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IEEE Standard Construction of Composite Fiber Optic Overhead Ground Wire (OPGW) for Use on Electric Utility Power Lines

Sponsor
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of the
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Abstract: The construction, mechanical and electrical performance, installation guidelines, acceptance criteria, and test requirements for a composite overhead ground wire with optical fibers, commonly known as OPGW are discussed.

Keywords: fiber optic cable, multimode fiber, optical cable, optical ground wire, single-mode fiber, rated breaking strength, stranded metallic wires

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Introduction

[This introduction is not a part of IEEE Std 1138-1994, IEEE Standard Construction of Composite Fiber Optic Ground Wire (OPGW) for Use on Electric Utility Power Lines.]

The Fiber Optic Standards Working Group is comprised of key personnel from all OPGW manufacturing companies as well as a large sampling of the user base. This standard is a result of both manufacturers and users wanting guidance on which specifications were important and what tests should be performed. Each manufacturer had a different set of specifications while very few customers had sufficient knowledge of the product to determine what tests and test results would guarantee adequate performance. Therefore, each customer required a different set of product tests and each manufacturer was required to perform many overlapping and redundant tests. This standard provides all customers with the same set of specifications and tests procedures so that they are not required to write their own.

This standard represents a compilation of the combined efforts of users and manufacturers and is endorsed by both communities for general customer and manufacturer use.

At the time this standard was completed, the Fiber Optic Standards Working Group had the following membership.

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CLAUSE PAGE

IEEE Standard Construction of Composite Fiber Optic Overhead Ground Wire (OPGW) for Use on Electric Utility Power Lines

1. Overview

1.1 Scope

This standard covers the construction, mechanical and electrical performance, installation guidelines, acceptance criteria, and test requirements for a composite overhead ground wire with optical fibers commonly known as OPGW. The OPGW has the dual performance functions of a standard ground conductor with telecommunications capabilities.

This standard provides both construction and performance requirements that ensure within the guidelines of this standard that the ground wire function and maintenance of optical fiber integrity and optical transmissions are proper.

2. References

This standard should be used in conjunction with the latest editions of the following standards:

ANSI/AA 53-1981, Packaging Standards for Aluminum Conductor and ACSR.[1]

ANSI/EIA 359-A-1984, Standard Colors for Identification and Coding.

ASTM B 398-1990, Specification for Aluminum-Alloy 6201-T81 Wire for Electrical Purposes.[2]

ASTM B 415-1992, Specification for Hard-Drawn Aluminum Clad Steel Wire.

ASTM E 29-1990, Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications.

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[1] ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[2] ASTM publications are available from the Customer Service Department, American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103, USA.

EIA/TIA 455-3A-1989, Procedures to Measure Temperature Cycling Effects on Optical Fibers, Optical Cable, and Other Passive Fiber Optic Components.[3]

EIA/TIA 455-25A-1989, Repeated Impact Testing of Fiber Optic Cables and Cable Assemblies.

EIA/TIA 455-30B-1991, Frequency Domain Measurement of Multimode Optical Fiber Information Transmission Capacity.

EIA/TIA 455-31B-1990, Fiber Tensile Proof Test Method.

EIA 455-41-1985, Compressive Loading Resistance of Fiber Optic Cables.

EIA/TIA 455-45B-1992, Microscopic Method for Measuring Fiber Geometry of Optical Waveguide Fibers.

EIA/TIA 455-46A-1990, Spectral Attenuation Measurement for Long-Length, Graded-Index Optical Fibers.

EIA/TIA 455-48B-1990, Measurement of Optical Fiber Cladding Diameter Using Laser-Based Instruments.

EIA 455-50A-1987, Light-Launch Conditions for Long-Length, Graded-Index Optical Fiber Spectral Attenuation Measurements.

EIA/TIA 455-51A-1991, Pulse Distortion Measurement of Multimode Glass Optical Fiber Information Capacity.

EIA/TIA 455-53A-1990, Attenuation by Substitution Measurement for Multimode Graded-Index Optical Fibers or Fiber Assemblies Used in Long-Length Communications Systems.

EIA/TIA 455-54A-1990, Mode Scrambler Requirements for Overfilled Launching Conditions to Multimode Fibers.

EIA/TIA 455-55B-1990, End-View Methods for Measuring Coating and Buffer Geometry of Optical Fiber.

EIA/TIA 455-58A-1990, Core Diameter Measurement of Graded-Index Optical Fibers.

EIA/TIA 455-59-1989, Measurement of Fiber Point Defect Using an OTDR.

EIA/TIA 455-61-1989, Measurement of Fiber or Cable Attenuation Using an OTDR.

EIA/TIA 455-62A-1992, Measurement of Optical Fiber Macrobend Attenuation.

EIA/TIA 455-78A-1990, Spectral Attenuation Cutback Measurement for Single-Mode Optical Fibers.

EIA 455-80-1988, Cutoff Wavelength of Uncabled Single-Mode Fiber by Transmitted Power.

EIA/TIA 455-81A-1991, Compound Flow (Drip) Test for Filled Fiber Optic Cable.

EIA/TIA 455-82B-1992, Fluid Penetration Test for Fluid-Blocked Fiber Optic Cable.

EIA/TIA 455-164A-1991, Single-Mode Fiber, Measurement of Mode Field Diameter by Far-Field Scanning.

EIA/TIA 455-167A-1992, Mode Field Diameter Measurement, Variable Aperture Method in the Far-Field.

EIA/TIA 455-168A-1992, Chromatic Dispersion Measurement of Multimode Graded-Index and Single-Mode Optical Fibers by Spectral Group Delay Measurement in the Time Domain.

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[3] EIA publications are available from Global Engineering, 1990 M Street NW, Suite 400, Washington, DC, 20036, USA.

EIA/TIA 455-169A- 1992, Chromatic Dispersion Measurement of Single-Mode Optical Fibers by the Phase-Shift Method.

EIA/TIA 455-170-1989, Cable Cutoff Wavelength of Single-Mode Fiber by Transmitted Power.

EIA/TIA 455-173-1990, Coating Geometry Measurement for Optical Fiber, Side-View Method.

EIA 455-174-1988, Mode Field Diameter of Single-Mode Optical Fiber by Knife-Edge Scanning in the Far Field.

EIA/TIA 455-175A-1992, Chromatic Dispersion Measurement of Single-Mode Optical Fibers by the Differential Phase-Shift Method.

IEEE Std 524-1992, IEEE Guide to the Installation of Overhead Transmission Line Conductors (ANSI).[4]

TIA/EIA 455-176-1993, Method for Measuring Optical Fiber Cross-Sectional Geometry by Automated Grey-Scale Analysis.[5]

TIA/EIA 455-177A-1992, Numerical Aperture Measurement of Graded-Index Optical Fibers.

3. OPGW and components

3.1 Description

The composite fiber optic overhead ground wire shall be made up of buffered flexible glass optical telecommunications fibers contained in a protective central fiber optic unit surrounded by concentric-lay stranded metallic wires in single or multiple layers. The dual purpose of the composite cable is to provide the electrical and physical characteristics of conventional overhead ground wire while providing the optical transmission properties of optical fiber.

3.2 Stranded metallic wires

a) The basic construction shall have bare concentric-lay stranded metallic wires with the outer layer having left-hand lay unless otherwise specified by the purchaser.
b) The stranded wires may be of multiple layers with a combination of various metallic wires within each layer. The direction of lay shall be reversed in successive layers.
c) The wires shall be so stranded that when the complete OPGW is cut, the individual wires can be readily regrouped and then held in place by one hand.
d) The preferred length of lay of the various layers of wires is 13.5 times the outside diameter of that layer, but the length of lay shall not be less than 10 nor more than 16 times this diameter.
e) The rated breaking strength of the completed OPGW shall be taken as 90% of the sum of the rated breaking strengths of the individual wires, calculated from their nominal diameter and the appropriate specified minimum tensile strength.
f) At the manufacturer's option, the rated breaking strength may include the strength of the optical unit. In this case, the manufacturer shall notify the customer if the fiber optic unit is considered a load bearing tension member when determining the total rated breaking strength of the composite conductor.
g) The finished wires shall contain no joints or splices unless otherwise agreed upon between the manufacturer and the purchaser.
h) Hybrid designs not included in items a)-f) are not excluded from this standard.

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[4] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.
[5] TIA/EIA publications are available from Global Engineering.

3.3 Design of central fiber optic unit

The central fiber optic unit shall be designed to house and protect the optical fibers from damage due to forces such as crushing, bending, twisting, tensile stress, and moisture. The fiber optic unit and the outer stranded metallic conductors shall serve together as an integral unit to protect the optical fibers from degradation due to vibration and galloping, wind and ice loadings, wide temperature variations, lightning and fault current, as well as environmental effects that may produce hydrogen. The fiber optic unit may include an aluminum tube and/or channeled aluminum rod, but is not limited to these designs.

3.3.1 Aluminum tube

The fiber optic unit may include an aluminum tube to house the fibers. The aluminum tube may be fabricated as a seamless extruded tube, seam welded, or a tube without a welded seam.

3.3.2 Aluminum rod

An aluminum rod may be fabricated with one or more channels or grooves and formed into a helix to house the optical fibers. An outer protective shield may be applied around the rod such as an aluminum tube or a helically applied overlapping aluminum tape to provide an additional mechanical and environmental barrier.

3.3.3 Filling compound

If required, the interstices of the fiber optic unit shall be filled with a suitable compound to prohibit any moisture ingress from outside or any water migration along the fiber optic unit. The filling compound used shall be compatible with all the components it may come in contact with and shall absorb and/or inhibit generation of hydrogen within the cable.

3.3.4 Central structural member(s)

Structural member(s) may be used to limit the stress on the fiber inside the central fiber optical unit.

3.4 Optical fiber

Single-mode fibers, dispersion-unshifted and dispersion-shifted, and multimode fibers with 50/125 µm and 62.5/125 µm core/clad diameters are considered in this document. The core and the cladding shall consist of all glass which is predominantly silica (SiO_2). The coating, usually made from one or more plastic materials or compositions, shall be provided to protect the fiber during manufacture, handling, and use.

3.5 Buffer construction

The individually coated optical fiber(s) may be surrounded by a buffer for protection from physical damage during fabrication, installation, and performance of the OPGW. Loose buffer or tight buffer construction are two types of protection that may be used to isolate the fibers. The fiber coating and buffer shall be strippable for splicing and termination.

3.5.1 Loose buffer

Loose buffer construction shall consist of a tube that surrounds each fiber or fiber group such that the inner diameter of the tube is greater than the outside diameter of the fiber or fiber group. The interstices inside and outside the tube may be filled with a filling compound.

3.5.2 Tight buffer

Tight buffer construction shall consist of a suitable material that comes in contact with the coated fiber.

3.6 Color coding

Color coding is essential for identifying individual optical fibers and groups of optical fibers. The colors and tolerances shall be in accordance with ANSI/EIA 359-A-1984.[6] The color coding method shall be mutually agreed upon by the user and manufacturer.

3.6.1 Color performance

The original color coding system shall be discernible throughout the design life of the cable.

4. Test requirements

Each requirement in this clause is complementary to the corresponding paragraph in clause 5, which describes a performance verification or test procedure.

4.1 Cable tests

4.1.1 Design tests

An OPGW cable shall successfully pass the following design tests. However, design tests may be waived at the option of the user if a fiber optic overhead ground wire of identical design has been previously tested to demonstrate the capability of the manufacturer to furnish cable with the desired performance characteristics.

4.1.1.1 Water ingress test

A water ingress test for cables designed for water blocking shall be performed in accordance with 5.1.1.1. No water shall leak through the open end of the 1 m sample. If the first sample fails, one additional 1 m sample, taken from a section of cable adjacent to the first sample, may be tested for acceptance.

4.1.1.2 Seepage of flooding compound

For filled fiber optic cable, a seepage of flooding compound test shall be performed in accordance with 5.1.1.2. The filling and flooding compound shall not flow (drip or leak) at 65 °C.

4.1.1.3 Short circuit test

A short circuit test shall be performed in accordance with 5.1.1.3. An increase in measured optical attenuation greater than 1.0 dB/test fiber km at 1550 nm for single-mode fibers and at 1300 nm for multimode fibers shall constitute failure. Birdcaging or breaking of the conductor strands shall also constitute failure.

Dissection of the cable following the test should show no distortion of any component of the cable, including the optical fibers, buffer tubes, and any aluminum or other components. Distortion of any kind that can be attributed to the test other than test set up procedures or hardware shall constitute failure.

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[6] Information on references can be found in clause 2.

4.1.1.4 Aeolian vibration test

An aeolian vibration test shall be carried out in accordance with 5.1.1.4. Any significant damage to any component of the cable, or permanent or temporary increase in optical attenuation greater than 1.0 dB/test fiber km at 1550 nm for single-mode fibers and at 1300 nm for multimode fibers shall constitute failure.

4.1.1.5 Galloping test (if required)

A galloping test shall be carried out in accordance with 5.1.1.5. Any significant damage to any component of the cable or permanent or temporary increase in optical attenuation greater than 1.0 dB/test fiber km at 1550 nm for single-mode fibers and at 1300 nm for multimode fibers shall constitute failure.

4.1.1.6 Sheave test

A sheave test shall be carried out in accordance with 5.1.1.6. Any significant damage to the OPGW cable or central fiber optic unit at any points above deformation limits of 0.50 mm shall constitute failure. A permanent increase in optical attenuation greater than 1.0 dB/test fiber km at 1550 nm for single-mode fibers and at 1300 nm for multimode fibers shall constitute failure.

4.1.1.7 Crush test and impact test

A crush and an impact test shall be performed in accordance with 5.1.1.7. A permanent or temporary increase in optical attenuation value greater than 0.1 dB change in sample at 1550 nm for single-mode fibers and at 1300 nm for multimode fibers shall constitute failure.

4.1.1.8 Creep test

A creep test shall be carried out in accordance with 5.1.1.8.

4.1.1.9 Fiber strain test

A fiber strain test shall be carried out in accordance with 5.1.1.9. Fiber breakage during the test shall constitute failure.

4.1.1.10 Strain margin test

A strain margin test shall be performed in accordance with 5.1.1.10. Strain margin is defined as the amount of stress a cable can sustain without strain on the fiber. A permanent or temporary increase in optical attenuation greater than 1.0 dB/test fiber km at 1550 nm for single-mode fibers and at 1300 nm for multimode fibers up to the strain margin shall constitute failure.

4.1.1.11 Stress-strain test

A stress-strain test shall be performed in accordance with 5.1.1.11. Any visual damage to the conductor strands or permanent or temporary increase in optical attenuation greater than 0.2 dB/test fiber km at 1550 nm for single-mode fibers and 0.5 dB/test fiber km 1300 nm for multimode fibers shall constitute failure.

4.1.1.12 Cable cutoff wavelength (single-mode fiber)

The cutoff wavelength λ_{cc} of the cabled fiber shall be less than 1250 nm.

4.1.1.13 Temperature cycling

Optical cables shall maintain mechanical and optical integrity when exposed to the following temperature extremes: –40 °C to +85 °C.

The change in attenuation between extreme operational temperatures for single-mode fibers shall not be greater than 0.2 dB/km. For unshifted single-mode fibers, the attenuation change measurements shall be made at 1310 nm and 1550 mm. For dispersion-shifted single-mode fibers, the measurements shall be at 1550 nm. For multimode fibers, the change shall not be greater than 0.5 dB/km. The multimode fiber measurement shall be made at 850 nm and 1300 nm.

4.1.2 Routine tests

Except where noted, routine tests shall be performed on a sampling basis such that each reel will meet the criteria stated below.

4.1.2.1 Mechanical and electrical test (wire before stranding)

These tests shall be performed in accordance with 5.1.2.1.

4.1.2.2 Mechanical and electrical tests on aluminum pipe and spacers

These tests shall be performed in accordance with 5.1.2.2.

4.1.2.3 Tests on complete OPGW

These tests shall be performed in accordance with 5.1.2.3.

4.1.2.4 Optical acceptance tests

These tests shall be performed on each reel in accordance with 5.1.2.4. Attenuation loss values exceeding those specified shall constitute failure.

4.2 Fiber tests

4.2.1 Design tests

4.2.1.1 Attenuation variation with wavelength

For unshifted single-mode fibers, the attenuation coefficient for wavelengths between 1285 nm and 1330 nm shall not exceed the attenuation coefficient at 1310 nm by more than 0.1 dB/km. For multimode or dispersion shifted single-mode fibers, the window requirements should be mutually agreed upon among the component suppliers and the user.

4.2.1.2 Attenuation at the water peak

For unshifted single-mode fibers, the attenuation coefficient at the water peak found within 1383 nm ± 3 nm shall not exceed 3 dB/km.

For multimode fibers, the attenuation coefficient at 1380 nm shall not exceed the attenuation coefficient at the 1300 nm wavelength by more than 3 dB/km.

4.2.1.3 Attenuation with bending

For multimode fibers, the attenuation per 100 turns on a 75 mm diameter mandrel shall not exceed 0.5 dB at 850 nm and 1300 nm including the intrinsic attenuation of the 23.6 m of the fiber. For single-mode fibers, the attenuation per 100 turns shall not exceed 0.5 dB at 1550 nm.

Also, the additional attenuation introduced when a single turn of a single-mode fiber is wound around a 32 ± 0.5 mm diameter mandrel shall not exceed 0.5 dB at 1550 nm.

NOTE — A 32 mm diameter bend in a fiber is only recommended for making short-term bend attenuation measurements. For considerations of long-term mechanical survivability, the recommendations of the manufacturer relative to minimum bend diameter should be followed.

4.2.1.4 Environmental requirements—Temperature cycling

Optical fibers shall maintain mechanical and optical integrity when exposed to the following operational temperature extremes: –55 °C to +85 °C. The change in attenuation between extreme operational temperatures for single-mode fibers shall not be greater than 0.05 dB/km. For unshifted single-mode fibers, the attenuation change measurements shall be made at 1310 nm and 1550 nm and for dispersion-shifted single-mode fibers, the measurements shall be at 1550 nm. For multimode fibers, the change shall not be greater than 0.2 dB/km. The multimode fiber measurement shall be made at 850 nm and 1300 nm.

4.2.2 Routine tests

4.2.2.1 Optical requirements

4.2.2.1.1 Attenuation coefficient

The multimode fiber attenuation coefficient shall be specified at 850 nm and/or 1300 nm (unless otherwise required by the user) on the basis of the maximum individual fiber attenuation coefficient in the cable.

The attenuation coefficient for unshifted single-mode fiber shall be specified at 1310 nm and at 1550 nm unless otherwise required by the user. The dispersion-shifted attenuation coefficient shall be specified at 1550 nm. The attenuation coefficient shall be specified on the basis of the maximum individual fiber attenuation coefficient in the cable.

4.2.2.1.2 Attenuation uniformity

The attenuation of the fiber shall be distributed uniformly throughout its length such that there are no point discontinuities in excess of 0.1 dB for single-mode fiber and 0.2 dB for multimode fiber at any design wavelength. If factory splicing is permitted by the user, the spliced fiber shall meet all optical, geometrical, and environmental requirements as stated in this standard.

4.2.2.1.3 Chromatic dispersion (single-mode fiber)

For dispersion-unshifted single-mode fibers, the zero-dispersion wavelength, λ_0, shall be between 1295 nm and 1322 nm. The nominal zero-dispersion wavelength should be 1310 nm. In the context of this objective, the nominal zero-dispersion wavelength is defined as the median of the measured distribution of λ_0. In addition, the maximum value of the dispersion slope at λ_0, S0max, shall be no greater than 0.095 ps/(km·nm^2).

For dispersion-unshifted single-mode fibers, Dmax, the maximum absolute value of the dispersion coefficient over a window 1 min to 1 max, can be found as the larger of the absolute value of:

$$\frac{S_o\max\lambda\min}{4}\qquad\left[1-\frac{\lambda_o\max^4}{\lambda\min^4}\right] \tag{1}$$

OR

$$\frac{S_o\max\lambda\max}{4}\qquad\left[1-\frac{\lambda_o\min^4}{\lambda\max^4}\right] \tag{2}$$

For dispersion-shifted single-mode fibers, the nominal zero-dispersion wavelength should be 1550 nm. In the context of this objective, the nominal zero-dispersion wavelength is defined as the median of the measured distribution of λ_0. The required maximum tolerance on the zero dispersion wavelength, $\Delta\lambda_0$max (i.e, 1550 nm ± $\Delta\lambda_0$max), is dependent on the specified maximum dispersion slope, $S_o$max as indicated below:

If $S_0\text{max} \leq 0.06$ ps/(km·nm^2) then $\Delta\lambda\text{max} \leq 25$ nm.
If $S_0\text{max} \leq 0.085$ ps/(km·nm^2) then $\Delta\lambda\text{max} \leq 15$ nm.

Fibers with values of low $\Delta\lambda_0$ S_0max and wide $\Delta\lambda_0$max have different potential upgrade possibilities than the fibers with values of high $\Delta\lambda_0$ S_0max and narrow $\Delta\lambda_0$max. Therefore, the two different dispersion-shifted fiber designs cannot be considered totally interchangeable.

4.2.2.1.4 Multimode fiber bandwidth

The minimum bandwidth(s) shall be specified at the wavelength(s) of intended use by either the end-to-end bandwidth requirement of the cable span or by an individual reel bandwidth requirement.

4.2.2.1.5 Mode field diameter (single-mode fiber)

The nominal mode field diameter (MFD) for dispersion-unshifted single-mode fibers at 1310 nm shall be no less than 8.3 µm and no greater than 10 µm. For dispersion-shifted single-mode fiber at 1550 nm, the nominal should be between 7 µm and 8.7 µm. A range about the specified nominal shall be less than ± 8% for both the dispersion-unshifted and dispersion-shifted single-mode fibers.

4.2.2.2 Geometrical requirements

4.2.2.2.1 Multimode optical fibers

a) *Core diameter*. The fiber shall have a core diameter of either 50.0 µm or 62.5 µm, as appropriate. The permissible deviation from the nominal value for all designs shall be ≤ 3 µm.
b) *Core noncircularity*. Core noncircularity error shall be ≤ 6%.
c) *Concentricity error*. The concentricity error shall be ≤ 6%.
d) *Numerical aperture (NA)*. The nominal value of NA shall be as follows:
    1) 50/125—The nominal NA shall be between 0.20 and 0.23.
    2) 62.5/125—The nominal NA shall be between 0.27 and 0.29.

For a given design, the permissible deviation from the nominal value of NA shall be ≤± 0.02.

The requirements on cladding diameter and cladding noncircularity shall conform to the dimensions as specified below.

4.2.2.2.2 Single-mode optical fibers

Concentricity error. Offset between the center of the core and the center of the cladding shall be ≤ 1.0 µm.

4.2.2.2.3 Parameters common to both multimode and single-mode fibers

Cladding diameter. The cladding outside diameter shall be 125.0 µm ± 2.0 µm.

Cladding noncircularity. The cladding noncircularity shall be ≤ 2%.

Coating diameter. The nominal coating diameter should be 250 µm for standard protective coating. For use in tight buffered cable designs, an additional buffering with a nominal diameter of 400, 500, 700, or 900 µm may be used.

4.2.2.3 Mechanical requirements

Fiber tensile proof test. All fibers shall be subjected to a minimum proof stress of 0.35 GN/m^2 for 1 s equivalent (100% testing) by the fiber manufacturer.

5. Test methods

Each procedure in this clause is complementary to the corresponding paragraph in clause 4, which describes the specific requirement. For all test procedures described in this clause, the test temperature is 25 ± 5 °C, unless otherwise stated. All measured and computed values shall be rounded to the number of decimal places given in the corresponding requirement using the procedures of ASTM E 29-1990.

5.1 Cable tests

5.1.1 Design tests

5.1.1.1 Water ingress test

Water ingress tests for cables designed for water blocking shall be conducted in accordance with the requirements of EIA 455-82B-1992, except that the retest length, if used, should be 1 m rather than 3 m.

5.1.1.2 Seepage of flooding compound

A 0.3 m sample of cable shall be tested in accordance with EIA/TIA 455-81A-1991, except that an optional preconditioning cycle as described in 5.1.1.2.1 may be used. The sample shall be prepared as per Method A of EIA/TIA 455-8 lA-1991. The unprepared cable end may be sealed.

5.1.1.2.1 Preconditioning cycle

A clean glass dish shall be placed directly under the test specimen. The sample shall be suspended vertically for 72 h at 65 °C ± 2 °C. After preconditioning, a small amount (less than 1% of the weight of the sample before testing) of mostly clear oil may be present. Presence of a greater amount of material in the glass dish constitutes failure.

5.1.1.3 Short circuit test

The short circuit test shall be performed on a sample cable in accordance with annex A.

5.1.1.4 Aeolian vibration test

The aeolian vibration test shall be performed on a sample cable in accordance with annex B.

5.1.1.5 Galloping test

The galloping test shall be performed on a sample cable in accordance with annex C.

5.1.1.6 Sheave test

The sheave test shall be performed on a sample cable in accordance with annex D.

5.1.1.7 Crush test and impact test

The crush test and impact test shall be carried out on a sample of cable approximately 1 m long, according to the method provided by EIA/TIA 455-25A-1989 and EIA 455-41-1985.

5.1.1.8 Creep test

A creep test shall be performed on an OPGW sample approximately 10 m long. The cable shall be terminated at each end and a tension of at least 25% of rated breaking strength shall be applied for a duration of at least 1000 h. The elongation of the cable versus time shall be measured at suitable intervals and recorded.

5.1.1.9 Fiber strain test

A fiber strain test shall be performed on a sample of cable of sufficient length to ensure that the cable test specimen under strain is a minimum of 10 m long and that the optical fiber test specimen under strain is a minimum of 100 m long. The test sample shall be terminated at both ends prior to strain in a manner such that the optical fiber ends cannot move relative to the cable ends. The change in the fiber length may be measured using a suitable optical arrangement (see 5.1.1.10). The overall change in length of the OPGW may also be measured by suitable displacement transducers of strain gauges attached to the outer strands. The fiber attenuation may also be simultaneously monitored by a suitable optical arrangement.

The sample shall be subjected to the loading schedule outlined in [B1][7] while the following measurements are made:

a) The applied load and cable elongation or cable strains at suitable intervals
b) The length variation of optical fibers at regular intervals and with increased frequency at higher loadings

The loading could be halted before the OPGW breaks, for example, at 80% of the rated breaking strength or continued until the cable breaks.

5.1.1.10 Strain margin test

A strain margin test shall be performed on a sample cable of sufficient length to ensure that the cable test specimen under strain is a minimum of 10 m long and that the optical fiber test specimen under strain is a minimum of 100 m long. The test sample shall be terminated at both ends prior to strain in a manner such that the optical fibers cannot move relative to the cable. Strain gauges shall be attached to the cable surface. Changes in the fiber length may be measured using a laser and optical receiver. The propagation delay caused by the change in fiber length may be determined by using either a pulse generator and digital storage oscilloscope, or by measuring the phase shift of a modulated signal.

Fiber attenuation at 1550 nm for single-mode and 1300 nm for multimode shall also be monitored on the same fiber or on another fiber using a laser and power meter. The cable sample is stretched while measuring tensile load, cable strain, fiber attenuation, and fiber length. The cable's strain margin is reached when the fiber begins to elongate at the same rate as the cable.

5.1.1.11 Stress-strain test

Stress-strain testing shall be performed in accordance with [B1]. The cable shall be terminated on each end with suitable fittings. The OPGW cable shall be extended through the dead-ends so that the glass fibers can be attached to optical measuring devices. The fibers shall be restrained at each end of the test cable. The test length of the optical fiber shall be a minimum of 100 m. In addition, attenuation loss at 1550 nm for single-mode and 1300 nm for multimode shall be measured at each test load level before and after the load is released to initial load.

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[7] The numbers in brackets correspond to the bibliographical item listed in clause 10.

5.1.1.12 Cable cutoff wavelength (single-mode fiber)

The cutoff wavelength of cabled fiber, λ_{cc}, shall be measured according to EIA/TIA 455-170-1989. The cable sample shall be 20 m long with additional 1 m fiber ends, each having one 76 mm loop to simulate the splice organizer. (The total fiber length is 22 m including the two 1 m ends.)

Alternatively, the test may also be applied to uncabled fiber by replacing the 20 m cable with 20 m of uncabled fiber coiled in a loop with a minimum diameter of 280 mm to simulate the effect of the cable. (The total fiber length is 22 m including the two 1 m ends.)

Rather than routinely making the cabled fiber cutoff wavelength measurement, a supplier can routinely measure the uncabled fiber cutoff wavelength, λ_{cf}, obtained via EIA 455-80-1988. The supplier shall establish an empirical mapping function to translate the cabled fiber cutoff wavelength requirements into uncabled fiber cutoff wavelength requirements specific to the supplier with a 99% confidence interval. This mapping shall be initially based upon and annually verified by direct fiber and cable cutoff measurements as outlined above for all fiber types in all cable design families.

5.1.1.13 Temperature cycling

Temperature cycling measurements shall be made in accordance with EIA/TIA 455-3A-1989, using a modified version of Test Condition B, –40 °C to +85 °C, two cycles.

5.1.2 Routine tests

5.1.2.1 Mechanical and electrical test (wire before stranding)

a) Tensile
b) Elongation
c) Diameter
d) Resistance
e) Thickness of aluminum (applicable to aluminum clad steel wire)
f) Twist test (applicable to aluminum clad steel wire)
g) Bending test (applicable to aluminum-alloy 6201-T81 wire)

The following specifications are applicable to the acceptance test of the OPGW strands:

Item	Spec
Aluminum Clad Steel Wire (20.3 IACS)	ASTM B 415-1992
Aluminum Clad Steel Wire (27% IACS)	ASTM B 415-1992
Aluminum Clad Alloy 6201-T81 Wire	ASTM B 398-1990

Tests for the mechanical and electrical properties of the wires shall be made before the stranding unless agreed on between the manufacturer and the purchaser at the time of order entry.

5.1.2.2 Mechanical and electrical tests on aluminum pipe and spacers

a) Tensile strength
b) Resistance

c) Elongation (Mechanical and electrical tests will be based on applicable ASTM or equivalent specifications as agreed upon by the manufacturer and the purchaser prior to time of order placement.)

5.1.2.3 Tests on complete OPGW

Tests for rated strength of the completed OPGW are not required, but may be made if agreed on by the manufacturer and the purchaser at the time of order placement. If tested, the breaking strength of the complete OPGW shall not be less than the specified rated breaking strength of the OPGW unless the failure occurs in the lab gripping device. If the failure occurs in the lab grip, the test value must not be less than 95% of the specified rated breaking strength.

5.1.2.3.1 Lay length measurements

Lay length measurement should be made on a straight length of the OPGW, preferably while under some tension load.

NOTE — Taking measurement at stranding operations between the closing die and capstan reel provides ideal conditions for this measurement.

The following procedure can be used for measurement:

a) Take a piece of paper (onion skin quality) that is a length greater than three times the maximum lay length specified for the OPGW under measurement.
b) Lay the paper over the OPGW and run a lead pencil over the length of the paper to obtain strand marks on the tracing paper.
c) The lay length is determined by measuring the strand marks for N strands of the OPGW (N number of strands in layer). Repeat for total of three measurements and average the measurements to determine lay length.

5.1.2.4 Optical acceptance tests

Attenuation test shall be performed on each fiber of each individual reel in accordance with 5.2.2.1.1. Certified test reports shall be supplied by the manufacturer.

5.2 Fiber tests

5.2.1 Design tests

5.2.1.1 Attenuation variation with wavelength

The measurement shall be made in accordance with EIA/TIA 455-78A-1990 or with EIA/TIA 455-46A-1990 for multimode fibers. The spectral width of the source shall be less than 10 nm.

5.2.1.2 Water peak requirements

The measurement shall be made using the same procedures described in 5.2.1.l.

5.2.1.3 Attenuation with bending

The two attenuation with bending requirements are measured by winding 100 turns of fiber on a collapsible reel or removable mandrel of 75 mm ± 2 mm diameter and by wrapping a single turn of fiber around a 32 mm ± 0.5 mm diameter mandrel. Attenuation with bending measurements shall be made in accordance with EIA/TIA 455-62A-1992. For multimode fiber, the launch conditions are critically important, and should sufficiently underfill the fiber mode volume so that modal transients are suppressed. The launch apparatus shall be in accordance with EIA 455-50A-1987. The spectral width of the source used to measure attenuation shall be less than 10 nm.

5.2.1.4 Environmental requirements —Temperature cycling

Temperature cycling measurements shall be made in accordance with EIA/TIA 455-3A-1989 using Test Condition A, –55 °C to +85 °C, 2 cycles.

5.2.2 Routine tests

5.2.2.1 Optical requirements

5.2.2.1.1 Attenuation coefficient

Single-mode fiber attenuation measurements shall be made in accordance with EIA/TIA 455-78A-1990 or with EIA/TIA 455-61-1989. If optical time domain reflectometers (OTDRs) are used, measurements shall be made from both directions and the results shall be averaged. Multimode fiber attenuation measurements shall be made in accordance with either EIA/TIA 455-46A-1990, EIA/TIA 455-53A-1990, or EIA/TIA 455-61-1989. If OTDRs are used, measurements shall be made from both directions and the results shall be averaged.

For multimode fiber, the launch conditions are critically important and should sufficiently underfill the fiber mode volume so that modal transients are suppressed. The launch apparatus shall be in accordance with EIA 455-50A-1987. The spectral width of the source used to measure attenuation shall be less than 10 nm.

Because multimode attenuation measurement accuracy becomes questionable when measured on short cable lengths and test procedures for short cable have not been written by the Electronic Industries Association (EIA), multimode attenuation measurements should be made on characterization cable lengths. If the shipping length of the cable is less than 1 km, the attenuation values measured on longer lengths of cable (characterization lengths of cable) before cutting to the shipping lengths of cable may be applied to the shipping lengths. For multimode fiber, the measurements made on the characterization lengths of cable can be applied to the shipping lengths of the cable only if characterization lengths are less than 3 km.

5.2.2.1.2 Attenuation uniformity

Attenuation uniformity is measured in accordance with EIA/TIA 455-59-1989. Measurements shall be made bi-directionally and the results shall be averaged.

5.2.2.1.3 Chromatic dispersion (single-mode fiber)

Dispersion measurements shall be made in accordance with EIA/TIA 455-168A-1992, EIA/TIA 455-169A-1992, or EIA/TIA 455-175A- 1992.

5.2.2.1.4 Multimode fiber bandwidth

Multimode fiber bandwidth measurements shall be made in accordance with EIA/TIA 455-30B-1991 or EIA/TIA 455-51A-1991. Launch conditions shall conform to EIA/TIA 455-54A-1990.

5.2.2.1.5 Mode field diameter (single-mode fiber)

Any one of three mode field diameter (MFD) measurement techniques may be used. The techniques are in accordance with EIA/TIA 455-164A-1991, EIA/ITA 455-167A-1992, and EIA 455-174-1988. The measurement wavelength shall be 1310 ± 20 nm for dispersion-unshifted single-mode fibers and 1550 ± 20 nm for dispersion-shifted single-mode fibers.

5.2.2.2 Geometrical requirements

If a vidicon-based alternative procedure such as that referenced in TIA/EIA 455-176-1993 is used in the test procedures of this subclause that reference EIA/TIA 455-45B-1992, the measurement accuracy and repeatability should be equivalent to procedures described in EIA/TIA 455-45B-1992.

5.2.2.2.1 Multimode optical fibers

Core diameter. The core diameter measurements shall be in accordance with EIA/TIA 455-58A-1990 (Method A, B, or C).

Core noncircularity. Core noncircularity measurements shall be in accordance with EIA/TIA 455-45B-1992 or TIA/EIA 455-176-1993. The calculated core ovality multiplied by 100% expresses the core circularity in percent. The core non-circularity is expressed as 100% minus the core circularity.

Concentricity error. Core-to-clad concentricity error measurements shall be made in accordance with EIA 455-45B-1992 or TIA/EIA 455-176-1993.

Numerical aperture measurement. The numerical aperture measurement shall be made in accordance with TIA/EIA-455-177A-1992.

5.2.2.2.2 Single-mode optical fibers

Concentricity error. Core-to-clad concentricity error measurements shall be made in accordance with EIA 455-45B-1992 or TIA/EIA 455-176-1993.

5.2.2.2.3 Parameters common to both multimode and single-mode fibers

Cladding diameter. For quality conformance inspection, the cladding diameter measurement shall be made in accordance with EIA/TIA 455-45B-1992 or TIA/EIA 455-176-1993. On-line process control measurements shall be made in accordance with EIA/TIA 455-48B-1990 (Method A or Method B).

Cladding noncircularity. Cladding noncircularity measurements shall be made in accordance with EIA/TIA 455-45B-1992 or TIA/EIA 455-176-1993.

Coating diameter. Coating diameter measurements shall be made in accordance with EIA/TIA 455-55B-1990 or EIA/TIA 455-173-1990. For tight buffer fibers, the manufacturer shall specify a method as long as the measurement accuracy and repeatability is equivalent to procedures described in EIA/TIA 455-55B-1990 or EIA/TIA 455-173-1990.

5.2.2.3 Mechanical requirements

5.2.2.3.1 Fiber tensile proof test

Individual fibers shall be proof tested in accordance with EIA/TIA 455-31B-1990. Fiber at each end of the test sample that has not been subjected to full proof test loading shall be discarded.

6. Sag and tension limits

The following are recommended as minimum controls to be used in preparing sag and tension charts for OPGW:

a) OPGW sags should be such that the tensions do not exceed the limits for open supply conductors, which are given in the latest edition of the National Electrical Safety Code (NESC) or appropriate national code(s) for the country where installed.
   These limitations are based on the use of recognized methods for reducing the likelihood of fatigue failures by minimizing chafing and stress concentrations.
b) Sag and tension recommendations regarding vibration protection should be obtained from the OPGW manufacturer or from other sources knowledgeable in the field of vibration protection of overhead cables.
c) In addition, it is known that some types of cable construction exhibit increased attenuation of the optical signal at tensions, which are permitted by the National Electrical Safety Code (NESC) or appropriate national code(s) for the country where installed. This may be a factor in the selection of the maximum design tension.
d) It is recommended that tension limits for a specific application be chosen through a coordinated study that should include the requirements of the user, recommendations from the cable manufacturer, and recommendations from the manufacturer of all supporting hardware.

7. Field acceptance testing

Upon receipt of the OPGW from the manufacturer, it is recommended that the purchaser perform acceptance tests in order to verify that the optical characteristics of the fiber meet the order requirements and to determine if optical fibers have been damaged during shipment. The results of these tests and the manufacturer's certified quality control information, which is attached to each reel, should be compared to the fiber requirements specified in the purchase order.

These tests may be performed by either of two methods. The first method is to use an OTDR and the second is to use a light source and a power meter. Access to only one end of the cable is required using the OTDR, but both ends of the cable must be accessible when using the light source and power meter. This means the protective wood lagging does not need to be removed when using the OTDR; whereas, it is necessary to remove at least a portion of the lagging to use the light source and power meter. A 1 km length of fiber may be spliced between the OTDR and the cable to improve resolution near the cable end. However, it should be noted when using the OTDR that breaks or damage within 10 m of either end of the fiber from where the OTDR is connected may not be detectable. If a reel fails using the single end OTDR method, then before rejection of the reel, the fiber(s) in question should be tested from the opposite end and the results averaged for the fiber(s). Mechanical splices have been used successfully to conduct these tests.

The end of the cable should be sealed after completion of these tests in order to prevent entry of moisture into the fiber. A visual inspection should be made of each reel. If any indication of physical damage to either the reel or lagging is found, then the following tests should be made:

a) *Fiber continuity*. A continuity check of each fiber may be made to determine if any fiber is broken or any attenuation irregularities exist.
b) *Attenuation*. Total attenuation for the entire reel length and attenuation per kilometer should be measured on each fiber. Attenuation uniformity shall meet the requirements of 4.2.2.1.2 and 5.2.2.1.2.
c) *Fiber length*. The fiber length may be measured using the OTDR. The index factor to be used in this measurement should be furnished by the fiber manufacturer. A check should be made to verify received reel numbers and lengths correspond to ordered quantities.

8. Installation recommendations

8.1 Installation procedure

It is recommended that IEEE Std 524-1992 and OPGW manufacturers' recommended procedures be used for the installation of OPGW.

8.2 Hardware and accessories

Suspension and dead-end hardware, some types of vibration damper hardware, and bonding clamps for OPGW are usually designed for a specific size and/or type of OPGW. Hardware is generally not designed to accommodate a range of sizes of OPGW.

Factors that may influence the interaction of the hardware to OPGW interface are as follows:

a) Excessive contact pressure under hardware can exceed the designed crushing limits of the OPGW.
b) The current transfer capability of the connection between hardware and OPGW could be exceeded if there is insufficient contact area.
c) Contact between dissimilar materials may cause excessive corrosion in some environments.

It is, therefore, recommended that hardware and other accessories connected electrically and mechanically to the OPGW be suitable for the OPGW being used.

9. Packaging requirements

a) OPGW shall be tightly and uniformly wound onto reel(s) in layers. Reel lengths may be either STANDARD LENGTHS or SPECIFIED LENGTHS. STANDARD LENGTHS are reel lengths normally provided by a manufacturer. This length will be defined by the manufacturer. SPECIFIED LENGTHS are reel lengths which are specified by the purchaser. A tolerance of +2% and –0% shall be maintained for SPECIFIED LENGTHS and STANDARD LENGTHS.
b) Reels shall be either a wooden nonreturnable or a steel returnable type that conforms to ANSI/AA 53-1981 or equal. Unless specified otherwise by the purchaser, the manufacturer will determine the size and type reel that will withstand normal shipping, handling, storage, and stringing operations without damage to the OPGW.
c) The drum and inside flanges shall be such that damage will not occur to the OPGW during shipping, handling, storage, and stringing. This may be provided for by a layer of suitable material that is water resistant and will not absorb moisture. The outer layer of the OPGW shall be protected by a water resistance wrapping over the exposed surface to prevent dirt and gritty material from coming in contact with the OPGW during shipment and storage.
d) Reels shall have wood lagging attached to the flanges unless specified otherwise by the purchaser. Wood lagging should be similar to a Grade 3, cured and dressed, 2 × 4 Southern Pine lumber as defined by 260 and 263 of the Southern Pine Inspection Bureau for Southern Pine Boards.[8] Lagging shall be attached to reels in such a manner where individual lagging strips will remain in place during normal shipment, handling, and storage.
e) Reel numbers shall be painted in a clear and legible manner in two locations on the outside of each flange and on two opposite locations on the lagging.
f) Each reel shall be tagged with two shipping tags. One tag shall be attached to the outside of one of the reel flanges and the second tag shall be attached to the inside of the reel flange. Tags shall beweather resistant. All essential information such as manufacturer's name; OPGW size and number of fibers; order number; reel number; ordered and shipped lengths; and gross, tare, and net weight shall appear legibly on the tags. The tags should clearly indicate OPGW in the description.
g) The outer end of the OPGW shall be fastened to the inner surface of the reel flange a minimum of 25 mm below the wood lagging. The cable end shall be securely fastened to prevent the cable from becoming loose during shipment. A minimum of 4 m of the inner end of the OPGW shall be accessible for connection to optical measuring equipment without removing wood lagging or outer layer of protection. This length of cable shall be securely fastened and protected during shipment.

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[8] For more information, contact the Southern Pine Inspection Bureau, 4709 Scenic Highway, Pensacola, FL 32504, +1 (904) 434-2611.

h) A seal shall be applied to each end of the OPGW to prevent the entrance of moisture into the optical fibers or the escape of filling compound during shipment and storage. Two extra seals shall be shipped with each reel and should be accessible without removing lagging.
i) The manufacturer shall furnish at the time of shipment, a certified record of final quality control measured values for each fiber on each reel. This certification shall be attached to the outside flange of the reel in a weatherproof package.
j) Each reel shall be marked on the outside flange to indicate the direction the reel should be rolled during shipment in order to prevent loosening of the cable on the reel.

10. Bibliography

[B1] Technical Committee on Electrical Conductors of the Aluminum Association, *A Method of Stress-Strain Testing of Aluminum Conductor and ACSR*. Washington, D. C., 1971.

Annex A

Short circuit tests

(Informative)

A.1 Definitions

The following are definitions for terms used within the short circuit test guidelines.

a) *Test field*. Any portion of the cable, cable terminating hardware, measuring devices, or any other associated equipment that is subject to the fault current, or the temperature rise or mechanical stresses directly or indirectly caused by the fault current.
b) *Current field*. Any portion of the cable, cable terminating hardware, measuring devices or any other associated equipment that has the fault current pass through it.
c) *Test fibers*. Optical fibers connected together with fusion splices to form one continuous length. The optical source shall be attached to one end of this length, while an optical receiver(s) shall be connected to the other end.
d) *Test length*. The total cumulative length of test fibers within the current field. As an example, if there are 6 test fibers, and the current field is 40 m long, then the test length is 6 × 40 m = 240 m.

A.2 OPGW lengths and configuration

A short circuit test shall be performed on an OPGW sample of sufficient length to ensure that the current field is a minimum of 10 m in length. The cable shall be terminated at each end with suitable fittings, and a tension of at least 2% of ultimate tensile strength (UTS) shall be applied.

At least half of the optical fibers within the cable shall be test fibers. These fibers shall be connected to each other by means of fusion or equally reliable splices. The test length of optical fiber shall be a minimum of 100 m.

The splices must be made and placed in such a manner that they are not within the test field, nor should they be subjected to vibration, sudden stress, or temperature change from fault current pulses, weather conditions, or handling.

Due to the significant stresses within the cable as a result of the fault current, the position of the core assembly with respect to the strands should be monitored at each end of the cable. Devices should be attached to prevent movement of the core assembly relative to the strands. In addition, the cable should be terminated and the core assembly brought out of the strands at least 5 m away from the current field.

A.3 Fiber count

A short circuit qualification test performed and passed on an OPGW cable may be used to qualify another OPGW cable provided that

a) The two cables are identical in every respect, except for the number of fibers.
b) The numbers of fibers within the nontested OPGW is less than the number of fibers in the tested OPGW.
c) Where fibers are enclosed loosely within buffer tubes, the maximum number of fibers within a buffer tube in the nontested OPGW is less than the maximum number of fibers within a buffer tube in the tested OPGW.

It would, therefore, be advantageous for manufacturers to perform the short circuit qualification test on their maximum fiber count and apply the results to all other designs where only the fiber count is different.

A.4 Optical equipment

A laser source shall be connected through an optical splitter to one end of the test fiber. The splitter shall divide the optical signal into two parts. One part shall be fed directly into an optical power meter. The other part shall be fusion spliced onto one free end of the test fiber. A second optical power meter shall be placed on the returning end of the test fiber such that signal from the optical source shall go through the test field on each of the test fibers, and then be read at this second meter. Any necessary power sources for these and all other measurement devices should be powered from a different power supply than that which feeds the fault current apparatus.

The output of the optical power meters shall be monitored using at least two different methods. At least one of these methods shall be functioning continuously from at least 1 h before to at least 2 h after the short circuit test. It should be kept in mind that changes to the optical attenuation can take place in as little time as 0.1 s. The monitoring methods shall be able to record changes occurring this quickly.

The wavelength of the laser source shall be nominally 1550 nm for single-mode fibers and nominally 1300 nm for multimode fibers.

In addition, optical time domain reflectometer (OTDR) measurements at the test wavelength could be made before and after the test to verify the location(s) of any attenuation increases. All OTDR measurements shall be made with a pulse width suitable to ensure accurate location of attenuation anomalies. The location accuracy of the OTDR is not to be confused with the stated distance resolution of the OTDR. Precautions are to be taken to ensure that the test fibers are outside of the dead zone of the OTDR, such as fusion splicing an appropriate length pigtail fiber onto the launch end.

A.5 Fault current pulses

Ten current pulses shall be applied with the OPGW cable being allowed to cool to within 5 °C of the ambient temperature between each pulse. Each current pulse I^2t rating shall be at the higher of the manufacturer's rated cable specification or the user's required cable specification. The exact fault current duration and amplitude shall be in accordance with the specification used for the testing. Fault durations shall not exceed 30 cycles. Each current pulse shall be applied with full asymmetry.

Optical attenuation of the test fibers shall be monitored continuously with at least two monitoring methods from at least 2 min before to at least 5 min after each current pulse. At least one monitoring method must be on continuously throughout the complete short circuit test.

The testing ambient temperature shall be at least 50 °C. Should this prove to be impossible under noncontrolled conditions, the cable shall have continuous current running through it to elevate the cable temperature to at least 50 °C. This current may be shut off up to 15 s before each current pulse, and shall be reapplied no longer than 30 s after. Fast-responding properly isolated thermocouples shall be attached to the cable strands to determine the cable temperature.

The cable shall be dissected after the last fault current pulse. Attention should be paid in particular to the sections of cable closest to the terminating hardware, and at the midpoint of the span. Each separable component of the cable shall be separated and inspected for excessive wear, discoloration, deformation, or other signs of breakdown.

NOTE — It should be realized that the internal cable temperature can be significantly different from the strand temperatures immediately after each fault current pulse. The temperatures of all components of the cable will converge between 1 and 2 minutes after the pulse. After this time the strand temperature can be taken to be the cable temperature.

Annex B

Aeolian vibration test

(Informative)

The objective of this test is to assess the fatigue performance of fiber optic ground wire and the optical characteristics of the fibers under typical aeolian vibrations.

B.1 Test setup

The general arrangement to be used for the aeolian vibration tests and the support details are shown in figure B.1. The end abutments are used to load and maintain tension in the fiber optic cable. The test section is contained between the two intermediate abutments. End and intermediate abutments need not be separate units if the combined unit affords sufficient space for the apparatus specified below. The fiber optic cable to be tested should be cut a sufficient length beyond the intermediate abutments to allow removal of the cable outer strands and to allow access to the optical fibers. Suitable dead-end assemblies are installed on the fiber optic cable to fit between the intermediate abutments. The test sample shall be terminated at both ends prior to tensioning in a manner such that the optical fibers cannot move relative to the cable. A dynamometer, load cell, calibrated beam, or other device should be used to measure cable tension. Some means should be provided to maintain constant tension to allow for temperature fluctuations during the testing. The cable should be tensioned to approximately 25% ± 1% of the rated tensile strength.

In order to achieve repeatability of test results, the minimum active span should be approximately 20 m, with a suitable suspension assembly located approximately two thirds of the distance between the two dead-end assemblies. Longer active and/or back spans may be used. It shall be supported at a height such that the static sag angle of the cable to horizontal is 1.5 degrees ± 0.5 degree in the active span.

Means shall be provided for measuring and monitoring the mid-loop (antinode) vibration amplitude at a free loop, not a support loop.

An electronically controlled shaker shall be used to excite the cable in the vertical plane. The shaker armature shall be securely fastened to the cable so that it is perpendicular to the cable in the vertical plane. The shaker should be located in the span to allow for a minimum of six vibration loops between the suspension assembly and the shaker.

The test length (i.e., between dead-end assemblies) of the optical fiber shall be a minimum of 100 m. Several fibers will probably have to be connected together using splices to achieve this. At least one fiber should be tested from each buffer tube or fiber bundle. An odd number of splices should be made so that the optical equipment can be located at the same end. Optical measurements shall be made using a light source with a nominal wavelength of 1550 nm for single-mode fibers and a nominal wavelength of 1300 nm for multimode fibers.

The source will be split into two signals. One signal will be connected to an optical power meter and will act as a reference. The other signal will be connected to a free end of the test fiber. The returning signal will be connected to a second optical power meter. All optical connections and splices must remain intact through the entire test duration.

An initial optical measurement shall be taken when the span is pre-tensioned to approximately 1335 N to 2224 N, prior to final tensioning. The difference between the two signals for the initial optical measurement provides a reference level. The change in this difference during the test will indicate the change in the attenuation of the test fiber. The signals may be output on a strip chart recorder for a continuous hard-copy record.

B.2 Test procedure

The cable shall be subjected to a minimum of 100 million vibration cycles. The frequency of the test span shall be equal to and maintained at the nearest resonant frequency produced by a 4.5 m/s wind (i.e., frequency = 830 ÷ diameter of cable in mm). The free loop peak-to-peak antinode amplitude shall be maintained at a level equal to one third the diameter of the cable.

In the initial stages the test span requires continuous attention and recordings should be taken approximately every 15 minutes until the test span is stabilized. After the span has stabilized, readings should be taken a minimum of two times per day, typically at the start and end of the working day.

A final optical measurement shall be taken at least two hours after the completion of the vibration test.

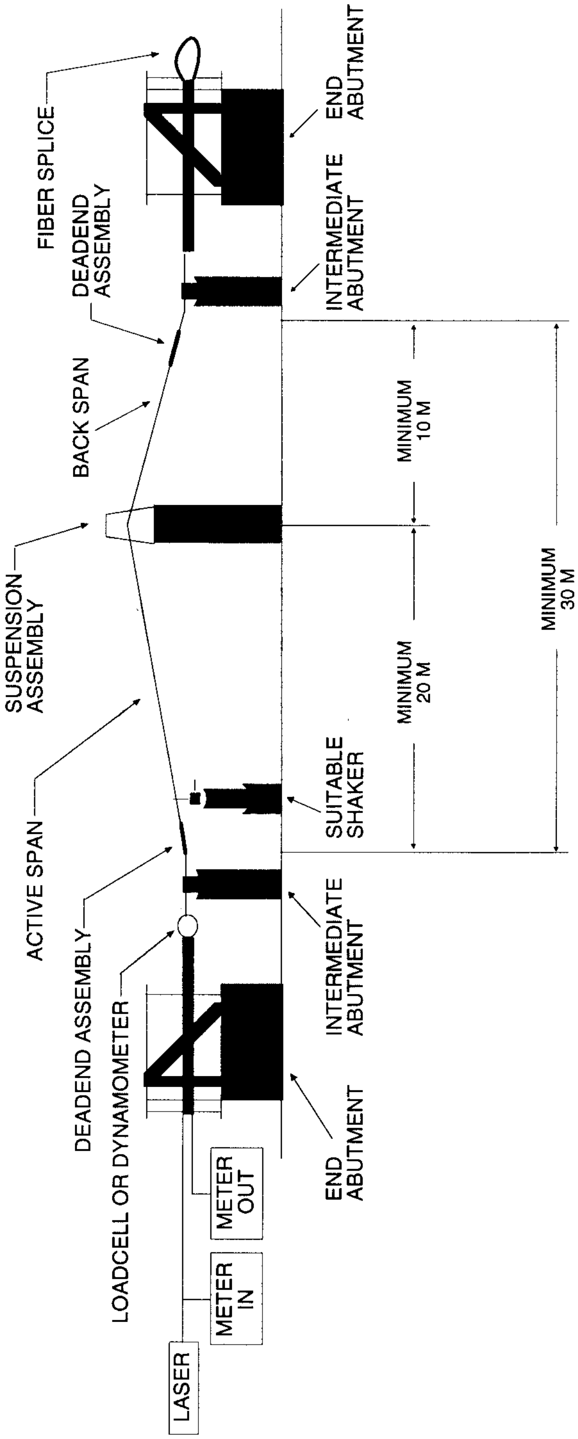

Figure B.1—Aeolian vibration test setup for fiber optic ground wire

Annex C

Galloping test

(Informative)

The objective of this test is to assess the fatigue performance of fiber optic ground wire and the optical characteristics of the fibers under typical galloping motions.

C.1 Test setup

The general arrangement to be used for the galloping test is shown in figure C.1. The overall span between dead-end assemblies should be a minimum of 40 m. The end abutments are used to load and maintain tension in the fiber optic cable. The test section is contained between the two intermediate abutments. End and intermediate abutments need not be separate units if the combined unit affords sufficient space for the 0 apparatus specified below. The fiber optic cable to be tested should be cut a sufficient length beyond the intermediate abutments to allow removal of the cable outer strands and to allow access to the optical fibers.

Suitable dead-end assemblies are installed on the fiber optic cable to fit between the intermediate abutments.

The test sample shall be terminated at both ends prior to tensioning in a manner such that the optical fibers cannot move relative to the cable. A dynamometer, load cell, calibrated beam, or other device should be used to measure cable tension. Some means should be provided to maintain constant tension to allow for temperature fluctuations during the testing. However, some tension fluctuations are expected from the galloping activity itself. The cable should be tensioned to a minimum of 2% of the rated tensile strength.

A suitable suspension assembly shall be located approximately midway between the two dead-end assemblies. It shall be supported at a height such that the static sag angle of the cable to horizontal does not exceed 1 degree. The suspension assembly shall be connected to the support structure in such a manner that feed-through galloping will be established in the back span. This can be accomplished by using hardware that provides freedom of movement for the suspension assembly.

Means shall be provided for measuring and monitoring the mid-loop (antinode), single loop galloping amplitude.

A suitable shaker shall be used to excite the cable in the vertical plane. The shaker armature shall be securely fastened to the cable in the vertical plane.

The test length (i.e., between dead-end assemblies) of the optical fiber shall be a minimum of 100 m. Several fibers will probably have to be connected together using fusion splices to achieve this. At least one fiber should be tested from each buffer tube or fiber bundle.

An odd number of splices should be made so that the optical equipment can be located at the same end. Optical measurements shall be made using a light source with a nominal wavelength of 1550 nm for single-mode fibers and a nominal wavelength of 1300 nm for multimode fibers. The source will be split into two signals. One signal will be connected to an optical power meter and will act as a reference. The other signal will be connected to a free end of the test fiber. The returning signal will be connected to a second optical power meter. The difference between the two signals for the initial optical measurement provides a reference level. The change in this difference during the test indicates the change in the attenuation of the test fiber. The signals may be output on a strip chart recorder for a continuous hard-copy record.

C.2 Test procedures

The cable shall be subjected to a minimum of 100 000 galloping cycles. The test frequency shall be single loop resonant frequency. The peak-to-peak vertical antinode amplitude/loop length ratio shall be maintained at a value of approximately 1/25, as measured in the active span. The amplitude (peak-to-peak) in the back span shall be no less than 50% of the amplitude of the active span. Appropriate restraining devices or fixtures shall be used to maintain the horizontal component of the galloping motion to 300 mm, peak-to-peak, or less.

Mechanical and optical data should be read and recorded approximately every 500 cycles or approximately 15 min.

The optical power meters shall be continuously monitored beginning at least one hour before the test and ending at least two hours after the test.

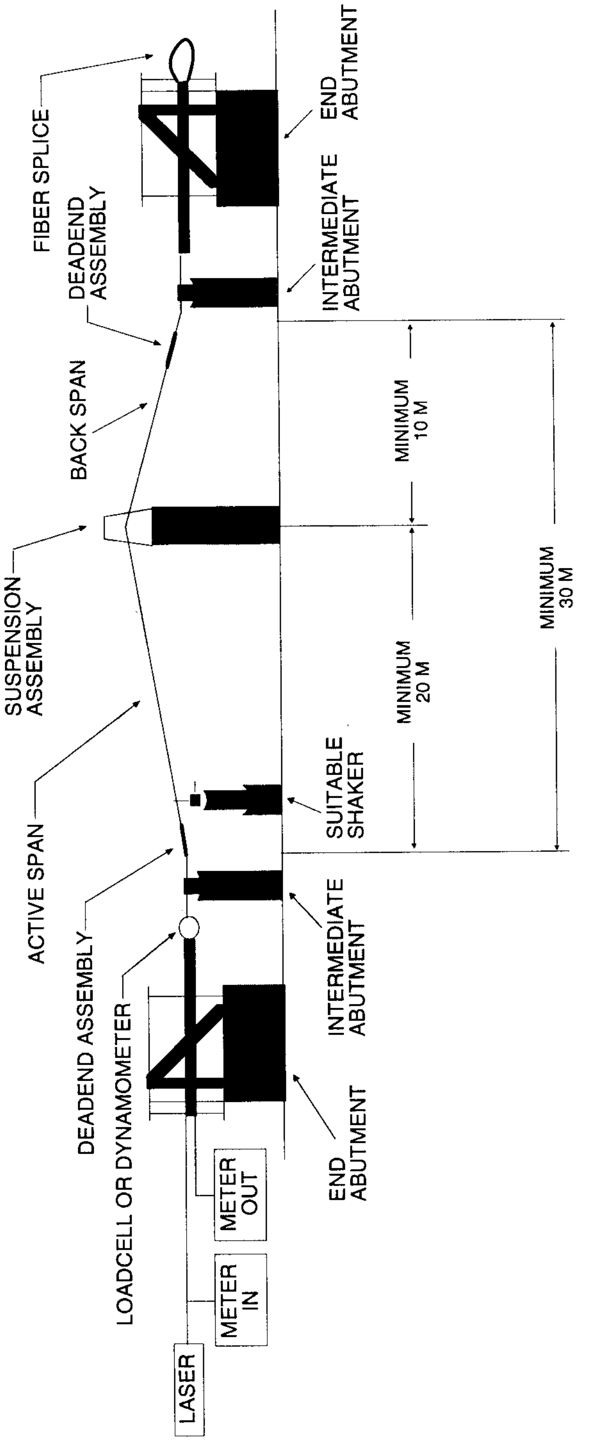

Figure C.1—Galloping test setup for fiber optic ground wire

Annex D

Sheave test

(Informative)

The objective of the test is to verify that stringing of the OPGW with the recommended sheave size and procedures would not damage or degrade the quality of the optical fibers.

D.1 Test setup

The general arrangement for the sheave test is shown in figure D.1. A sheave test shall be performed on a sample cable of approximately 21 m long. Dead-end fittings shall be clamped approximately 3 m in from each end of the test sample, leaving about 15 m of cable between them. The optical fibers shall be connected to each other by means of fusion or equally reliable splices. The test length of optical fiber shall be a minimum of 100 m. A light source shall be connected to one end of the test fiber. At the other end, an optical power meter shall be used to monitor the relative light power level. The power meter shall be connected to a strip chart recorder that shall run continuously during the test.

The sample shall be led through a sheave. The minimum recommended sheave diameter is 40 × cable diameter. The cable shall be pulled at one dead-end at 25% of its rated tensile strength at a deflection angle of 30 ± 2 degrees as shown in figure D.1. The method of attachment, while not rigid, shall limit the amount of twist that could occur at the lead end. A dynamometer and a swivel shall be installed between the yoke and the other dead-end.

D.2 Test procedures

A 2 m minimum length of the OPGW test sample shall be pulled 70 times forward and backward through the sheave (35 times in each direction). Before the first pull, the beginning, midpoint, and end of this length shall be marked. Micrometer readings shall be taken after the first pass through the sheave and thereafter every tenth cycle. The output of the optical power meter shall be monitored continuously during the test. After the test is completed, the aluminum clad steel strands shall be removed in the test section, and the aluminum pipe diameter shall be measured at the marked points and at the one-third points between each marked point.

The test length (i.e., between dead-end assemblies) of the optical fiber shall be a minimum of 100 m. Several fibers will probably have to be connected together using splices to achieve this. At least one fiber should be tested from each buffer tube or fiber bundle. An odd number of splices should be made so that the optical equipment can be located at the same end. Optical measurements shall be made using a light source with a nominal wavelength of 1550 nm for single-mode fiber and a nominal wavelength of 1300 nm for multimode fiber.

The source will be split into two signals. One signal will be connected to an optical power meter and will act as a reference. The other signal will be connected to a free end of the test fiber. The returning signal will be connected to a second optical power meter. All optical connections and splices must remain intact through the entire test duration.

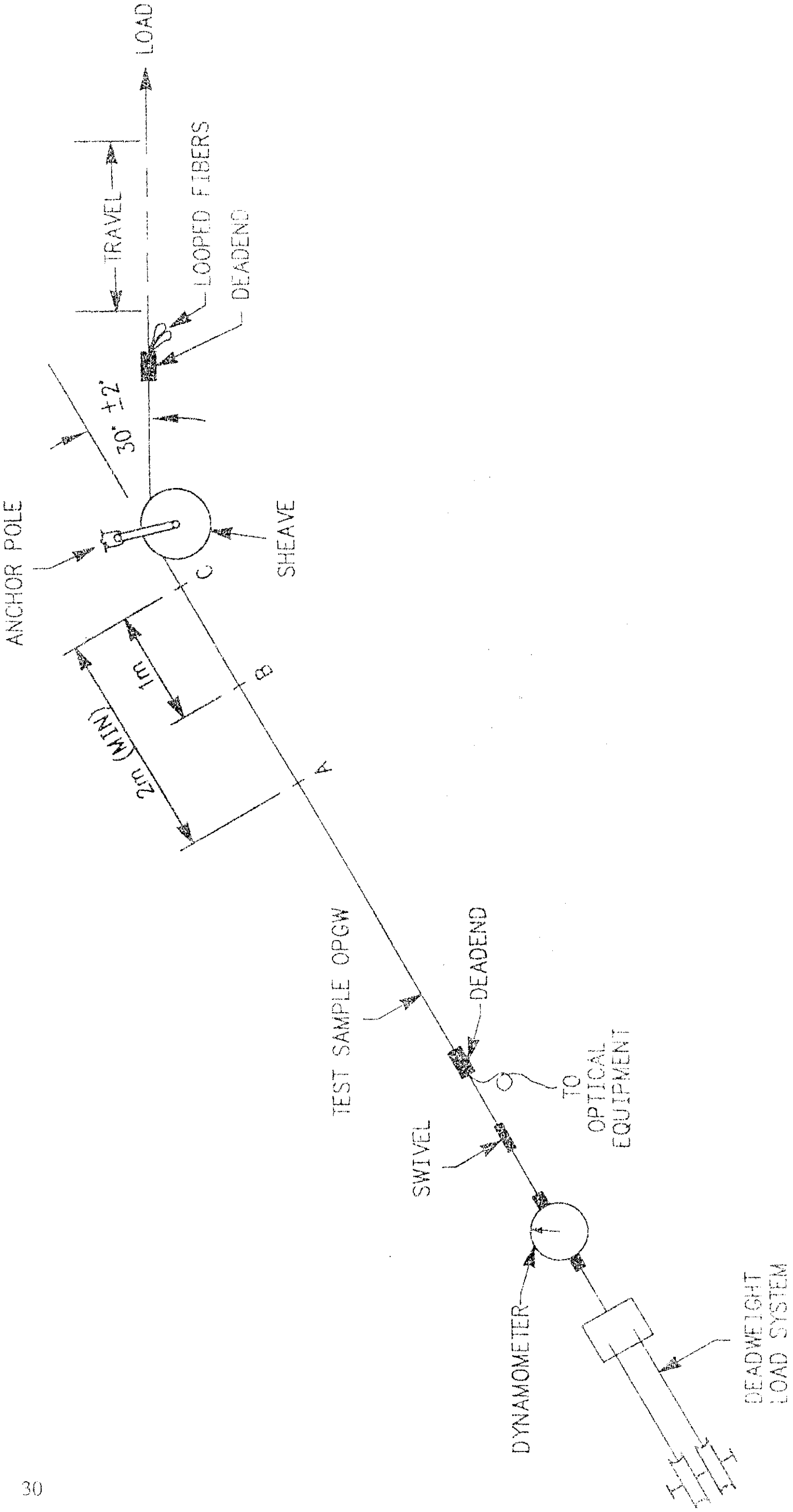

Figure D.1—Sheave test