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SERIES L: ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

Maintenance and operation – Optical fibre cable maintenance

Water detection in underground closures for the maintenance of optical fibre cable networks with optical monitoring system

Recommendation ITU-T L.315

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ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

OPTICAL FIBRE CABLES	
Cable structure and characteristics	L.100–L.124
Cable evaluation	L.125–L.149
Guidance and installation technique	L.150–L.199
OPTICAL INFRASTRUCTURES	
Infrastructure including node elements (except cables)	L.200–L.249
General aspects and network design	L.250–L.299
MAINTENANCE AND OPERATION	
Optical fibre cable maintenance	**L.300–L.329**
Infrastructure maintenance	L.330–L.349
Operation support and infrastructure management	L.350–L.379
Disaster management	L.380–L.399
PASSIVE OPTICAL DEVICES	L.400–L.429
MARINIZED TERRESTRIAL CABLES	L.430–L.449

For further details, please refer to the list of ITU-T Recommendations.

Recommendation ITU-T L.315

Water detection in underground closures for the maintenance of optical fibre cable networks with optical monitoring system

Summary

Widely used underground optical fibre cables employ water-blocking materials and are maintenance free in regard to water penetration. However, water penetrated into closures/cabinets would increase the risk of significant degradation to the optical fibres and/or connectors. Recommendation ITU-T L.315 describes the methodology for water detection in splice closures/cabinets, the fundamental requirements for water sensors and technical considerations concerning the optical time domain reflectometry (OTDR)-based water ingress monitoring and location system design.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
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Keywords

Cabinet, closure, optical fibre cable, OTDR testing, underground, water detection, water sensor.

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Table of Contents

Recommendation ITU-T L.315

Water detection in underground closures for the maintenance of optical fibre cable networks with optical monitoring system

1 Scope

This Recommendation covers:

– water detection systems in splice closures/cabinets to ensure the reliability of underground optical fibre cable networks;

– fundamental requirements for water sensors attached to non-active optical fibre dedicated for maintenance use;

– technical considerations for the design of an optical fibre cable maintenance support, monitoring and testing system to monitor and locate water penetration.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.652] Recommendation ITU-T G.652 (2016), *Characteristics of a single-mode optical fibre and cable*.

[ITU-T G.653] Recommendation ITU-T G.653 (2010), *Characteristics of a dispersion-shifted, single-mode optical fibre and cable*.

[ITU-T G.654] Recommendation ITU-T G.654 (2016), *Characteristics of a cut-off shifted single-mode optical fibre and cable*.

[ITU-T G.655] Recommendation ITU-T G.655 (2009), *Characteristics of a non-zero dispersion-shifted single-mode optical fibre and cable*.

[ITU-T G.656] Recommendation ITU-T G.656 (2010), *Characteristics of a single-mode optical fibre and cable with non-zero dispersion for wideband optical transport*.

[ITU-T G.657] Recommendation ITU-T G.657 (2016), *Characteristics of a bending-loss insensitive single-mode optical fibre and cable*.

[ITU-T L.300] Recommendation ITU-T L.300/L.25 (2015), *Optical fibre cable network maintenance*.

[ITU-T L.302] Recommendation ITU-T L.302/L.40 (2000), *Optical fibre outside plant maintenance support, monitoring and testing system*.

[IEC 60793-2-50] IEC 60793-2-50 (2015), *Optical fibres – Part 2-50: Product specifications – Sectional specification for class B single-mode fibres*.

[IEC 60794-1-31] IEC 60794-1-31 (2018), *Optical fibre cables – Part 1-31: Generic specification – Optical cable elements – Optical fibre ribbon*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 maintenance support, monitoring and testing system [ITU-T L.300].

3.1.2 preventative maintenance [ITU-T L.300].

3.1.3 surveillance [ITU-T L.300].

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

CRT	Cathode Ray Tube
CPU	Central Processing Unit
GP-IB	General Purpose Interface Bus
IL	Insertion Loss
OTDR	Optical Time Domain Reflectometry
RL	Return Loss

5 Conventions

None.

6 Fundamental requirement of water detection in underground splice closures/cabinets

6.1 Overview of monitoring system

With the goal of ensuring the sustainability of optical fibre cable networks, it is very important to keep optical fibres and splices away from water penetrating into closures/cabinets. The lifetimes of optical fibres with residual stress at splice points are significantly affected by environmental conditions such as water and contaminants associated with water immersion. Although underground closures/cabinets are normally designed to be sealed for protection, as specified in [b-ITU-T L.201] and [b-IEC 61753-111-8], water penetration may occur in actual cable networks because it depends on the level of protection afforded to the products, the immersion period, pressure and the quality with which they are assembled in the field.

Water detection is defined as a function of surveillance and testing maintenance activity that is categorized in preventative maintenance [ITU-T L.300].

An overview of the entire monitoring system is shown in Figure 1. The fundamental requirements are as follows:

– it should be conducted in conjunction with the optical time domain reflectometry (OTDR) testing using a maintenance support, monitoring and testing system [ITU-T L.302];

– it should use an inactive optical fibre (not carrying a communication signal) dedicated for maintenance use as a monitor line;

– it should be capable of monitoring multiple sensors in the longitudinal direction of an optical fibre link within the dynamic range of OTDR testing, and;

– it should be capable of locating splice closures/cabinets where water penetration has occurred. The locating resolution should be higher than the minimum installation distance of the water sensors in an optical fibre link.

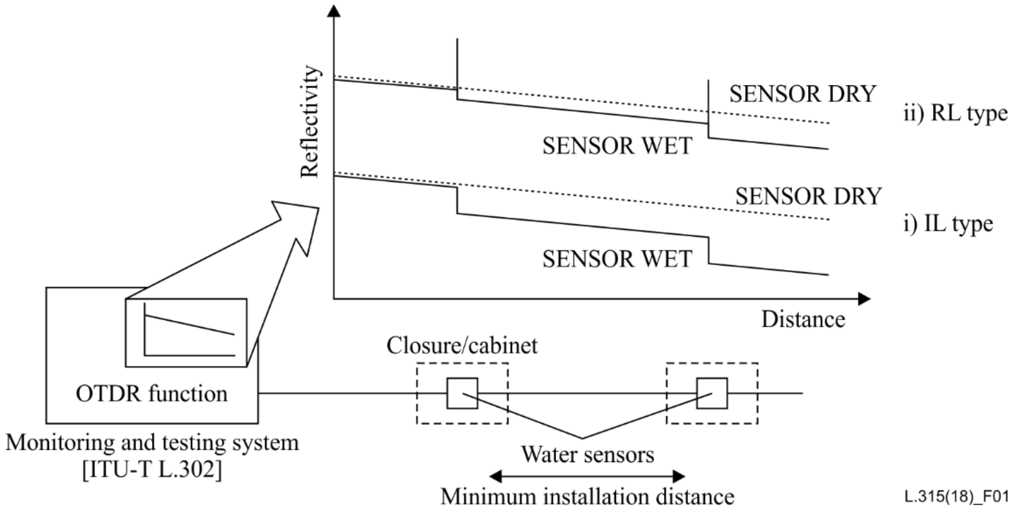

Figure 1 – Overview of monitoring system

6.2 Water sensor

6.2.1 Configuration

6.2.1.1 Sensing principle

– *insertion loss (IL) type*: This type of water sensor changes insertion loss to a monitor line when water surrounds the sensor;

– *return loss (RL) type*: This type of water sensor changes return loss to a monitor line when water surrounds the sensor.

6.2.1.2 Installation method

According to installation methods used for dedicated optical fibres, the water sensor can be classified as follows:

– *external type*: This type of water sensor is externally attached to a dedicated optical fibre, such as a bender mechanism;

– *pigtail type*: The pigtails of this type of water sensor are spliced to a dedicated optical fibre.

6.2.1.3 Size

The water sensor should be small enough to be accommodated in fibre organizing trays in closures/cabinets.

6.2.1.4 Material

The water sensor should not contain conductive materials. The constituent materials should have sufficient durability in underground environmental conditions.

6.2.2 Applicable fibre and cable

The characteristics of the optical fibre in this Recommendation should comply with [ITU-T G.652], [ITU-T G.653], [ITU-T G.654], [ITU-T G.655], [ITU-T G.656] and [ITU-T G.657].

The water sensor can be applied to primary coated fibre [IEC 60793-2-50] and/or optical fibre ribbon [IEC 60794-1-31].

One sensor product does not necessarily cover all fibre/cable types. For example, several different products may be required depending on the fibre type.

6.2.3 Functional requirements

The functional requirements of the water sensor are summarized in Table 1.

The IL/RL change should not reach the threshold value before water gets in contact with the sensor. After sufficient amount of water surrounds the sensor, the IL/RL change should exceed their thresholds within the response time and maintain their states (latching).

The IL/RL threshold should be designed to be clearly distinguishable from normal events on an OTDR trace such as splices and/or connectors.

Table 1 – Functional requirements of water sensor

Type	IL	RL
Operational temperature (Note 1)	0°C to 60°C	
Threshold (Note 2)	≥ 2 dB	≥ 25 dB
Response time (Note 3)	≤ 24 hours	
Hold after detection (Note 4)	Latching	
NOTE 1 – Water with contamination may not freeze exactly at 0°C. Lower operational temperature is possible. NOTE 2 – For wavelengths of 1550 nm ± 20 nm. NOTE 3 – Time taken to reach the threshold value after sufficient amount of water surrounds the sensor. NOTE 4 – Function that maintains the state over thresholds after detection. The hold time should be determined by operator's maintenance policy.		

The mechanical characteristics of the sensor module itself should be comparable to those of passive optical components. The details should be agreed upon between the operator and the supplier.

6.3 Test procedure

6.3.1 Test wavelength

A wavelength of 1550 nm ± 20 nm or longer is used.

6.3.2 Periodic test cycle

The periodic test cycle should be less than the sensor hold time. The cycle is also defined by considering the risk to the mechanical reliability of optical fibre caused by the time of exposure to the water and the mean time to repair after water penetration has been detected in accordance with the maintenance policy of the operators (see Appendix II).

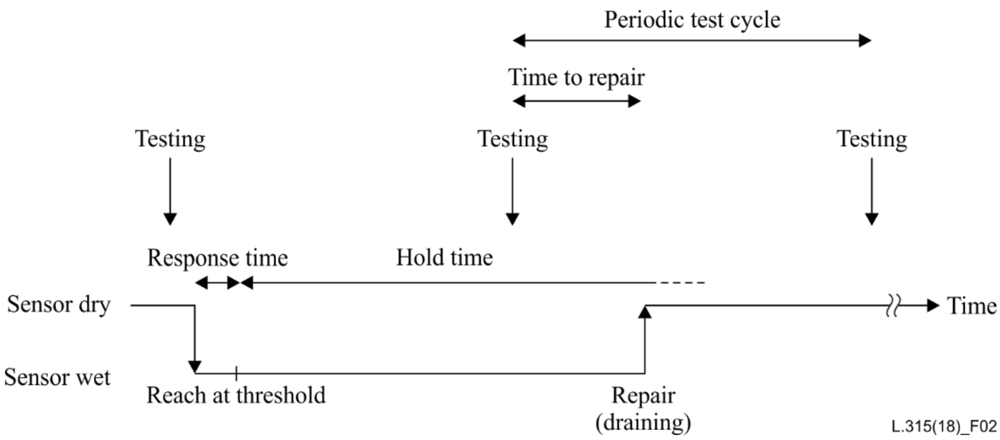

Figure 2 – Timeline for performing periodic test

6.3.3 Action after water detection

If an event exceeding the threshold is detected, the maintenance system should send an alarm, or report the problem to the appropriate division. After restoration, the sensor should be treated in accordance with the manufacturer's instructions.

Appendix I

Information on insertion-loss type water sensor

(This appendix does not form an integral part of this Recommendation.)

This appendix introduces an example of the IL-type water sensor with a bender mechanism for detecting water penetration. This appendix does not contain the RL-type water sensor, which can be found in, for example, [b-Hsu].

I.1 Introduction

The fibre optic bending-type water sensor is externally attached to a fibre in optical fibre closure. It is designed to cause loss increase in fibre attenuation when water penetrates into the closure. The loss increase is measured by OTDR so that water penetration and its location can be detected (Figure I.1). The maintenance ribbon fibres are usually adapted.

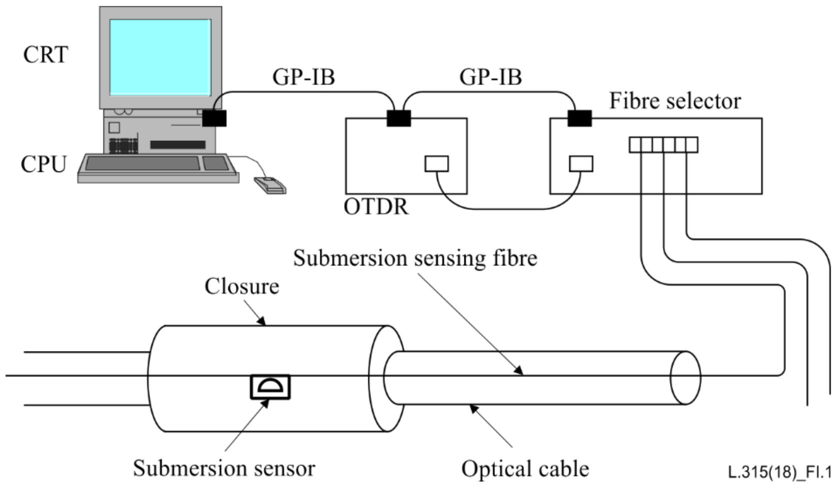

Figure I.1 – Fibre optic water submersion-detecting sensor

I.2 Structure of the sensor

Figure I.2 shows the structure of the fibre optic water submersion-detecting sensor. The sensor is mainly composed of two parts. One is water absorbent portion and the other is fibre guiding portion. There is a bending guide to bend the fibre in guiding portion. The bending radius is designed depending on the parameter of the optical fibre. This sensor is adaptable to ribbon fibres.

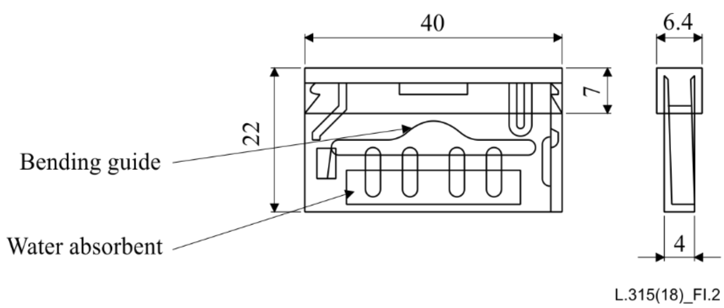

Figure I.2 – Structure of the water submersion-detecting sensor

I.3 Principles of water detection

Water penetration can be detected as follows:

– when water penetrates into the closure and the sensor is soaked, the water absorbent material of the sensor expands. This sensor is insensitive to water vapor;
– the expanding water absorbent material pushes the bending guide to bend the fibre and to cause a loss increase (Figure I.3);
– by measuring the loss increase by OTDR, water penetration and its location can be detected (Figure I.4).

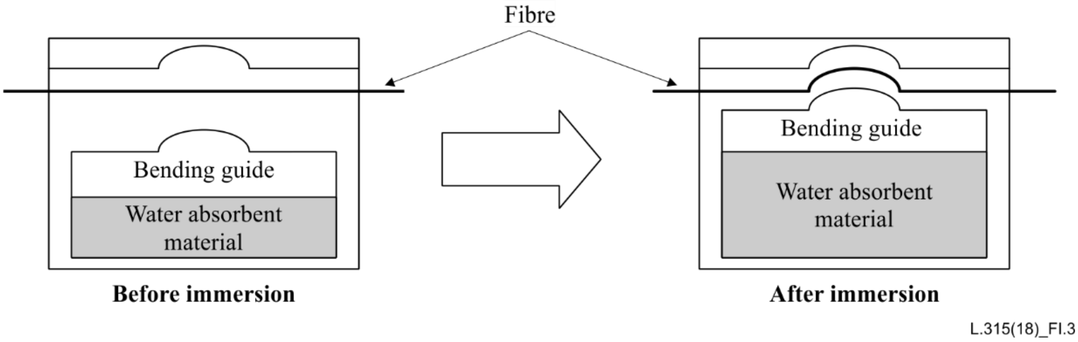

Figure I.3 – Fibre bending after water absorption

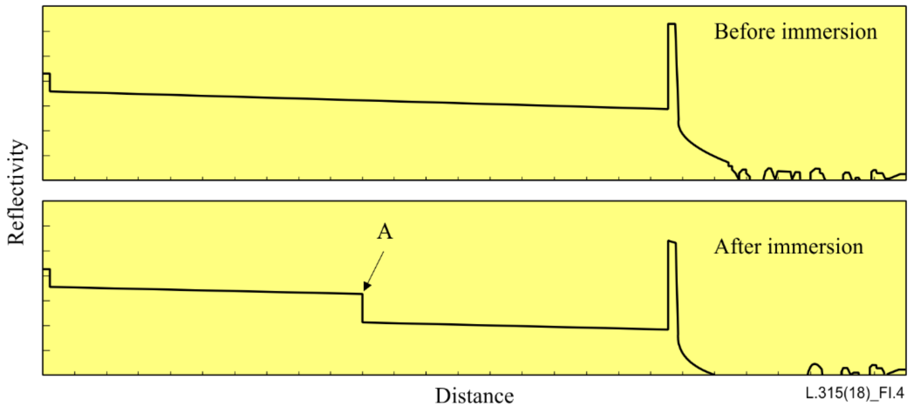

Figure I.4 – OTDR trace before and after water penetration

I.4 Characteristics of the sensor

Characteristics of the sensor are listed in Table I.1.

Table I.1 – Characteristics of the sensor

Item	Description
Applicable optical fibre (Note)	4-fibre ribbon (G.652, G.657)
Operating temperature	0°C to 40°C
Response time	within 24 hours
Hold time	more than 2400 hours
Insertion loss before immersion	0.01 dB
Loss increase at a wavelength of 1550 nm	more than 2.0 dB
Weight	4 g approx.
NOTE – One sensor product does not necessarily cover all fibre types.	

Appendix II

Consideration of periodic test cycle for detecting water penetration

(This appendix does not form an integral part of this Recommendation.)

This appendix introduces an example for consideration regarding periodic test cycling for detecting water penetration based on a design of optical fibre mechanical reliability.

II.1 Introduction

An appropriate periodic test cycle for a water sensor can be determined by considering the risk to the mechanical reliability of the optical fibre caused by the time of exposure to the water and the mean time to repair after water penetration has been detected. When optical fibre housed in an organizer tray in an underground closure/cabinet is exposed to water over a long period of time, the lifetime of the optical fibre with bending stress at its splice points is reduced by mechanical degradation via accelerated stress corrosion. In general, the failure probability of optical fibre in water is more than ten times greater than that in dry air. The increased failure rate can be suppressed by restricting the time of exposure to water by undertaking maintenance work with periodic testing and draining the water from the closure/cabinet.

II.2 Example of periodic test cycle consideration

The failure probability of an optical fibre, F, can be estimated by employing the widely-used conservative model described in [b-ITU-T G-Sup.59], and is given by

$$F = 1 - exp\left\{N_p L\left[1-\left(1+\left(\frac{\sigma_p}{\sigma_a}\right)^n\left(\frac{t_p}{t_a}\right)\right)^{\frac{m_d}{n+1}}\right]\right\}$$

where:

- t_a: is the time under the operation to be calculated, and the parameters (values) used in this example are given when assuming a static fatigue with uniform bending of optical fibre loosely stored in a closure/cabinet
- N_p: number of failures in proof test (0.01 km^{-1})
- L: fibre length under bending (3 m)
- σ_p: proof stress/strain (1%)
- σ_a: applied stress/strain (0.318% for 20 mm radius bending)
- T_p: proof test time (1 s)
- m_d: Weibull parameter (2.5)
- n: stress corrosion parameter

Here, the values are just examples and should be revised in accordance with the applications. When considering the deployment of old fibres, the values for the manufacturing conditions at that time should be used. Regarding the stress corrosion parameter, n, it is difficult to determine an accurate value for actual conditions as described in [b-ITU-T G-Sup.59] since it depends on the details of the environmental conditions (e.g., temperature, humidity, chemical attacks) during the lifetime. In this example, n = 15 and 20 are assumed as conservative values for the water and air conditions, respectively, referring to some experimental results, for example, in [b-Matthewson] and [b-Kapron].

Figure II.1 shows the failure probabilities of a 3-meter bent optical fibre loosely stored in a closure/cabinet. The maintenance work of draining a closure/cabinet can reduce the risk of increased failure probability as shown schematically in Figure II.1, even though the transition to failure probability is difficult to calculate accurately. Table II.1 shows periodic test cycles estimated by considering the allowed failure probability and the mean time to repair after identifying water penetration. For example, considering a failure probability of less than 10^{-6}, which is comparable to the reliability of cable portions, a period of less than 100 days is required for the maintenance.

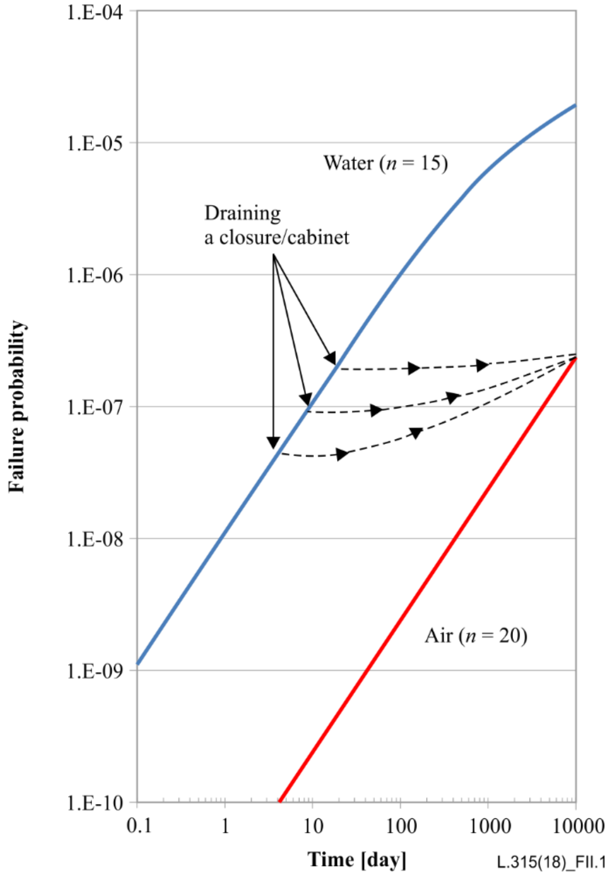

Figure II.1 – Failure probabilities of a 3-meter optical fibre loosely stored with a 20-mm bending radius

Table II.1 – Estimated periodic test cycles for each level of failure probability

Allowed failure probability	Time to allowed probability [day]	Time to repair [day]	Periodic test cycle [day]
5.0×10^{-6}	735	10	≤ 725
1.0×10^{-6}	102	10	≤ 92
5.0×10^{-7}	49	10	≤ 39

II.3 Conclusion

An example consideration of a periodic test cycle for water detection was presented. An appropriate periodic test cycle can reduce the risk of shortening fibre lifetime. Note that there is a need for a comparison with the allowed probability for each operators and actual deployed conditions.

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[b-Matthewson] Matthewson (1994), Kinetics of degradation during fatigue and aging of fused silica optical fiber, *Proc. Soc. Photon-opt. Instrum*. Eng., Vol. 2290, pp. 204-210.

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