kv/mm, min.	40 (1000 V/mil)

6.7 Lead Alloy Sheath

6.7.1 General

The lead alloy sheath applied over the protective tape shall consist of a close fitting seamless tube of uniform thickness applied by a continuous extrusion process without "stop" marks. It shall be impervious to oil and water.

6.7.2 Chemical Requirements of the Material

The lead alloy "E" employed as the lead sheath shall comply with the following chemical requirements:

Element	Composition, Weight % Min.	Max.
Tin	0.38	0.43
Antimony	0.16	0.19
Sodium	0.005	0.008
Lead	Remainder	

The lead pigs shall be clean and with a minimum amount of oxides.

The alloy shall be treated with a lead-sodium alloy in order to obtain the above specified amount of sodium.

6.7.3 Dimensions

The lead alloy sheath shall have the following dimensions:

Nominal Thickness	3.3 mm (0.130 in)
Minimum Average Thickness	3.3 mm (0.130 in)
Minimum Point Thickness	3.0 mm (0.118 in)

6.8 Reinforcement and Anticorrosion Protection

6.8.1 Reinforcement and Anticorrosion Design

The following materials, applied over the lead sheath in the order indicated, constitute the reinforcment structure and provision for protection against corrosion:

Bitumen
Semiconducting cotton tape
Four layers of two bronze tapes each.
Bitumen
Semiconducting cotton tape

6.8.2 Chemical and Physical Properties

6.8.2.1 Bitumen

The bitumen shall be obtained from oil containing prevailing napthenic hydrocarbons. The aqueous extract of the bitumen shall give rise to a neutral reaction and shall not adversely affect the lead sheath or the polyethylene jacket. The bitumen shall not contain derivatives of gas tar or other foreign materials. The softening point shall be 60 ± 5°C (140 ± 9°F)

6.8.2.2 Semiconducting Cotton Tape

The cotton cloth, prior to the rubber coating, shall have the sizing completely removed and the cloth shall be treated to be water repellent. The cloth shall be free from knots and other weaving defects. The weight factor for the tape shall be 80-100 g/m^2 (21.1-26.0 lb/100 sq.yd).

The rubber filling and coating material shall be a solution of butyl rubber compound containing properly dispersed conductive carbon black. The semiconducting butyl rubber compound shall be applied to the cotton tape such as to fill the spaces and to coat the surface of the tape. The surface of the tape shall be smooth and uniform. The weft and warp yarns shall not be visible.

The requirements for the semiconducting tape determined on a 220 x 50 x 0.3 mm (8.7 x 2.0 x 0.012 in) sample are as follows:

Resistivity CMD, ohm/m, max.	1.0 (0.30 ohms/ft)
Tensile strength, N, min.	245 (55 lb)
Elongation at Rupture, %, min.	4
Tear resistance, g, min.	20 (0.71 oz)

6.8.2.3 Bronze tapes

The bronze tapes shall be rolled from a bronze alloy contaning 93% copper and 7% tin. The tapes shall be free of holes, burrs, flakes, dents and irregularities.

The requirements for the bronze tape are as follows:

Resistivity at 20°C, ohms-mm^2/m	0.14 min.-0.15 max.
Tensile strength, N/mm^2, min.	685 (99,210 lbs/in^2)
Elongation at Rupture, %, min.	4

6.8.3 Dimensions

6.8.3.1 Semiconducting Tape

The thickness and width of the tape shall be 0.30 ± 0.03 mm (0.012 ± 0.001 in) and 65 mm (2.56 in), respectively.

6.8.3.2 Bronze Tape

The bronze tapes shall be rolled to a thickness of 0.15 ± 0.01 mm (0.0060 ± 0.0004 in) and a width of 30.00 ± 0.20 mm (1.180 ± 0.008 in).

The reinforcement tapes shall be applied with a 1 mm (.040 in) gap with successive layers centered over the underlying gaps.

The tapes shall have uniform dimensions throughout and shall be free of welds as received.

6.9 Polyethylene Jacket

6.9.1 General

A semiconducting polyethylene jacket shall be extruded over the aforementioned core to prevent corrosion between the lead alloy sheath, bronze reinforcement tapes and the galvanized steel flat armor wires and to limit the voltage which may arise across the jacket as a result of transient voltage conditions.

6.9.2 Chemical and Physical Properties

The compound shall be a polymer or copolymer of low density polyethylene with the addition of properly dispersed conductive carbon black and suitable antioxidant. The compound shall be Unifos DHDS 7710 or equal.

6.9.3 Test Requirements

The semiconducting polyethylene jacket shall comply with the following physical and electrical requirements:

Density, kg/m^3	1125(70 lb/cu ft)
Unaged Tensile Strength, N/mm^2, min.	11(1600 psi)
Tensile Strength After Aging at 135°C for 168 hr.,% of Unaged, min.	80
Elongation, %, min.	200
Elongation After Aging at 135°C for 168 hr, % of Unaged, min.	80
DC Volume Resistivity at 23°C, ohm-cm,max.	100
Durometer Hardness, Shore D	54

6.9.4 Compound Packaging and Handling

The compound shall be supplied in pellet form pre-dried, and packed in welded polyethylene bags. The compound shall be properly handled in all stages of preparation, granulation, storage and feed to the extruder to prevent contamination and to ensure minimum moisture absorption.

6.9.5 Dimensions

The dimensions of the semiconducting polyethylene jacket shall comply with the following:

.. Nominal Thickness	4.0 mm (0.160 in)
.. Minimum Average Thickness	4.0 mm (0.160 in)
.. Minimum Point Thickness	3.0 mm (0.118 in)

6.10 Antiteredo Tape Structure

6.10.1 Description

The antiteredo protective structure shall consist of a bedding layer of treated cotton tape followed by two tinned annealed copper tapes applied in one layer with 5 mm (0.2 in.) overlap. (double start)

6.10.2 Chemical & Physical Properties

6.10.2.1 Cotton Bedding Tape

The fabric used for the tape shall consist of a good quality cotton fabric free from knots, spots, small holes or other weaving defects. It shall not be sized. It shall be selvaged and treated for resistance to the effect of moisture. It shall be treated against rotting with pentachlorophenyllaurate at a percentage of not less than 1.7%. The weight factor is 150 $\pm$ 10 g/sq. m (4.4 $\pm$ 0.3 oz/sq.yd).

6.10.2.2 Tinned Annealed Copper Tape

The copper tapes shall be fully annealed 100% conductivity copper and shall be free of holes, burrs, flakes, dents and irregularities.

Tinning shall be carried out by the hot dip process so that the tapes are covered by tin on the faces as well as on the edges. The tin coating shall be smooth, clean and of uniform thickness and free from defects. The weight of the coating shall be not less than 7 g/m2 (0.023 oz/ft^2).

6.10.3 Dimensions

6.10.3.1 Cotton Tape

The thickness and width of the cotton tape shall be 0.34 ± 0.02 mm (0.0130 ± 0.0008 in) and 35 mm (1.38 in), respectively.

6.10.3.2 Tinned Copper Tape

The copper tape shall be rolled and slit to the following dimensions. There shall be no welds in the tape as received.

Thickness 0.10 ± 0.01 mm (0.0040 ± 0.0004 in)
Width 40.0 ± 0.5 mm (1.57 ± 0.02 in)

6.11 Bedding-Armor-Serving

6.11.1 Bedding-Armor-Serving Design

The bedding-armor-serving design comprises the following layers:

A bedding for the armor consisting of a layer of polypropylene yarn in a nominal thickness of 1.1 mm (0.043 in).

A layer of 29 flat high strength galvanized steel wires each having a thickness of 3 mm (0.120 in) and a width of 10 mm (0.40 in). The armor shall be applied with a right hand lay. The lay angle shall be not greater than $11^{\circ}30'$.

Layer of bitumen

A layer of polypropylene yarn having a nominal thickness of 1.6 mm (0.063 in).

A layer of 31 flat high strength galvanized steel wires each having a thickness of 3 mm (0.120 in) and a width of 10 mm (0.40 in). The armor shall be applied with a left hand lay. The lay angle shall be not greater than $11^{\circ}30'$.

Bitumen

Serving consisting of a layer of polypropylene yarn having a nominal thickness of 3.3 mm (0.130 in).

6.11.2 Chemical & Physical Properties of Polypropylene Yarn

The yarn shall be prepared with a suitable polypropylene fiber filled with 1.5% carbon black. The polypropylene yarn shall be uniform in diameter such that no enlargements or thinnings are visible. The yarn shall not be jointed and shall not cointain knots.

The yarn count for bedding, binding and serving are respectively 1.0 ± 0.1 kg/km (0.672 ± 0.067 lbs/1000 ft), 3 x 0.55 ± 0.05 kg/km (3 x 0.0369 ± 0.0034 lbs/1000 ft) and 4 x 1.9 ± 0.1 kg/km (4 x 1.277 ± 0.067 lbs/1000 ft).

Test Requirements

Sample of polypropylene yarn 500mm (20 in.) long shall comply with the following requirements:

Yarn Count, kg/km x 1000	1000	3x550	4x1900
Tensile Strength, N,	175(39 lb)	315(70.7 lb)	1470(330 lb)
Elongation at Rupture, %, min.	20	20	20

6.11.3 Chemical and Physical Properties of Galvanized Steel Flat Wires

Chemical Composition

The steel shall be of the following chemical composition:

Element	Composition, Weight, %
Carbon	0.75 ± 0.05 max
Silicon	0.25 max
Manganese	0.65 ± 0.15
Phosphorus	0.15 max
Sulphur	0.20 max
Iron	Remainder

Test Requirements

Test requirements on a sample 250 mm (10 in.) long:

Tensile Strength, N/mm^2	1200–1400 (174,000–203,000 psi)
Elongation at Rupture, %, min.	5
Resistivity, $ohm\text{-}mm^2/m$,	0.25

The galvanized flat steel wires shall have a uniform, smooth surface free from flakes and other defects. The zinc coating shall be applied by the hot dip process. The weight of the coating shall be not less than 300 g/m2 (0.984 oz/ft2).

Dimensions

The dimensions of the galvanized steel flat wires shall be as specified previously.

The flat wire rolled to the specified dimensions shall be free of welds or any other kind of joint. However, electric welding of the rod is permitted.

Where joints in the wire are required during application to the cable, they shall be welded and any surface irregularities removed. The minimum distance between two welds in different armor wires shall be two lay lengths.

6.11.4 Bitumen

Refer to paragraph 6.8.2.1

6.12 Bending Diameter of Finished Cable

The allowable bending diameter of the finished cable shall be not less than 6 m (19.7 ft).

6.13 Residual Torque of Finished Cable

The finished cable shall be free of residual torque which could adversely affect the deployment operation.

7. QUALITY ASSURANCE/QUALITY CONTROL

7.1 General

7.1.1 A QA/QC Program, in use in the factory for this type of cable shall be submitted for review and approval by the purchaser's representative.

7.1.2 A listing of all tests to be performed, their frequency and acceptance/rejection criteria shall be submitted to the purchaser's representative for review prior to initiation of applicable tests.

7.1.3 Quality assurance reports that include all results from incoming material inspection to tests on completed cable shall be provided to indicate compliance with the QA/QC Program.

7.1.4 Technical audits will be conducted by staff technical personnel to verify that actual inspection testing and procedures are in accordance with those stated in the QA/QC Program.

7.1.5 The manufacturer shall have instrument standards certified annually. The calibration of each testing instrument in the factory must be checked by using a specific documented calibration procedure.

7.1.6 The purchaser may elect to witness tests and to make inspections of the cable during the process of manufacture, excepting those processes of a confidential nature.

The purchaser's representative shall be notified at least ten days prior to scheduled tests so that tests can be witnessed by responsible personnel if desired.

7.1.7 Inspections and tests will be performed by qualified QA personnel.

7.2 QA/QC Program

7.2.1 Quality Assurance and Quality Control Procedures

The cable manufacturer shall apply Quality Assurance/Quality Control procedures, according to the following guidelines:

7.2.1.1 Acceptance Testing of Purchased Materials

Using as a starting point the chemical and physical requirements of the raw materials indicated in Section 6 of this specification, detailed material specifications shall be developed for each raw material. The specification shall contain material characteristics and tolerances, acceptance test requirements and procedures, as well as sampling procedures.

A portion of the material acceptance tests shall be carried out at the supplier's factory. If those acceptance tests are successful the material shall be delivered to the cable manufacturer. Further acceptance tests shall be carried out by the cable manufacturer at the factory when the material has been received and is in the incoming store. If the tests are successful the material shall be approved for production use.

7.2.1.2 Tests During Fabrication

Suitable in-process test procedures covering each individual manufacturing process shall be employed during cable manufacture to ensure that all cable characteristics will meet the specification requirements.

7.2.1.3 Tests on Completed Cable

The completed cable shall be factory tested to demonstrate compliance with all specification physical and electrical requirements.

7.2.2 Acceptance and In-Process Test

A partial list of acceptance and in process tests is given in the following paragraphs. The QA/QC Program shall be based on but not necessarily limited to the tests shown.

7.2.2.1 Acceptance Testing of the Purchased Materials

The following tests for the various materials are a partial list of the acceptance tests that are to be carried out. The actual tests shall include, but not be limited to, those that are indicated. Specific test values and tolerances shall be identified in the material specifications. Where different tests or test procedures are proposed, their equivalency shall be demonstrated to the purchaser's representative.

Aluminum Wires

Tests on the aluminum wire rod:
a) Chemical composition
b) Electrical resistivity at 20°C (68°F) - ASTM B 193
c) Tensile strength
d) Elongation at break

Tests on the hard drawn shaped wires:
a) Width measurement
b) Thickness measurement
c) Weight per unit length
d) Shaped wire angle inspection

Tests on the annealed wires
a) Elongation at break
b) Tensile strength
c) Electrical resistivity at 20°C (68°F)

Each drawn wire spool shall be provided with a card with the inspection results, namely:

Dimensions
Elongation
Tensile strength

Semiconducting Carbon Black Paper

a) Thickness	ASTM D 202
b) Tensile strength	ASTM D 828
c) Elongation at rupture	ASTM D 828
d) Fold endurance	ASTM D 643
e) Moisture content	ASTM D 644
f) Ash content	ASTM D 586
g) Alkalinity	ASTM D 202
h) Electrical resistance and its variation when dried and impregnated	ASTM D 257
i) Air resistance	ASTM D 726

Semiconducting Duplex Paper

a) Thickness	ASTM D 202
b) Tensile strength	ASTM D 828
c) Elongation at rupture	ASTM D 828

d) Fold endurance	ASTM D 643
e) Moisture content	ASTM D 644
f) Ash content	ASTM D 586
g) Alkalinity	ASTM D 202
h) Electrical resistance and its variation when dried and impregnated	ASTM D 257
i) Air resistance	ASTM D 726

Insulating Paper

a) Thickness	ASTM D 202
b) Tensile strength	ASTM D 828
c) Elongation at break	ASTM D 828
d) Apparent density	ASTM D 202
e) Moisture content	ASTM D 644
f) Ash content	ASTM D 586
g) Conductivity of the aqueous extract	ASTM D 202
h) D.C. electrical strength (impregnated)	ASTM D 149
i) Air resistance	ASTM D 726
j) Loss factor	ASTM D 2413
k) Ohm x F (Product of insulation resistance times capacitance)	

Rayon/Copper Tape

a) Thickness	ASTM D 751
b) Width	ASTM D 751
c) Weight per unit length	ASTM D 751
d) Oil contamination	

Fluid Synthetic Impregnant

a) Viscosity at 20°C (68°F) and at 50°C (122°F)	ASTM D 445
b) Density at 20°C (68°F)	ASTM D 1298
c) Flash point	ASTM D 92
d) Flow point	ASTM D 97
e) Aniline point	ASTM D 611
f) Electrical strength at 20°C (68°F)	ASTM D 877
g) Loss factor at 100°C (212°F)	ASTM D 924

Lead Alloy "E"

a) Chemical composition carried out on:

lead samples	ASTM D 37
lead alloy samples	ASTM D 37
extruded lead alloy samples	ASTM D 37

Bitumen

a) Softening point	ASTM D 36
b) Volatile products	ASTM D 6
c) Penetration at 25°C (77°F)	ASTM D 5
d) Flash point	ASTM D 92
e) Adherence	

Semiconducting Tape

a) Thickness	ASTM D 751
b) Weight per unit length	ASTM D 751
c) Tensile strength	ASTM D 751
d) Elongation at rupture	ASTM D 751
e) Tear resistance	ASTM D 751
f) Volume resistivity	

Bronze Tape

a) Width	ASTM E 8
b) Thickness	ASTM E 8
c) Tensile strength	ASTM E 8
d) Elongation at rupture	ASTM E 8
e) Electrical resistivity at 20°C (68°F)	ASTM B 193
f) Visual inspection of external surface	

Semiconducting Polyethylene Jacket Compound

a) Density	ASTM D 729
b) Durometer	ASTM D 2240
c) Electrical resistivity	
d) Melt index	ASTM D 1248
e) Resistance to environmental stress cracking	IEC 538 A
f) Carbon black content	ASTM D 1603
g) Moisture content	Karl Fisher Method
h) Tensile strength	ASTM D 2633
i) Elongation at rupture	ASTM D 2633
j) Heat deformation	ASTM D 2633

Treated Cotton Tape

a) Width	ASTM D 751
b) Thickness	ASTM D 751
c) Weight per unit area	ASTM D 751
d) Check of PCFL (pentacholorofenillaurate)	

Antiteredo Annealed Copper Tape

a) Width	ASTM E 8
b) Thickness	ASTM E 8
c) Tensile strength	ASTM E 8
d) Elongation at rupture	ASTM E 8
e) Tin weight per unit area	ASTM B 189
f) Visual inspection of surface condition	ASTM B 189

Polypropylene Yarn

a) Count of yarn	ASTM D 1907
b) Tensile strength	ASTM D 2256
c) Elongation at rupture	ASTM D 2256
d) Number of twists per unit length	
e) Carbon black content	ASTM D 1603

Galvanized Steel Flat Wire

a) Width	ASTM E 8
b) Thickness	ASTM E 8
c) Tensile strength	ASTM E 8
d) Elongation at rupture	ASTM E 8
e) Twist endurance	A-411
f) Zinc weight per unit area	BS 443/ASTM A 90
g) Electrical resistivity	ASTM B 193

7.2.2.2 Tests During Fabrication

The following process control tests constitute a partial list of the tests that are to be carried out at the various operations. The actual tests shall include but not be limited to those that are indicated.

Shaped Aluminum Wire Washing and Coiling

a) Visual inspection
Wire shall be examined to assure compliance with surface condition requirements.

b) Contamination test
Carried out to determine effect of residual drawing lubricant on the fluid impregnant.

Stranding

a) Weld machine settings
Qualification welds shall be made when starting a shift. The following tests shall be done on both the as-received and welded wires:
Tensile strength
Elongation at rupture
Bending around a mandrel

b) Inspection during stranding
A continuous visual inspection of the strand shall be carried out by the machine operator assuring the correct positioning of shaped wires in each layer.

Measurements of the diameter of each layer shall be made at least four times per shift. Strand ovalization, before and after the machine capstan, shall be checked. Difference between max. O.D. and min. O.D. at any point shall not exceed 0.6 mm.

c) Electrical resistance measurement
Electrical resistance measurements shall be made on samples 2.5 m (8.2 ft) long at the start and approximately every 1500 m (4920 ft.) of conductor produced during the stranding operation and at the completion of the finished length.

Paper Slitting

The water moisture of paper samples taken from each package shall be checked. If the water content exceeds 4% the roll shall be re-dried.

Lapping

a) Lapping room conditioning

The relative humidity value of the lapping room shall be checked and maintained at a level less than 5%.

Room pressure measurements shall be taken to assure that the room internal pressure is at least 2 mm of water higher than the external pressure.

b) Lapping machine

Measurements shall be taken to ensure that the tension of the pads are equal to the specified nominal values. Also, the tension difference between full pad and empty pad shall be checked.

c) Periodic inspections

Once per day:
Reading of relative humidity recorders
Lapping room pressure measurements

Hourly
Diameter over the conductor shield
Insulating thickness
Diameter over the insulation
Diameter over the insulation shield

Every 10 km of lapped cable
Paper tension measurement

During the last three days of lapping:
Cable temperature in the impregnation tank
Ambient temperature at the center of the impregnating tank

Cable Drying and Impregnation

a) Preliminary Operations and Inspections

Before each tankload, all temperature gauges shall be carefully calibrated.
Residual gas pressure measurements shall be taken. If the residual gas pressure value is greater than 2 mm of mercury, then the pipes and system components shall be flushed with degassified oil.

b) Impregnant Control

The loss factor and the product of Ohm x F (product of insulation resistance times capacitance) shall be checked for compliance with manufacturing requirements.

c) Drying and Impregnation

Before closing the impregnation tank lid, the conductor resistance, (based on the average thermocouple temperature) shall be measured by means of a double bridge. This is to be done with and without heating with electric current. The obtained values shall be compared to the resistance values measured both during stranding and on samples in the conditioning room. The purpose is to determine the conductor resistance and consequent average temperature to the highest possible accuracy.

During the electric heating phase and subsequent phases, the average temperature of the conductor shall be determined through resistance measurements.

d) Inspections

The following measurements shall be performed at least four times per shift during the drying phase:

Conductor resistance
Average conductor temperature
Temperature of the tank heating units
Local average temperature of the coil
Vacuum in the tank and between O-rings
Product of Ohm x F

<u>Lead Sheathing</u>

a) Instrument Calibration
All temperature gauges and air-flow meters shall be carefully calibrated.

b) Inspections
During extrusion, the following values shall be continuously measured and recorded:

Screw r.p.m.
Cable running speed
Motor load

Hourly measurements shall be taken of the:
lead sheath diameter
lead sheath thickness

Reinforcement

a) Welding machine settings

Qualification welds shall be made at the start of each shift and the following tests shall be done on both the as-received and welded tapes:
- Tensile strength
- Elongation at rupture
- Bending around a mandrel

b) Inspections

The following parameters shall be checked:

Every 10 km of cable
Tape lapping tension

Hourly:
Diameter over the outer layer

Semiconductive Polyethylene Jacket

a) The following parameters shall be measured hourly:

- Diameter over polyethylene jacket
- Thickness of the jacket

Armoring

a) Visual Inspection

A constant monitoring of the entire armoring operation shall be carried out by the machine operator. In particular, when starting, the number and dimensions of tapes and wires shall be checked.

b) Welding machine settings

Qualification welds shall be made at the start of each shift and the following tests shall be done on both the as-received and welded wires:
- Tensile strength
- Elongation at rupture
- Bending around a mandrel

c) Inspections

The following parameters shall be measured at the start of each shift:

- Diameter over the antiteredo protection
- Diameter over the polypropylene bedding

Thickness of the polypropylene bedding
Diameter over the first armor
Diameter over the polypropylene binding
Thickness of the polypropylene binding
Diameter over the second armor
Diameter over the polypropylene serving
Thickness of the polypropylene serving

7.2.2.3 Acceptance Tests on Completed Cable

The following acceptance tests shall be carried out on the completed cable in accordance with CIGRE Electra No. 72 "Recommendations for Tests of Power Transmission D.C. Cables for a Rated Voltage up to 600 kV":

Conductor resistance test
Capacitance test
High voltage test
Power factor test

7.2.2.4 Qualification Tests

The following qualification tests shall be performed on selected samples of the completed cable in accordance with CIGRE-Electra No. 72. "Recommendations for Tests of Power Transmission D.C. Cables for a Rated Voltage up to 600 kV":

Mechanical handling - Clause 9.2
Loading cycle and polarity reversal test - Clause 10
Impulse withstand test - Clause 11.1

The following additional Qualification tests shall be performed in accordance with CIGRE-Electra No. 68 "Recommendations for Mechanical Tests on Submarine Cables"

Bending test - Clause 3.2
Tensile test - Clause 3.3
External water pressure withstand test - Clause 3.4
Internal pressure withstand test - Clause 3.5