CHAPTER 10

MAINTENANCE, SAFETY AND ENVIRONMENTAL ASPECTS

Introduction

Maintenance aspects are very important in a telecommunication network. A suitable maintenance of the optical fibres, cables and systems is a crucial element for offering to the customers a high level of quality and availability of the services. Moreover, maintenance has a direct impact on the amount of the operational expenditures (OPEX). Clause 1 of this Chapter points out the ITU-T specifications related to the maintenance of the optical fibres, cables, facilities and systems.

Also, safety and environmental aspects are becoming more and more important for the telecommunication networks and the optical plants. Clause 2 deals with the optical power safety aspects, with the fire hazards and with some environmental aspects such as life cycle analysis of products and processes, environmentally friendly materials and waste disposal.

1 Maintenance aspects

Communication traffic is increasing rapidly due to the increase in new services.

Also, the number of FTTx subscribers in the world is increasing rapidly and broadband access network provision currently requires thousands of optical fibres to be accommodated in a single central office. Additionally, new telecommunication infrastructures are deployed in the access networks, using a lot of elements such as enclosures, cabinets and passive optical components.

At the same time, the DWDM technology is widening its application in metro and backbone networks with the deployment of a great number of optical network elements (optical amplifiers, OADM, ROADM, optical multiplexers and demultiplexers, photonic cross-connects, etc.) able to transport an ever increasing number of channel count and channel speed.

Concrete solutions for managing all these items are becoming essential, from the point of view of optical facility operations, to reduce maintenance costs and to improve service reliability.

1.1 Maintenance aspects of optical fibres

(For further information see Recommendation ITU-T L.40).

Maintenance and testing are required to provide high reliability and quick response to faults for optical fibres in access / metro / long-haul / submarine networks.

After a cable is installed, functions like fibre monitoring and control have to be done without interfering with the data transmission signals. By monitoring dark fibres (that is, without signal traffic) an indication is given of the performance of the in-service fibres as the degradation and breaks that a cable undergoes affects all fibres in the same way. Nevertheless, greater reliability is achieved by monitoring the fibres with traffic. Also, fibre identification is important to control fibre networks because several fibres may have to be chosen from within a cable, even if the cable has many fibres in service.

In particular, an outdoor optical fibre maintenance support, monitoring and testing system for optical fibre cable networks is necessary. In the following clauses, fundamental requirements, principles, and architecture to develop a suitable support system are described. A specific application to the access network can be found in Recommendation ITU-T L.53 both for point-to-point and for ring topologies.

1.1.1 Fundamental requirements for a maintenance support system

The maintenance support, monitoring and testing system should have the functions shown in Table 10-1. In this Table the term "surveillance" means the monitoring of the condition of network elements (NE). Surveillance has two functions: to inform of NE degradation before trouble occurs and to inform of NE abnormality when trouble occurs.

The term "control" means the restoration of the NE to normal functioning or to take action to maintain service quality.

Table 10-1 – Functions and status

Category	Activity	Functions	Status
Preventative maintenance	Surveillance. (e.g. Periodic testing, continuous testing)	• Detection of fibre loss increase. • Detection of signal power loss increase. • Detection of water penetration	Optional Optional Optional
	Testing. (e.g. Fibre degradation testing)	• Measurement of fibre fault location. • Measurement of fibre strain distribution. • Measurement of water location	Optional Optional Optional
	Control. (e.g. Network element control)	• Fibre identification. • Fibre transfer	Optional Optional
After installation before service or post-fault maintenance	Surveillance. (e.g. Reception of transmission system alarm or customer trouble report)	• Interface with path operation system. • Interface with customer service operation system	Optional Optional
	Testing. (e.g. After installation testing, Fibre fault testing)	• Confirmation of fibre condition. • Fault distinction between transmission equipment and fibre network. • Measurement of fibre fault location	Required Required Required
	Control. (e.g. Cable install/repair/ replacement)	• Fibre identification. • Fibre transfer. • Interface with outside plant database. • Interface with mapping system	Required Optional Required Optional

The support system can be controlled by humans or by other systems. The system shall be able to be remotely controlled. So, operation terminals with HMI (human-machine interface) should be included in the system. The system shall be able to gather data about outdoor fibres from the outside plant database and it should have an interface with the path operation and customer service system.

1.1.2 Testing and maintaining principle

(For further information see Recommendation ITU-T L.25).

There are several ways commonly used to implement the functions listed in Table 10-1:

i) OTDR testing;

ii) loss testing with the measurement of the level of a specific wavelength injected into the fibre outside the wavelengths of the data signal;

iii) monitoring a proportion of the data signal power (power monitoring);

iv) identification light detection.

Table 10-2 shows where these methods are used.

Table 10-2 – Suitable test methods

Category	Activity	Functions	Methods
Preventative maintenance	Surveillance	• Detection of fibre loss increase. • Detection of signal power loss increase. • Detection of water penetration	OTDR/loss testing. Power monitoring. OTDR/loss testing
	Testing	• Measurement of fibre fault location. • Measurement of fibre strain distribution. • Measurement of water location	OTDR testing. B-OTDR testing. OTDR testing
	Control	• Fibre identification. • Fibre transfer	ID light detecting[a)] Switching[b)]
After installation before service, or post-fault maintenance	Surveillance	• Interface with path operation system. • Interface with customer service operation system	On-line/external medium. On-line/external medium
	Testing	• Confirmation of fibre condition. • Fault distinction between transmission equipment and fibre network. • Measurement of fibre fault location	OTDR/loss testing. OTDR/loss testing. OTDR testing
	Control	• Fibre identification. • Fibre transfer. • Interface with outside plant database. • Interface with mapping system	ID light detecting. Switching[b)]. On-line/external medium. On-line/external medium

[a)] ID light means identification light such as 270 Hz, 1 kHz, 2 kHz modulated light.

[b)] Switching includes mechanical and manual switching.

The OTDR-based monitoring systems are capable of periodic measurements of the fibres' attenuation coefficient and, when integrated with transmission equipment alarms, they are capable of immediate reporting fault location data in case of cable damage.

Loss testing and power monitoring, through the continuous monitoring of a power level received at the end of the optical fibre (just before the receiving equipment), are able to collect and store power-level data and provide an immediate detection of fibre faults through the activation of an OTDR function when the monitored power decreases below a certain level.

All these systems are designed to minimize the service outages as well as the economic loss through the immediate location of failures and alarm generation and, at different degrees, are intended to predict failures due to the degradation of fibre performance.

1.1.3 Wavelengths for maintenance

(For further information see Recommendation ITU-T L.41).

For the power monitoring system it is important to choose the correct wavelength to be monitored. Specifically, maintenance functions have to be performed without interfering with data transmission signals. Table 10-3 shows appropriate wavelengths for given functions.

The wavelength allocation of PON and WDM applications are defined in Recommendations ITU-T G.983.3 and ITU-T G.694.2, and in Supplement 39 to the ITU-T G-series of Recommendations, as shown in Figure 10-1. Moreover, Recommendation ITU-T G.694.1 specifies a frequency grid for DWDM systems with a minimum channel spacing of 12.5 GHz (for further details see Chapter 6).

Table 10-3 – Wavelength selection

Category	Activity	Functions	Wavelength
Preventative maintenance	Surveillance	• Detection of fibre loss increase. • Detection of signal power loss increase. • Detection of water penetration	Maintenance wavelength[a)] Signal wavelength. Any wavelength on fibres not carrying signals
	Testing	• Measurement of fibre fault location. • Measurement of fibre strain distribution. • Measurement of water location	Any wavelength on fibres not carrying signals. Any wavelength on fibres not carrying signals. Any wavelength on fibres not carrying signals
	Control	• Fibre identification. • Fibre transfer	Maintenance wavelength[a)] None
After installation before service, or post-fault maintenance	Surveillance	• Interface with path operation system. • Interface with customer service operation system	None. None
	Testing	• Confirmation of fibre condition. • Fault distinction between transmission equipment and fibre network. • Measurement of fibre fault location	Any wavelength. Any wavelength. Any wavelength
	Control	• Fibre identification. • Fibre transfer. • Interface with outside plant database. • Interface with mapping system	Any wavelength. None. None. None

[a)] Refer to the Recommendation of maintenance wavelength on fibres carrying signals, Recommendation ITU-T L.41.

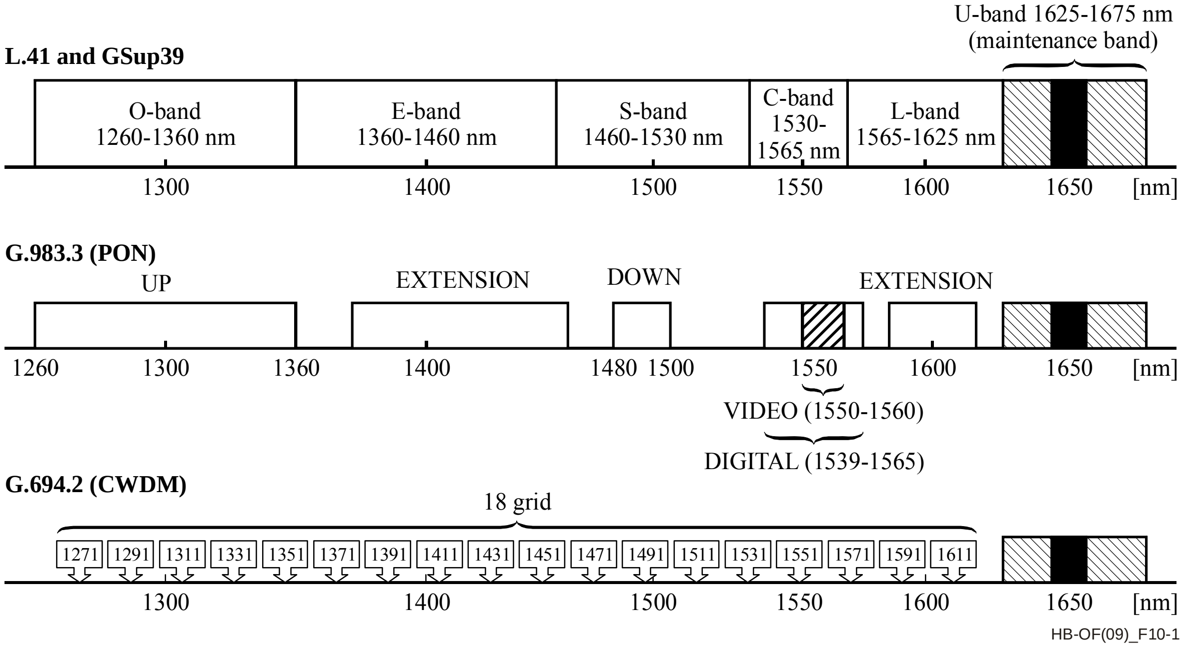


Figure 10-1 – Maintenance wavelength allocation

Figure 10-1 shows that communication wavelength bands extend to the long wavelength band (L-band: 1 565-1 625 nm). To eliminate interference with the test light, the maintenance test light wavelength must not be a wavelength used for communication signals.

The maintenance wavelength assignment for in-service testing, shown in Table 10-4, is defined in Recommendation ITU-T L.41. There are several recommended maintenance wavelength bands, depending on the communication light wavelength used by a given transmission system. When the communication wavelength band extends to the L-band, the 1650 nm wavelength in the ultra long wavelength band (U-band: 1 625-1 675 nm) is used for maintenance testing, as shown in Figure 10-1.

Table 10-4 – Maintenance wavelength assignment

	1 310 nm-window	**1 550 nm-window**	**1 625 nm-window**[a]	**1 650 nm-window**[a]
Case 1	Active	Vacant or maintenance	Vacant or maintenance	Vacant or maintenance
Case 2	Vacant or maintenance	Active	Vacant or maintenance	Vacant or maintenance
Case 3	Active	Active	Vacant or maintenance	Vacant or maintenance
Case 4	Active or vacant	Active	Active	Vacant or Maintenance

[a] More details are shown in Recommendation ITU-T L.41.

1.1.4 In-service fibre line testing

(For further information see Recommendation ITU-T L.66).

With a view to realizing a highly reliable optical network that transports WDM signals with a wide spectral bandwidth, in-service fibre line monitoring techniques are important in terms of providing effective and efficient maintenance of optical cable networks. The fundamental requirements of in-service fibre line testing are as follows:

i) it should be carried out without degrading optical communication signals;

ii) it must be capable of evaluating optical fibre characteristics even if there is interference with the communication light.

Figure 10-2 shows a test set-up for an in-service line in an optical access network.

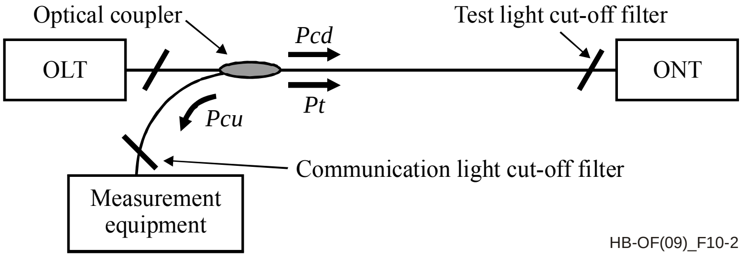


Figure 10-2 – Test set-up for in-service line

The wavelength bandwidth and the output power of the test light source should be designed taking into consideration the cut-off bandwidth and cut-off value of the optical filter, respectively. Moreover, in order to accurately measure the characteristics of the optical fibre line carrying communication signals, the measurement equipment (such as an OTDR and an optical power meter (OPM)) should have a tolerance to the communication light power.

1.1.5 General support system architecture

(For further information see Recommendation ITU-T L.40).

Support systems for fibre monitoring must have at least an operation terminal and an optical testing module (OTM). The minimum system consists of only these two items. This type of system is convenient for initial installation. A server can improve performance by keeping outside plant, test results, and interfaces with other systems. The server can also control OTMs.

There are several choices for the data communication network (DCN), which connects the server and the OTM(s), including POTS, ISDN and X.25. Traffic analysis is important for an economical high-performance system.

Two typical configurations of a support system are shown in Figure 10-3.

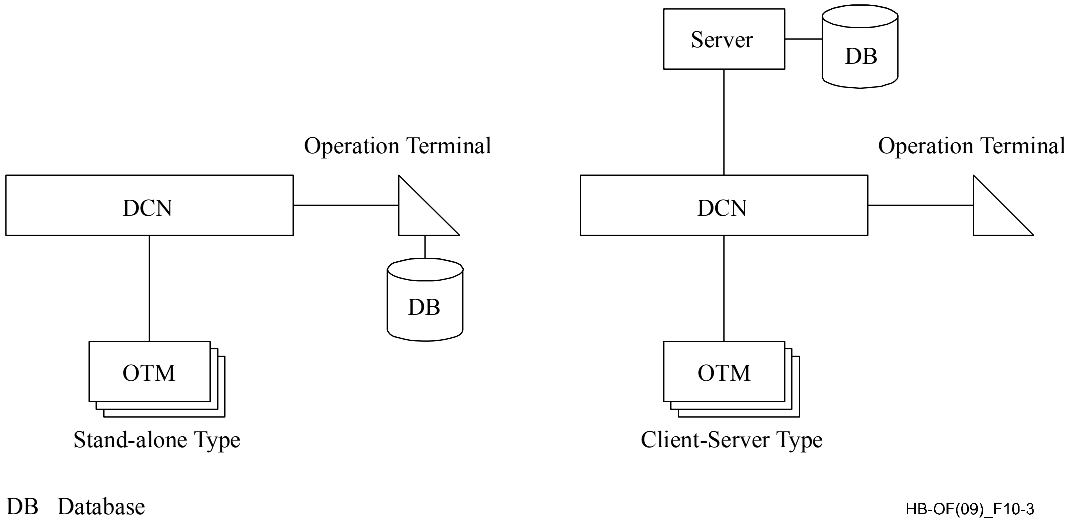


Figure 10-3 – Typical support system configurations

There are several kinds of interfaces between an operating system (OS), which runs on an operation terminal or server, and the OTM. A proprietary interface is convenient for closed systems, and standard interfaces are useful for open systems, but a hybrid type is also possible.

1.1.6 Main features of the support system

The main features of the optical cable supervisory system allowing the attainment of the mentioned maintenance objectives are listed below:

i) *non-intrusiveness* on the service traffic, due to the design of a completely passive optical probe: non-intrusiveness is a key characteristic of the monitoring system, especially where cable owners are not permitted to adopt an OTDR-based monitoring process on in-service fibres (e.g. leased fibres);

ii) *sensitivity* to even very rapid degradation effects, which can have a negative influence on optical fibre performance in the long period (e.g. mechanical vibrations due to road and railway traffic);

iii) *real-time alarm reporting*: optical power and attenuation threshold-crossing events are immediately detected and reported to the system presentation interface, in order to fully exploit preventive maintenance capabilities;

iv) *automated OTDR measurement activation* when a threshold-crossing event referring to a variation of attenuation is reported, in order to have a minimum location time when a sudden fault or anomaly is faced;

v) *permanent storage of monitoring results* and fibre reference traces, in order to enable a powerful analysis of the optical fibre attenuation trend.

1.1.7 Optical fibre cable maintenance system for optical fibre cable carrying high total optical power

(For further information see Recommendation ITU-T L.68).

There are several fibre-optic components in optical fibre cable maintenance systems for optical fibre cables that carry a high total optical power. When the components have a larger optical loss than usual, this may pose a fire-hazard, in the worst case.

Table 10-5 shows the functions in optical fibre cable maintenance systems for optical fibre cables carrying high optical power. The list below includes the system requirements for high power light input and the methods employed to achieve them.

Table 10-5 – Functions in optical fibre cable maintenance systems

Functions	System requirements for high power light input	Methods
Connection	No fibre fuse or intense temperature increase	Use of fusion splices. No need for optical connectors or polishing and cleaning of connector endfaces
Termination	No tight bending of optical fibre	Minimum bending radius R ≥ 30 mm for testing optical fibre cords in optical distribution frames; but fibres with improved bending capability will allow more severe conditions
Testing access for optical fibre line	No fibre fuse or intense temperature increase	Use of fusion splices. Optical branching component with high tolerance to high power light exposure
Optical switch with butt-joint splice connection mechanism (e.g. fibre selector)	No intense temperature increase or optical loss increase	Attenuation of high power light or gap between fibres at butt-joint splice $d < 10$ µm

1.2 Optical fibre and cable restoration

The very large transmission capacity contained within a single sheath of an optical fibre cable necessitates the development and implementation of a plan for rapid restoration of cable failures. The plan should detail the action from receipt of an alarm to completion of restoration. Its primary objective should be to re-establish service as quickly as possible employing the following general strategy:

i) re-route as much traffic as possible;

ii) locate the cable damage;

iii) temporarily re-connect the damaged cable, if required;

iv) restore service.

After the transmission of an alarm, the fault must be located before restoration can begin. Fault locating instruments are used to locate cable faults. Sheath faults in optical fibre cables containing metallic pairs can be located with standard earth leakage test sets, pulse echo tests, and DC bridge sets. The presence of optical power in a fibre may be checked by the appropriate test sets (see § 1.1). Fibre breaks may be located with an optical time domain reflectometer (OTDR) using a backscattering measurement.

1.2.1 Restoration methods

The choice of an appropriate emergency restoration method for a damaged optical fibre cable, as well as its permanent repair, depends on the extent of the damage and particularly on the distribution of fibre breaks. Thus, a basic understanding of the mechanics of cable behaviour, with regard to the mechanical tension applied to the cable, in damage situations is important in developing and applying these methods.

Cable damage mechanisms fall into two broad categories: low-tension and high-tension. Damage mechanisms with low (or zero) tension include fires, most lightning strikes, and most types of vandalism. If the damage can be visually confirmed to be low-tension, it is likely that fibre damage will be confined to a small area. In these cases a local repair at the damage site is quite likely to restore all service.

If, however, the damage results from a high-tension mechanism, e.g. a backhoe dig up or a fallen utility pole, the choice of restoration method must now consider more than the visually obvious damage. Cables damaged in high-tension dig ups should be replaced with a spare cable (joint-to-joint) as the preferred emergency restoration method.

In principle, permanent repair has priority. This is primarily to avoid duplication of work and service interruption in the permanent repair after emergency restoration. Nonetheless, emergency restoration is required in some cases, such as when conduits are broken by a backhoe.

1.2.2 Restoration procedures

The restoration procedures presented below are based on the premise that optical fibre cable systems carry large traffic cross sections and warrant a substantial investment of manpower and other resources to ensure that service interruptions are minimal.

Planning and readiness are critical to the speed and success of restoration. Initial system design should be based in part on restoration considerations. Alarm and voice communication systems must be efficient and well maintained. Emergency materials and equipment should be centrally located, and systematically inventoried and maintained. Documentation on circuit assignments and their relative priorities must be up-to-date and readily available, along with a corresponding circuit rearrangement plan.

Also, designated restoration coordinators and teams should be well trained and available 24 hours a day.

When damage to an optical fibre cable has been reported, located and evaluated, a method will have to be chosen for its *provisional repair*. The method for provisional repair preferred in most situations, because it is fast and reliable, is joint-to-joint cable replacement. With this method, teams disconnect the joints at each end of the damaged cable and provide in its place, either in a spare duct or aboveground, an emergency cable. For most protected routes it is sufficient to stock one long and one short cable of appropriate (maximal) fibre count and fibre grade. This method avoids excavation and precise fault location, works in spite of distributed fibre breakage, and permits substantial advance planning to eliminate roadblocks.

An example of provisional repair for a duct cable is shown in Figure 10-4.

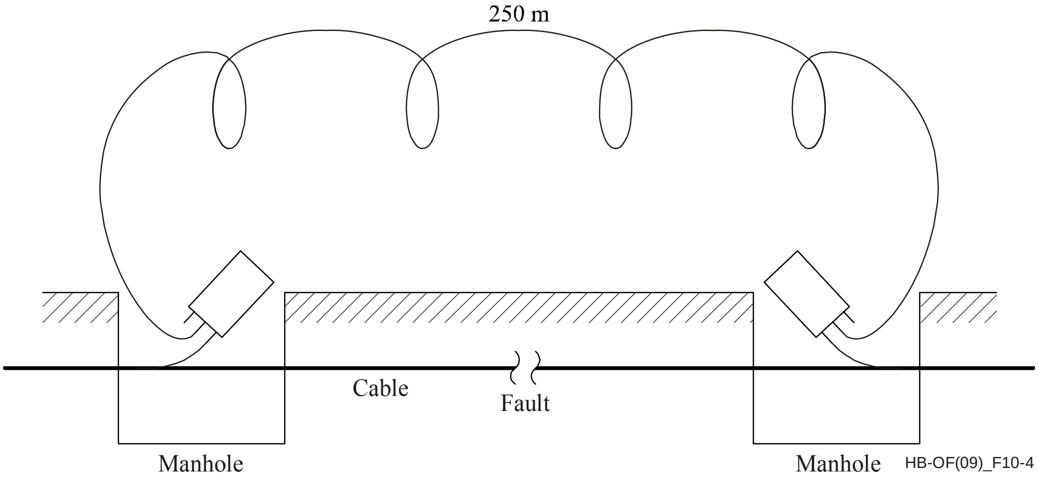


Figure 10-4 – Provisional repair of a duct cable

After service has been provisionally restored through one of the above methods, a number of important decisions will remain relating to the *permanent repair* of the damaged cable section. If there is assurance that fibre damage was localized, the original cable may be put back into service, provided it has been suitably and permanently repaired and tested. On the other hand, if the original cable suffered scattered fibre breakage or structural damage, it will probably be more economical and service-effective to replace it, joint-to-joint, with a new permanent cable. Temporary materials, if used, would normally be carefully removed from service, tested, and restocked for future emergency use.

Regardless of the implemented permanent repair, appropriate service rearrangements must be done to correct any temporary circuit assignments, and end-to-end conformance tests performed to ensure that system standards are met.

1.3 Maintenance of underground plastic ducts

(For further information see Recommendation ITU-T L.73).

Placing cables in conduits is preferred because it has a principle advantage that the cable placement operation is separated in time from the actual conduit construction phase. Moreover, the protection of the cable with the passage of time and the possibility of repeated access, cable removal and delayed cable installation make the method of placing cables in ducts more attractive. The method, however, has a disadvantage in that the initial cost of conduit construction is expensive. It is noted that underground ducts are prone to being deformed by the burden of earth pressure, which makes it necessary to check the ducts before cable installation, and to repair defective ducts before placing cables in conduits.

After a conduit is installed in a trench and has been backfilled, but before any surface construction begins, it is common practice to check duct quality because certain plastic conduits can become oval-shaped, pierced or broken. A classification of these possible defects is shown in Table 10-6. The description of inspection methods, such as the use of test mandrels and closed-circuit television (CCTV) systems, to check duct quality can be found in Recommendation ITU-T L.73, which also describes various methods that are used to repair underground conduits.

Table 10-6 – Classification of defects

Defects	Causes
Crack or fracture	Excessive pressure. Insufficient duct strength
Duct failure	Ground settlement. Excessive loads
Pointed deformation	Sharp shaped crushed stone
Oval shaped deformation	Excessive pressure. Insufficient duct strength. Dynamic compacting loads during construction
Soil intrusion	Disconnection of ducts
Offset	Faulty construction. Ground settlement

A classification of repair methods is given in Table 10-7.

Table 10-7 – Duct repair methods

Test		Inspection by CCTV (Note 2)	Repair methods
Duct rod (Note 1)	Mandrel		
Can pass the whole length without any difficulties	Can pass the whole length without any difficulties	The whole length of duct is clean and does not have any defects	No need to repair
		Debris or sludge that may block test mandrel is observed inside a duct	High pressure water jetting
	Cannot pass the whole length without any difficulties	If defective parts such as cracks, duct failure, oval-shaped deformation, and offset are observed, it is considered that the defective parts are not severe and are limited to a small extent	Conventional methods (dig and replace). Methods for removing irregularities or enlarging a duct: – re-rounder method; – robotic repair system
Cannot pass the whole length without difficulty		If the CCTV camera cannot pass because of blockage or obstruction, it is considered that the defects are severe and affect a large section of the duct	Conventional method (dig and replace method). Pipe bursting and/or splitting method

NOTE 1 – A duct rod is a tool that is used to manually insert pulling lines through the duct.

NOTE 2 – Inspection by CCTV is applied only when the mandrel cannot pass due to defects in the duct.

The conventional repair methods are "open-cut" or "dig-and-replace". These methods involve direct replacement of the defective section with a new duct in the open-cut trenches. Although conventional methods are simple and reliable, they involve social and traffic costs.

When these costs are not negligible, it is recommended to use trenchless techniques. Several different trenchless techniques are used. As an example: high pressure water jetting, insertion of an expansion device, remote controlled device (e.g. a robot) with CCTV monitoring. More details are given in Chapter 3.

1.4 Maintenance of cable tunnels

(For further information see Recommendation ITU-T L.74).

Cable tunnels (see Chapter 3) can also present dome issues related to cracks or water leakage caused by deterioration of steel-reinforced concrete or reinforcing steel. The typical deteriorations that may occur in cable tunnels are cracks, water leakage and the corrosion of reinforcing steel. If such deteriorations are left unrepaired, additional large-scale repair and reinforcement projects will probably be required, which will further increase cost in the future. The purpose of preventive maintenance in this case is to detect the defects in cable tunnels at an early stage and to take appropriate actions in order to enhance its durability and serviceability.

1.4.1 Inspection

Notwithstanding how well a cable tunnel is constructed, it will require preventive maintenance to preserve its integrity and to prolong its life. Maintenance will necessarily require inspection and testing to determine the condition of the structures and to establish appropriate repair and maintenance measures. The inspection of cable tunnels is performed to detect damage or defects that are detrimental to the structural safety and durability. When crucial damage or defects are observed, they are evaluated by skilled experienced engineers, and then appropriate and prompt countermeasures, such as repair and reinforcement work, are taken. Inspections can be divided into regular and detailed inspections, as follows:

Regular inspections, also called routine inspections, are usually performed visually to check the degradation status of the concrete surface such as cracks, water leaks, or exposed reinforced steel. At this stage, deformation is detected, and is evaluated to judge whether or not detailed inspections and/or temporary countermeasures are needed.

It is recommended that procedures be established for the manager of the cable tunnel to schedule/undertake regular inspections. These inspections are mainly done by observing the surface of the cable tunnel using visual inspection, and measuring crack width with a crack gauge. The inspection is carried out using comprehensive identification sheets on which observations and measurements can be conveniently recorded.

Detailed inspections are carried out when the defects and deformations are critical to the safety of the cable tunnel. These inspections are also carried out when there is degradation that cannot be identified by visual inspection or when the cause of degradation must be clarified to judge whether countermeasures are needed and to select the optimum method. At this stage, a detailed investigation of the measurements and deformation detected in the regular inspection are conducted by a specialist.

These inspections use destructive testing of a concrete sample and chemical analysis of a core sample to determine the degree of degradation. In addition, non-destructive testing methods can be used to determine abnormalities, defects and voids.

1.4.2 Inspection technologies

Items used for inspection differ depending upon the type of cable tunnel. Cable tunnels are generally divided into two categories as follows:

i) rectangular cross-section (box type);

ii) circular cross-section.

A rectangular cross-section cable tunnel is constructed by a cut and cover method, and is made of reinforced steel concrete. On the other hand, a circular cross-section cable tunnel is constructed by methods such as shield driving, boring, drilling and blasting, and jacked tunnelling. The cross-sections of these two types of cable tunnels are shown in Figure 10-5.

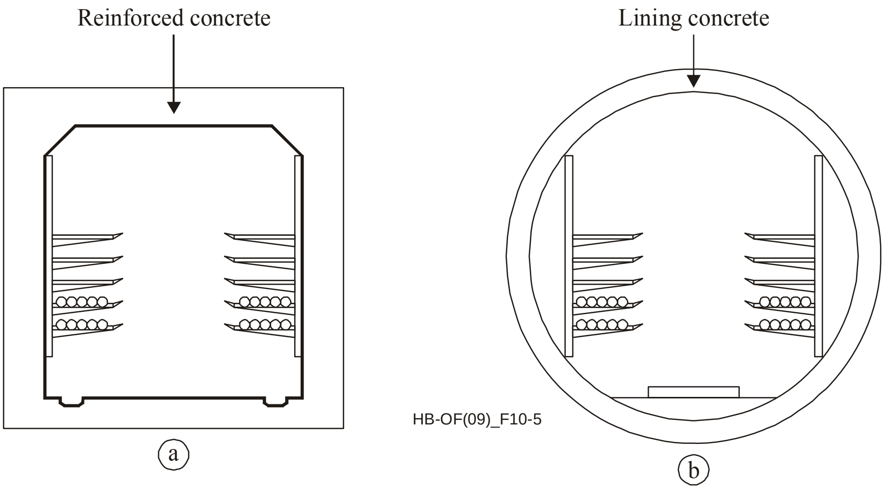


Figure 10-5 – Typical types of cable tunnel: rectangular or box type and circular type

Since the design and construction procedures of these cable tunnels are different, deteriorations occur differently. Typical inspection items are summarized in Table 10-8.

Table 10-8 – Typical inspection items

	Regular inspection	**Detailed inspection**
Rectangular cross-section cable tunnel	Cracks; water leakage; exposed steel	Include regular inspection items; compressive strength of concrete; corrosion of reinforcing steel; carbonation depth, etc.
Circular cross-section cable tunnel	Cracks in lining surface; water leakage; contamination of lining concrete; spall of lining concrete	Include regular inspection items; deformation of lining; heaving of tunnel bottom; settlement of tunnel bottom; cavities inside lining concrete; voids behind lining

Figure 10-6 shows some typical deteriorations of a tunnel.

Inspection methods mainly consist of visual inspection and non-destructive testing methods. When a defect is found during visual inspection, its cause is then established and its size and condition are investigated in detail. Since the crack is one of the most important inspection items, it is recommended to measure the crack width and depth using a crack gauge, and to check whether or not the crack propagates. Table 10-9 summarizes typical inspection technologies, including non-destructive testing methods.

Figure 10-6 – Typical deteriorations: a) cracks; b) water leakage; and c) the corrosion of reinforcing steel

1.5 Optical monitoring of optical DWDM systems

(For further information see Recommendation ITU-T G.697).

DWDM technology is improving at a rapid pace, continuously stretching the channel count, channel speeds and reach limits. Long haul multi-span DWDM systems are capable of taking optical signals thousands of kilometres without using electrical terminations or regeneration. This continuing trend is driving the increasing importance of optical monitoring.

As a matter of fact, fully regenerated optical networks traditionally had optical-to-electrical conversions in all network elements, including the 3R regenerators. Transmission performance is measured at the electrical layer using performance parameters such as errored seconds (ES) and severely errored seconds (SES) (see Recommendation ITU-T G.826), since SDH and OTN have built an overhead in its frame structure to measure error performance. So, it is relatively easy to measure network performance in all network elements within fully regenerated SDH and OTN networks.

While these methods give a reliable measure of the end-to-end performance of an optical channel, they cannot be applied inside a transparent optical domain where no 3R regenerators are available to terminate the frame overhead. Therefore, they may not provide sufficient information to isolate root cause of problems in complex DWDM networks.

This necessitates performance monitoring in the optical domain to assess the health of the optical channel (OCh), as optical monitoring provides the function of monitoring the optical signal directly without processing the electrical frame.

Table 10-9 – Typical inspection technologies

Typical inspection items	Technologies	Descriptions
Cracks, water leakage, and exposed steel	Visual inspection	Crack width can be measured by a crack gauge with magnifier
Carbonation depth	Phenolphthalein indicator	Core cut from hardened concrete is sprayed with phenolphthalein indicator, and then a purple-red coloration will be obtained where alkaline concrete has been unaffected by carbonation, but no coloration will appear in carbonationed zones
Voids, water leakage	Infrared thermo-graphy (Note)	This method measures the thermal radiation emitted by the tunnel's walls, and can identify defects in the lining, and voids. Infrared techniques allow visual presentation of the temperature distribution on the surface
Compressive strength of concrete	Testing of cores	This is a well-established method. Cores are cut from hardened concrete by a core drill, and compressive testing is performed
	Surface hardness method (Note)	This test is based on the principle that the rebound of an elastic mass depends on the hardness of the surface. The results give a measure of the relative hardness of this zone, as there is a close correlation between the number of rebounds and the compressive strength of the concrete
	Ultrasonic pulse velocity method (Note)	This method injects ultrasonic waves into the concrete to analyse it internally by detecting the wave transmitted and reflected by substances with different elastic properties in the concrete wall. This method can identify structural abnormalities such as cracks, thickness variations and degradation of the compressive strength
Defects inside lining concrete	Stress wave propagation method (Note)	This method is based on the use of impact-generated stress waves that propagate through concrete and are reflected by internal flaws and external surfaces. This method can be used to determine the location and extent of flaws such as cracks and voids
Voids inside lining concrete	Ground penetrating radar (GPR) (Note)	This is a geophysical method that uses radar pulses to image the subsurface. This method uses electromagnetic radiation and detects the signals reflected from subsurface structures. GPR uses transmitting and receiving antennae. The transmitting antenna radiates short pulses of high-frequency (usually polarized) radio waves into the ground. When the wave hits a buried object or a boundary with different dielectric constants, the receiving antenna records variations in the reflected return signal. The depth range of GPR is limited by the electrical conductivity of the ground and the transmitting frequency. Higher frequencies do not penetrate as far as lower frequencies, but give a better resolution. In cable tunnels, the wave frequencies are between 900 and 2 000 MHz. This method can identify structural abnormalities such as voids, thickness variations and interface voids between the lining and the ground in a cable tunnel
NOTE – Non-destructive testing technologies.		

Optical Monitoring can help in DWDM systems to perform the following activities:

i) configuration management for system and channel activation, addition of new channels, etc.;

ii) fault management to detect and to isolate faults;

iii) degradation management in order to keep the system running and to detect degradations before a fault occurs.

In other words an appropriate level of optical monitoring gives some visibility inside optical networks ensuring that channel paths are properly configured and optical parameters are appropriate for reliable service delivery. The collection of optical monitoring data in a network operations centre (NOC) makes the management of complex DWDM networks easier.

1.5.1 Signal monitoring

Optical monitoring does not measure every impairment, but, rather, the effect of these impairments on the parameters that can be measured.

The monitoring equipment can be classified in two categories: embedded and external monitoring equipment.

Embedded monitoring equipment is usually tightly integrated with the management functions of an optical network element. For cost reasons, embedded monitoring is usually limited to a few basic parameters.

External monitoring equipment typically serves a different purpose than embedded monitoring equipment. It is normally used for measuring additional, more sophisticated performance parameters, or when a more accurate value of certain performance parameters is required.

The main applications of external monitoring equipment are the location of hard-to-find failures that cannot be isolated by the embedded monitoring devices, as well as function tests and accurate parameter measurements during installation, commissioning or repair.

1.5.2 Optical monitoring parameters

The list of the optical parameters that can be measured using current technology in optical transmission systems is given below:

i) Channel power;
ii) total power;
iii) optical signal-to-noise ratio (OSNR) when no significant noise shaping is present;
iv) channel wavelength;
v) Q-factor.

The list of correlation between the impairments and the monitoring parameters is given in Table 10-10.

Table 10-10 – List of correlation between the underlined impairments and monitoring parameters

Parameters	Total power	Channel power	Channel wavelength	OSNR	Q-factor
Variation of attenuation	X	X		X	X
Frequency (or wavelength) deviation from nominal		X	X	X	X
Optical channel power changes due to gain variations		X		X	X

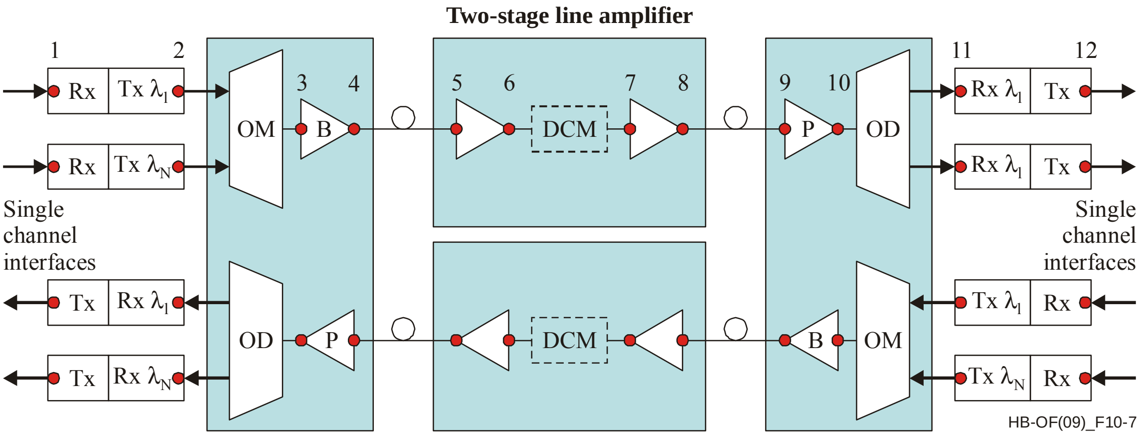
1.5.3 Applications

While optical monitoring is implemented (and in service) in many current optical transmission systems, there are significant differences between the optical monitoring deployments between them. This is due to the presence of different transmission and control systems design, the size of the network and the different strategies for impairment management in the various systems. For this reason, a general requirement as to which parameter value with which particular accuracy is a reliable indicator of the operational condition of such a system cannot be generalized.

The choice of which option to deploy depends upon the specific characteristics of the ONE. In particular for a DWDM system, it depends on characteristics like length, number of spans, number of channels and inaccessibility of the sites, as well as cost/benefit considerations. In particular, it has to be considered that as the number of the monitoring points grows, there is an increasing consumption of signal power with the consequent reduction of the DWDM system reach.

In conclusion, several monitoring choices could be considered for internal monitoring in DWDM systems, with the resulting data available both locally and at a remote location.

An example of positioning of embedded monitoring equipment (EME) in a long distance DWDM line segment with optical channels operating at 10 Gbit/s is shown in Figure 10-7.



B	Booster amplifier	P	Preamplifier
Tx	Transmitter	Rx	Receiver
DCM	Dispersion compensating module	●	Possible EME position

Figure 10-7 – Example of EME positioning inside a long distance DWDM line segment

The optical parameters that can be measured at the various monitoring points of Figure 10-5 are shown in Table 10-11.

Table 10-11 – Possible monitoring in a DWDM line segment

Monitoring parameters	EME position
Total power at the input of various stages of optical amplification	3, 5, 7, 9
Total power at the output of various stages of optical amplification	4, 6, 8, 10
Channel input power	1, 11
Channel output power	2, 12
Channel power at the output of various stages of optical amplification	4, 6, 8, 10
Channel OSNR at the output of various stages of optical amplification	4, 6, 8, 10
Channel wavelength	2
NOTE – This table lists possible monitoring positions. The appropriate choice of monitoring depends on the particular system.	

1.6 Maintenance aspects of submarine optical systems

(For further information see Recommendation ITU-T G.977 and the ITU-T Handbook on Marinized Terrestrial Cables).

Maintenance of submarine optical systems is mainly carried out by a routine control and by fault location.

1.6.1 Routine maintenance

Routine maintenance is performed from the terminal stations using the supervisory system. It consists of periodic monitoring of the system parameters and, when required, in preventive redundancy switching.

A supervisory and maintenance controller located in the terminal, in association with the repeater (or BU) supervisory unit, normally provides for fault localization, repeater performance monitoring and remote controlled redundancy switching.

The supervisory facilities commonly include one or more of the following:

- i) provision, on an in-service basis, of sufficient information to enable preventive maintenance, particularly if switchable redundancy is provided;
- ii) provision for further out-of-service fault location or system monitoring through loopback, remotely controlled from appropriate terminals;
- iii) indication of approaching failure of the in-service equipment, so that preventive action may be undertaken or planned;
- iv) the means to locate hard faults and intermittent faults (of duration and frequency), that cause the system to fail.

1.6.2 Fault localization

In *repeaterless* systems it may be sufficient to perform optical tests with an OTDR to locate, within instrumentation accuracy, the fault. If the cable contains metallic parts of known resistance per kilometre, it may be possible to evaluate if the damage is limited to the fibres or to the whole cable by means of resistance DC measurements.

The position of the fault can normally be determined from OTDR measurements, taking into account any fibre overlength.

Another alternative method that can be used is the electroding method, if both the cable and repair vessel offer such possibility. A low frequency signal (4-50 Hz) is injected into the cable. A repair vessel may be able to detect, by means of sensors, the signal along the cable route. When the signal disappears, the vessel is above the fault. This method is suitable up to a distance of typically over 100 km from the station.

For *repeatered* systems equipped with optical submarine repeaters, a first localization to within one supervisory section is obtained using the supervisory system.

For the end cable sections, cable fault localization may be achieved from the terminal stations, using adequate electrical measurement (resistance, capacitance, insulation, etc.) and optical reflectometry.

Similarly, cable fault localization may be achieved from the cable ship after cable recovery, using the same methods.

1.6.3 Fault repair

During *cable recovery* it may be necessary, in order to limit the mechanical tension applied to the cable, to cut the cable on the sea bottom prior to recovering both ends separately.

Several methods can be used for *sea repair*, depending on the sea depth:

i) the shallow water repair may necessitate the addition of a cable length, but not that of a repeater; a repair margin is generally included in the shallow water optical power budget since the shallow water sections are the most exposed to risk from external aggression, even though precautions are taken;

ii) the deep sea repair usually necessitates the addition of a cable length and sometimes of a repeater to compensate for the extra attenuation, if the extra attenuation incurred cannot be accommodated in the available margin; generally, a very low repair margin is included in the deep water optical power budget, since deep sea repairs are not frequent.

Repair safety procedures are applied on board the cable ship and in the terminal station, so as to ensure the safety of the personnel operating on board the cable ship. In particular, power safety procedures involve earthing the cable in the terminal station, on board the cable ship and at the branching unit.

2 Safety and environmental aspects

With the introduction of concepts of environmental sustainability, and standards such as ISO 9000 and ISO 14000 in telecommunications segments, safety and environmental aspects have become of great importance.

2.1 Safety aspects for optical power

2.1.1 Safe working conditions on optical interfaces

Recommendation ITU-T G.664 provides guidelines and requirements for techniques to enable optically safe working conditions (for the human eye and skin) on optical interfaces of the optical transport network, in particular, for systems employing high-power Raman amplification techniques.

The actual definition and specification of optically safe levels are considered outside the scope of ITU-T. The IEC is the organisation responsible for these matters. Therefore in Recommendation ITU-T G.664 specific references are made to IEC 60825-1, “Safety of laser products – Part 1: Equipment classification, requirements and user’s guide”, IEC 60825-2, “Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS)” and IEC/TR 61292-4, “Optical amplifiers – Part 4: Maximum permissible optical power for the damage-free and safe use of optical amplifiers, including Raman amplifiers”.

The historical background of Recommendation ITU-T G.664 is very important for understanding its content and its objectives.

When (around 1990) the first transversely compatible optical interface (see Recommendation ITU-T G.957) was created, the optical levels specified therein were not considered completely safe according to the version of IEC 60825-1, which was then valid. In order to achieve interworking between equipment from different vendors, it was considered necessary to specify a transversely compatible procedure that would guarantee optically safe levels under all working conditions, including fibre break. Therefore, in the first version of Recommendation ITU-T G.664 the automatic laser shutdown (ALS) procedure was specified.

More recently, the IEC decided that much higher levels were considered optically safe and newer versions of IEC 60825-1 and IEC 60825-2 were issued. As a consequence, all of the optical levels currently specified in any of the ITU-T optical interface Recommendations on transversely compatible optical interfaces Recommendations ITU-T G.691, ITU-T G.693, ITU-T G.695, ITU-T G.698.1, ITU-T G.698.2, ITU-T G.957 and ITU-T G.959.1 are considered to be safe in “restricted locations”. As a result, for none of these systems it is necessary to perform optical shutdown or power reduction to achieve optically safe working conditions. Therefore, in the present version of ITU-T G.664, the description and specification of the ALS procedure has been moved from the normative (mandatory) main body to a non-normative (informative) appendix in order to preserve it for historical reasons. It is specifically mentioned that the inclusion of the ALS procedure in this appendix does not imply that it should be used.

The same considerations apply to the automatic power shut-down (APSD) procedure specified several years later for systems that use optical amplifiers.

Despite the fact that, as noted above, none of the existing ITU optical interface Recommendations contain optical power levels that are not considered safe, there are many non-interworking (proprietary or single-vendor) systems that are operated at potentially hazardous or dangerous optical power levels. Examples are optical transport systems using Raman amplification and DWDM systems with large channel counts. Recommendation ITU-T G.664 provides guidance on maintaining optically safe working conditions for the designers and users of these systems, by outlining some basic requirements for designing automatic power reduction (APR) techniques that are recommended by the IEC documents for maintaining safe conditions in these particular cases. Furthermore, some examples of APR techniques are described in an informative appendix to Recommendation ITU-T G.664. It should be noted that APR refers to a situation in which the optical power is not switched off totally, but reduced to a level sufficiently low to be considered safe.

2.1.2 Best practices for optical power safety

(For further information see Supplement 39 to the ITU-T G-series of Recommendations).

Optical transport systems using Raman amplification and DWDM systems with large channel counts are one of the most critical from the point of view of the safety because they can operate at sufficiently high powers that can also cause damage to fibre or other components. In the following, the best practices to be adopted for these systems are shown.

Before activating the Raman power:

i) calculate the distance to where the power is reduced to less than 150 mW;

ii) if possible inspect any splicing enclosures within that distance. If tight bends, e.g. less than 20 mm diameter, are seen, try to remove or relieve the bend, or choose other fibres;

iii) if inspection is not possible, a high resolution OTDR might be used to identify causes of bends or connector losses that could lead to damage at high power;

iv) if connectors are used, it should be verified that the ends are very clean. Metallic contaminants are particularly prone to causing damage. Fusion splices are considered to be the least subject to damage.

While activating Raman power:

i) in some cases, it may be possible to monitor the reflected light at the source as the Raman pump power is increased. If the plot of reflected power vs. injected power shows a non-linear characteristic, there could be a reflective site that is subject to damage;

ii) other sites subject to damage, such as tight bends in which the coating absorbs the optical power, may be present without showing a clear signal in the reflected power vs. injected power curve.

Operating considerations:

i) if there is a reduction in the amplification level over time, it could be due to a reduced pump power or to a loss increase induced by some slow damage mechanism such as at a connector interface. Simply increasing the pump power to restore the signal could lead to even more damage or catastrophic failure;

ii) the mechanism for fibre failure in bending is that light escapes from the cladding and some is absorbed by the coating which results in local heating and thermal reactions. These reactions tend to increase the absorption and thus increase the heating. When a carbon layer is formed,

> there is a runaway thermal reaction that produces enough heat to melt the fibre which then goes into a kinked state that blocks all optical power. Thus, there will be very little change in the transmission characteristics induced by a damaging process until the actual failure occurs. If the fibre is unbuffered, there is a flash at the moment of failure which is self-extinguishing because the coating is gone very quickly. A buffered fibre could produce more flames, depending on the material. For unbuffered fibres, sub-critical damage is evidenced by a coloring of the coating at the apex of the bend.

The complete list of the practices to be followed is rather long and can be found in Supplement 39 to the ITU-T G-series of Recommendations.

More information on the safety for the optical fibre cable maintenance support, monitoring and testing system for optical fibre cable networks carrying high total optical power can also be found in Recommendation ITU-T L.68.

2.2 Fire hazards

During maintenance work, operators must handle optical fibres or fibre-optic components carefully in central offices that employ high power systems, in order to prevent fire hazards.

2.2.1 Fire protection

(For further information see Recommendation ITU-T L.22).

Taking into account the serious damage that can occur when fires break out and the importance of fire prevention to the security, service provision and economics of communication systems, there are several aspects that should be considered, such as:

i) reduction of the fire-load coefficient;

ii) division of the building into compartments (fire sectors) to reduce and delay the spread of fire;

iii) fire statistics.

Reduction of the fire-load coefficient

For a fire to start, develop and spread, three factors must take place simultaneously:

i) the existence of sufficient quantity of combustible materials (combustible charge);

ii) the presence of oxygen;

iii) the temperature to produce ignition of the materials.

From the three factors described above, the most important is the amount of combustible materials in the building. Building designers can exert significant control on the use of combustible materials, which will benefit fire prevention by reducing the fire-load that would feed the fire. If the extra combustible charge from decorative items and soft furnishings is added, the amount of combustible material (fire-load) reaches a limit that could be dangerous in the event of a fire. For example, in most telecommunication buildings the fire-load is formed by:

i) plastic and natural or synthetic wood elements used for floors, dividing walls, partitions, cabinets and suspended ceilings;

ii) materials of organic origin such as paints, papers and textiles;

iii) insulating materials, ducts, plastic or rubber equipment parts;

iv) decorative items and furnishings such as curtains, upholstery and combustible foam padding, carpets, pictures, books and writing materials.

Creation of fire sectors

Combustion is an oxidation process which, once initiated, keeps going if combustible materials are heated over their ignition temperature and continue to receive enough oxygen through the air supply. This creates a thermal exchange by conduction, radiation and convection to surrounding materials that encourages the fire to spread. By dividing the building into compartments to form fire sectors, the fire can be contained or delayed from spreading. The compartments are created using partitions of high-performance fire-stopping elements which are difficult to ignite. The degree of fire resistance of the partition elements will depend on the size of the compartments and their use, for example, as offices or storage areas.

The elements of the structure that form the boundaries of a fire sector should have fire resistance despite through-cable penetration points. The fire resistance of the boundaries should be such as to ensure that the propagation of smoke and fire between fire sectors is avoided before the extinction system is activated. For further details see Recommendation ITU-T L.32.

Fire statistics

Fires are isolated catastrophes affecting a limited number of people and buildings at any one time. Once the fire has broken out, every effort is applied to fighting the fire with the activation of various systems and devices, such as detection systems, alarm systems, extinguisher systems and fire-fighting personnel.

When the fire has been controlled and extinguished, investigations are started to find the possible causes of the fire. The reports produced can be turned into fire statistics, which can be taken into account in the design of new buildings and procedures to reduce the outbreaks of fire.

2.2.2 Fire detection and alarm systems, detector and sounder devices

In order to protect property and, when applicable, life, protective fire detection and alarm systems can be installed to initiate a number of different activities:

i) detection and location of a fire;

ii) provision of assistance to contain and/or extinguish the fire;

iii) emergency evacuation procedures;

iv) summoning of fire-fighting forces.

It should be noted that a fire detection and alarm system can do nothing to reduce the incidence of fires. It can however reduce the delay between ignition and effective fire-fighting. A satisfactory alarm system for the protection of property will automatically detect the fire at an early stage, raise an effective alarm in time to summon the fire-fighting forces, and indicate the location of the fire. An early alarm of fire enhances the safety of personnel by increasing their chances of escape.

Taking into account the risk of fire and the action needed to reduce the magnitude of the fire hazard, quick detection is the first criterion to be considered, followed by the activation of measures to extinguish the fire.

Detection devices are part of the automatic fire detection and alarm systems. These systems monitor continuously, or at frequent intervals, the physical and/or chemical characteristics of a protected fire area (zone).

The description of the various types of fire detectors (automatic; heat, smoke, flame detectors; etc.) and the criteria for their location can be found in Recommendation ITU-T L.21.

2.2.3 Equipment and installation for fire extinction

The different functions taking place in a telecommunication building generates possibilities and provides strong causes for fires on the premises. Fire extinction action involves concentrating the fire fighting at the origin of the fire, inside the building itself, using a choice of extinguishing systems.

The fire-fighting means to be adopted in a telecommunication building, may vary according to the usage and location of the premises and whether it is occupied. These are factors which determine the amount of fire service assistance initially allocated in case there should be a fire.

Fire extinction can involve a number of systems which are mutually supportive, although each may be independent of the others. The success of one or more systems may make unnecessary or reduce the need for the others. These systems are:

- *Initial fire fighting* with transportable or movable fire-fighting devices, such as portable extinguishers, fire blankets, etc., and other equipment that assist fire fighting personnel, such as masks, insulated garments, etc.
- *Fixed fire extinguishing systems* which involve non-transportable fire-fighting fixtures that are fixed extinguishing installations incorporated into the building and other accessory installations, such as hydrants, water supply networks, water spraying installations, sprinklers, automatic powder or gaseous extinguishers, water hoses, etc.
- *Action by the fire service*. This involves using their own equipment and/or using non-transportable fire-fighting fixtures, such as hydrants, hose reels and foam inlets.
- *Portable fire extinguishers* should be placed in all telecommunication buildings. The type should be appropriate for the fire risk.
- *Fire sectors* should be established that can be equipped with fixed extinguishing installations.

More details on types and placement of the above equipment and systems can be found in Recommendation ITU-T L.23.

Methods for the inspection and maintenance of every component of fire extinction systems should be introduced, with a view to guaranteeing their effectiveness in the event of a fire. Details can be found in Recommendation ITU-T L.33.

The safety practices for personnel and fire protection in outdoor installations are also important for telecommunications installations such as duct systems; manholes; tunnels; aerial, underground and buried networks; and subscriber equipment within the outside plant. More information on this issue is in Recommendation ITU-T L.63.

2.3 Environmental aspects

(For further information see Recommendation ITU-T L.45).

As a result of climate change, the interest on environmental issues is growing in areas that include life cycle analysis of products and processes, environmentally friendly materials and waste disposal.

Environmental sustainability can be defined as the ability to maintain the qualities that are valued in the physical environment, taking care of the aspects of the environment that produce renewable resources such as water, energy and air.

Products used in outside plant are typically manufactured using thermoplastic materials, lead, copper and wood, and preservative substances or antioxidants are added to ensure the long term performance of products. The proper replacement and final disposal of these materials is a goal for all environmentally correct countries. Moreover, new classes of materials that minimize environmental impact have to be studied, also taking into account that huge quantities will be deployed as developing countries extend their networks.

On the other hand, not only materials and equipment, but also the related installation and operation processes can affect the environment.

Therefore, the mitigation of these sources of environmental damage must also be considered:

i) to contribute in all industrial activities to reduce the effects of global warming;

ii) to minimize energy consumption and reduce greenhouse gases in accordance with the technique of life-cycle analysis in ISO 14040;

iii) to use ISO 14020 and ISO 14025 as criteria for an environmental declaration on products and systems;

iv) that each organization involved should have an environmental policy and an environmental plan with measurable goals on how to improve products and methods for a reduction of the energy consumption;

v) to keep track of toxic and dangerous substances and to have a waste management system.

2.3.1 Life-cycle analysis

In an attempt to cover the whole life cycle using a "cradle to the grave" perspective for cables and equipment, the life cycle is divided into several phases:

Manufacturing. The manufacturing phase includes raw material, transportation and production of a product. It is important to use materials with low impact on the environment and to follow the legislation in each country and the recommendations regarding banned materials.

Usage. The "usage" phase can be divided into installation, operation and maintenance. It is established that optical cables, due to their light weight and improved installation capability technique, use less energy and emit less CO_2 than copper cables.

During the installation phase of the cables it is also very important to organize transportation in an optimal way. This is done by using a fleet of well-maintained vehicles and machinery that causes minimal pollution by using suitable fuel and having catalyst exhaust fume cleaning systems.

Scrapping. Scrapping of cables is divided into disassembling and recycling/waste. Scrapping of optical cables is not common today. Scrapping of the optical cable ends (short cable pieces) is currently performed when splicing cables and the cable waste is disposed of in a way similar to the one used in the manufacturing process. Scrapping of old copper cables is industrialized in most parts of the world. The copper is recycled and the plastic materials are burned or disposed of as waste. If cables or batteries contain lead, the recycling process should be carried out according to safety requirements. Scrapping of old telephone poles impregnated with preservatives also requires sound environmental practices.

Disassembling. Excluding the duct and poles, optical cables can be removed with the same technique with which they were installed (blowing, floating and pulling). Due to the ease of their removal, it is potentially possible to reuse the cable or to recycle the cable material. They can also be left in the duct (if allowed), as they cause no contamination underground.

Recycling/waste. Sheath materials from optical cables and fibres can easily be separated mechanically and most of the plastic materials recycled.

Where optical cables are metal free and only contain thermoplastic plus optical fibres, the energy content in the thermoplastic can be regained as heat when burnt in heating plants, as its content is similar to petroleum oil.

For poles, attention should be paid to local legislation concerning their disposal or reuse.