Telecommunications Standards Advisory Committee (TSAC)

Next Generation National Broadband Network (NGNBN)

Optical Fibre Deployment

Part 2 – Optical Fibre Cables and Field Installation

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Contents

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Optical Fibre Cables and Field Installation

1 Scope

Without any mechanical protection, a bare piece of glass fibre is easily broken into pieces because of its very thin diameter. A cable is a structure designed to protect the bare fibre from the environment during installation and throughout its operational lifespan. The cable also provides ease of handling during shipping and installation. This section will cover the various types of cable construction, and summarise many techniques and practices used by the industry today for installing fibres and protecting them from the environment. This is necessary in preparation for advanced hands-on training for operating installation equipment or machineries.

2 Abbreviations

This Reference Specification uses the following abbreviations:

PVC	Polyvinyl Chloride
PE	Polyethylene
FTTH	Fibre to the Home
SMF	Single-mode Fibre
MMF	Multi-mode Fibre
SPD	Surge Protective Device
FOBOT	Fibre Optic Break-out Tray

3 Plastic Coatings

General methods of manufacturing optical fibres involve the drawing of an optical fibre preform into a long strand of core and cladding material. However, the silica surface is susceptible to attack by moisture, airborne contaminants and being scratched. For ease of manufacturing and to prevent the glass surface from being scratched, a special coating is applied during the drawing process. During the manufacturing process, the fibre is usually coated with a very thin layer of plastic bonded closely to the cladding. It is applied as a continuous process as the fibre is drawn. Fibre coatings are very important for the following reasons:

(1) To prevent water or moisture from diffusing into the fibre during the manufacture of the fibre. Humidity can rapidly produce defects and cracks on the silica surface. Fibre coating can prevent water from diffusing into the fibre and protect the fibre core and fibre cladding. If water is diffused into the fibre, there will be an increase in the fibre attenuation due to absorption loss.

(2) To identify individual fibres. In loose-tube or gel-filled cables, multiple fibres are often packed close together in a common sheath. After coating of the fibre is completed, the fibre undergoes a colouring process. During this process, a colour layer, that is a few microns thick, is introduced as a dye on top of the coating layer. This makes identifying individual fibres easier.

(3) The fibres are easier to handle and less susceptible to damage.

3.1 Primary Coating

The primary coating is normally a thin, ultraviolet cured acrylate layer with a diameter of around 250 – 750 microns, depending on the fibre geometry. It immediately surrounds the cladding of an optical fibre. Fibre coating is very important during the manufacturing process. The primary coating serves to protect the fibre from mechanical damage and chemical attack.

The primary coating on a modern fibre is an easy-to-strip substance, yet it provides an essential part of the mechanical integrity and water resistance of the optical fibre structure as a whole. The following figure illustrates a primary-coated optical fibre. The primary coating is also defined in ITU-T Rec. G.650.1 [1].

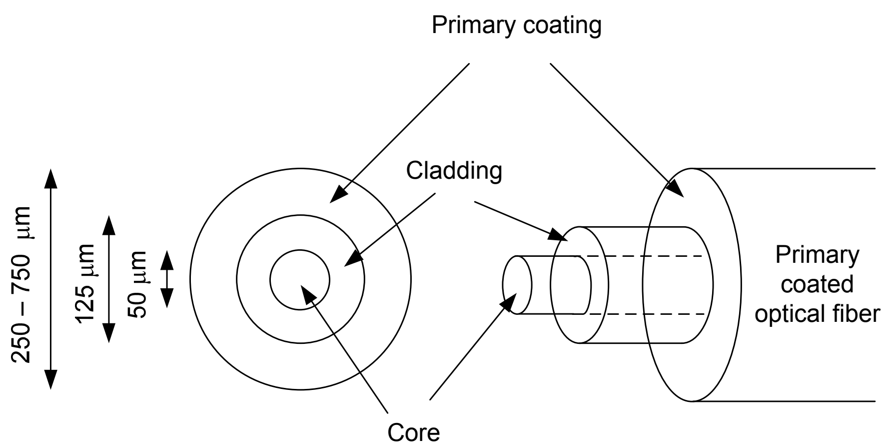

Figure 1: Primary-coated Multi-mode Optical Fibre

3.2 Secondary Coating

Secondary-coated optical fibres are often referred to as tight-buffered fibres. Secondary coating refers to an additional layer of plastic that is extruded on top of the primary-coated optical fibre. The secondary coating element is typically 900 µm in diameter and can be incorporated within much more flexible constructions such as those that are required within buildings or for use as patch or jumper cables. The application of the secondary coating necessitates a further production stage and hence cables containing secondary coating are always more expensive. The following figure illustrates the secondary coating of an optical fibre. The secondary coating is also defined in ITU-T G.650.1 [1].

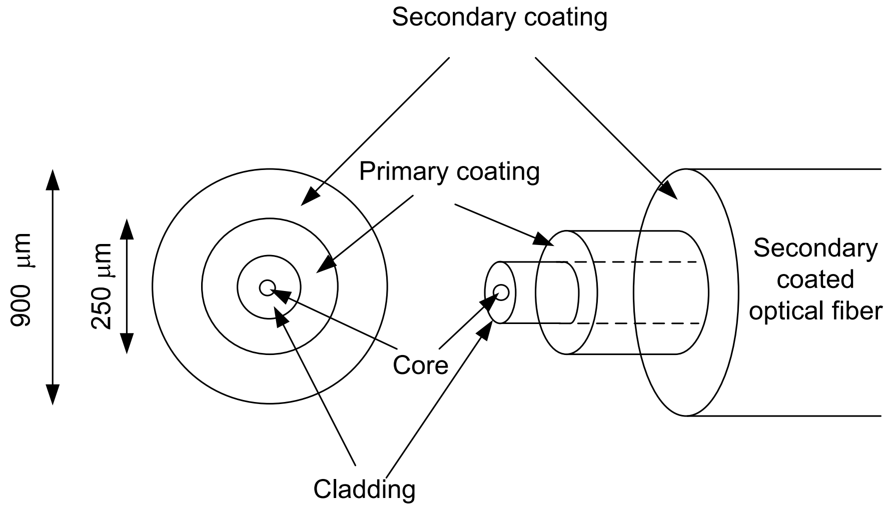

Figure 2: Secondary-coated Optical Fibre

3.3 Fibre Ribbon

Optical fibre ribbon refers to the arrangement of fibres parallel to each other and equally spaced, bonded in a flat configuration by a coating. The number of parallel fibres can range from 2 to 12. Generally, there are two types of optical fibre ribbons: one is the edge-bonded type and the other is the encapsulated type. Several fibre ribbons can be placed on each other to form a stack within a groove of a slotted core or in a tube. Fibre ribbons are usually used when there is a need for maximum connectivity within a minimum amount of space. The characteristics of optical fibre ribbons are specified in both IEC 60794-3 [2] and ITU-T L. 59 [3].

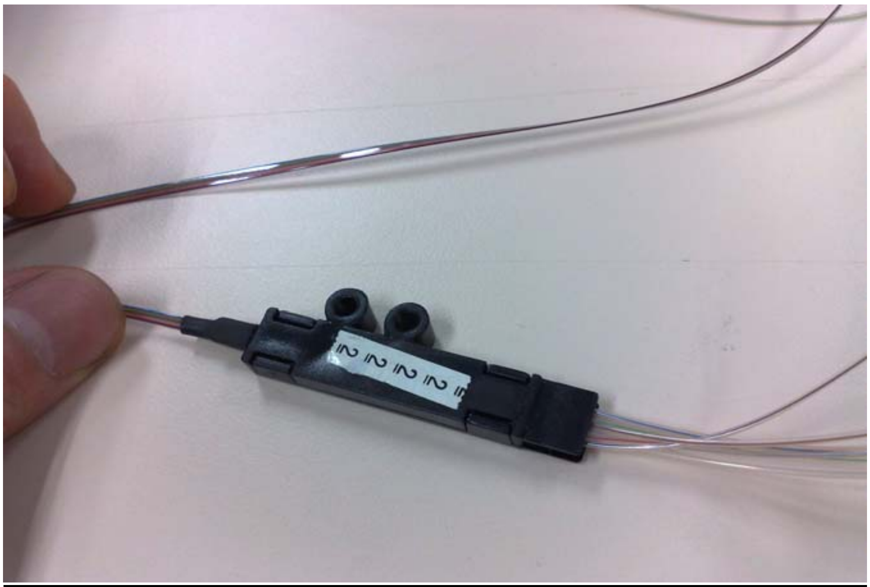

Figure 3: A Typical Ribbon Fibre

Standards those are applicable to ribbons:

- o Dimensions (IEC 60794-1-2-G2/G3/G4) [4]
- o Separability of individual fibres from a ribbon (IEC 60794-1-2-G5) [4]

3.4 Dimensions

The fibre and coating geometries are specified in IEC 60793-1-20 [5] or IEC 60793-1-21 [6], respectively.

Core diameter – 9-10 microns
Cladding diameter – 125 microns
Primary coating diameter – 250 microns
Secondary coating diameter – 900 microns

3.5 Coating strippability

When installing fibres to optical connectors or splicing two or more fibres, the coatings of the fibres may need to be removed. The IEC 60793-1-32 [7] standard establishes uniform requirements for coating strippability. This test specifies the force required to mechanically remove the protective coating from optical fibres along their longitudinal axis. The test is designed for fibres with polymeric coatings (or tight buffered) that possess nominal diameters in the range of 250 to 900 microns.

3.6 Compatibility with Filling Materials

Fillers used in an optical cable should be such that the fibre should not undergo any stresses due to the presence of the fillers that may lead to the fibre failure.

3.7 Fibre Identification

In practical implementations, a number of fibres are always bundled within a cable core. These fibres should be easily identified and clearly distinguished. Otherwise this might result in the wrong fibres being used, leading to unnecessary fault in the fibre transmission system. The fibres are generally identified by either colour or position.

4 Cable Structural Elements

The cross section of a typical loose tube optical fibre cable is shown in Figure 4. The main elements are the strength member, sheaths, armour, fillers and tubes that surround the fibres.

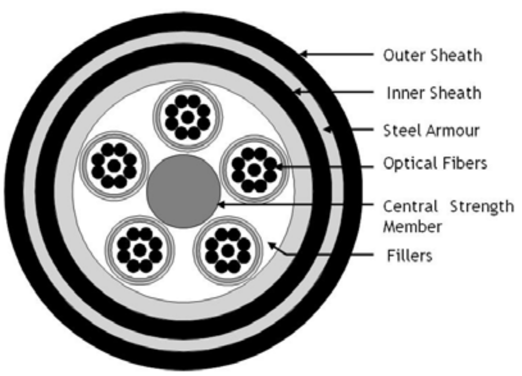

Figure 4: Cross-section of a Typical Loose Tube-type Optical Fibre Cable

Figure 5: Photograph of a Loose Tube-type Optical Fibre Cable
(Courtesy of Furukawa Electric Co., Ltd.)

4.1 Strength Member

A strength member is a structural element in a fibre cable for absorbing tensile and compressive forces. It is normally made up of fibreglass with or without an additional steel rod, and is found in the centre of the cable, where it imparts strength to the cable. It helps in keeping the fibre fairly rigid such that the cable cannot be bent at a sharp angle that might lead to severe bending loss in the fibre. Usually the strength member is made of Kevlar aramid yarn, fibreglass filaments, or steel strands. When selecting an optical fibre cable, the performance of the strength member should be matched to the installation and operational conditions.

4.2 Sheath

The fibre cable is covered by a heavy-duty plastic sheet known as a sheath. This helps in protecting the cable from scratches, cuts, getting crushed (to a large extent), and it gives additional resistance to excessive bending. The sheath can be used to protect an optical fibre cable during its installation and throughout its operational lifetime. Indoor cable sheaths are made of Polyvinyl Chloride (PVC) or Polyurethane material while outdoor cable sheaths are made of Polyethylene (PE). Sometimes, thin layers of Nylon and/or Teflon are used to provide protection against rodents.

4.3 Metal Armour

Steel wire armouring or corrugated steel tape amouring is used to surround the sheath, and this is further covered with another sheath to prevent corrosion.

4.4 Tube

A tube is used to package one or multiple optical fibres for protection purposes.

4.5 Water-blocking Material

Hydroxyl ions (OH^-) could contaminate the fibres, leading to degradation of the fibres in the long run. Hence, it is very important to keep the fibres protected from moisture. Most of the cables use petroleum jelly, silicone rubber, or water absorbent material to help keep the moisture from affecting the optical fibres in the cable.

4.6 Slotted Core

In an optical fibre cable, optical fibres and/or ribbons are located in extruded cavities which surround a central strength member. This extruded cavity is the slotted core. The slotted core is used to contain optical fibres and/or ribbons to protect optical fibres and/or ribbons from being pressured directly from the outside of the cable.

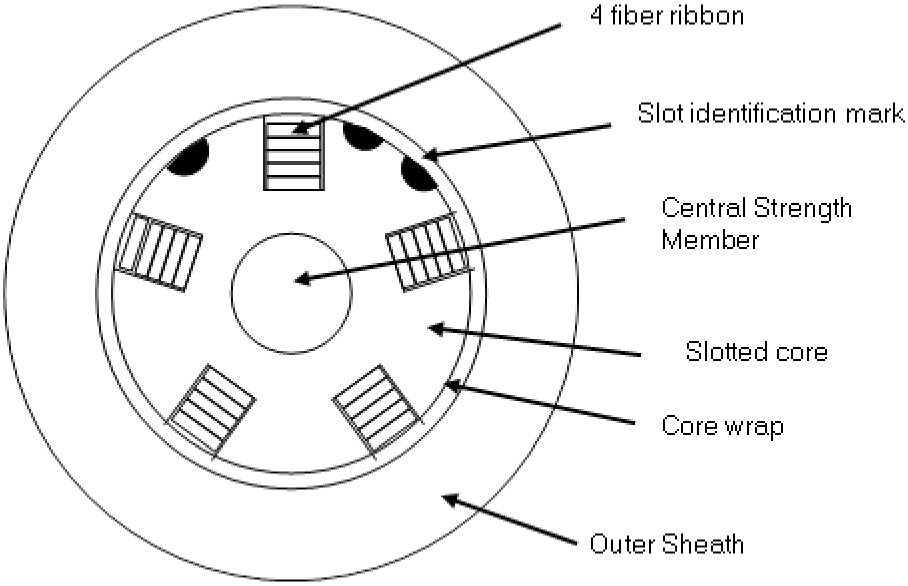

Figure 6: A Typical Ribbon Slot-type Optical Fibre Cable Cross-section (Courtesy of Furukawa Electric Co., Ltd.)

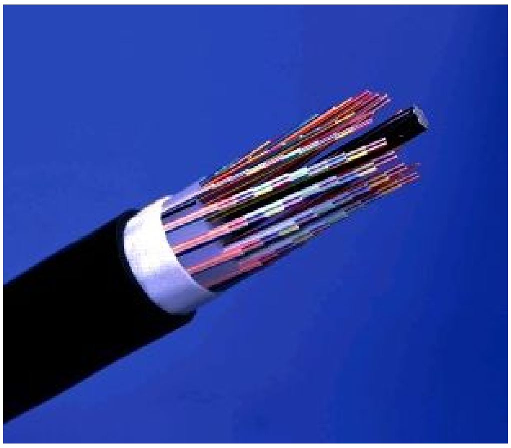

Figure 7: A Typical Ribbon Slot-type Optical Fibre Cable (1,000 fibres) (Courtesy of Furukawa Electric Co., Ltd.)

5 Classification of Cables

There are four types of cables: aerial, underground, subaqueous and indoor.

5.1 Aerial Cables

Aerial cables are installed between two poles. They are either tied to steel cables that are fixed between the poles or directly held onto the pole using in-built steel strength members. These cables are always exposed to the natural elements, external forces and hazards. The cable's own weight, temperature, moisture and wind greatly affect the tensile forces acting on the cable. The span length between the poles is an extremely important design parameter. Aerial cables are very advantageous in places where it is difficult to bury them or install them in ducts. Such cables are also used for temporary installations.

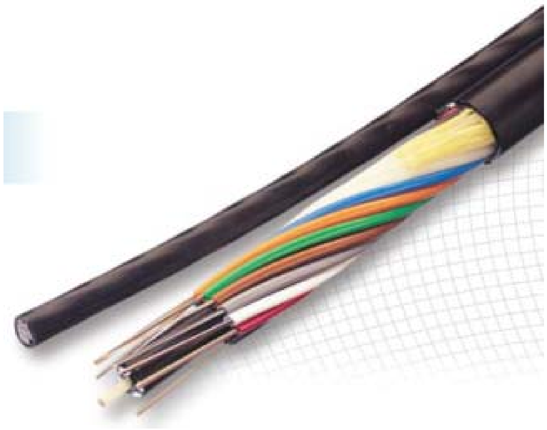

Figure 8: A Typical Aerial Optical Fibre Cable (Self-support type)
(Courtesy of Furukawa Electric Co., Ltd.)

5.2 Underground Cables

Underground cables can be easily buried or installed in ducts. In situations where a moisture barrier is required, these cables use a polymer-coated aluminium laminate that is bonded to the inside of the PE sheath. Such cables are the most cost-effective and secure method for the outdoor installation of cables. Although well protected from the environment, they could be damaged by flooding, farming, construction works, and rodents gnawing through them.

Figure 9: A Typical Underground (Duct) Optical Fibre Cable (Single Jacket)
(Courtesy of Furukawa Electric Co., Ltd.)

5.3 Subaqueous Cables

Subaqueous cables are designed for underwater cabling. They are normally used for deep-sea communication carriers. They can also be used across lakes and other water channels where other alternatives may not be cost effective, and in areas where the water table is high or where the area is highly prone to flooding.

5.4 Indoor Cables

Indoor cables are specially designed for use inside buildings. The properties of these cables have to conform to strict fire codes. Indoor cables are mostly tightly buffered cables so as to be water resistant. Typically, there are five types of indoor cables: patch cords, distribution (or breakout) cables, riser cables, plenum cables and zip-cord cables. Recently, flat-type indoor cables or low-friction sheath micro-indoor cables have also been deployed for FTTH networks.

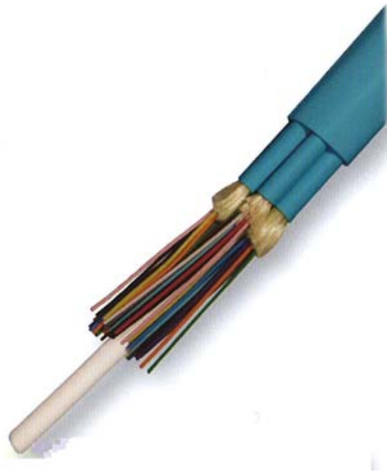

Figure 10: A Typical Indoor Distribution Optical Fibre Cable (Plenum-rated)
(Courtesy of Furukawa Electric Co., Ltd.)

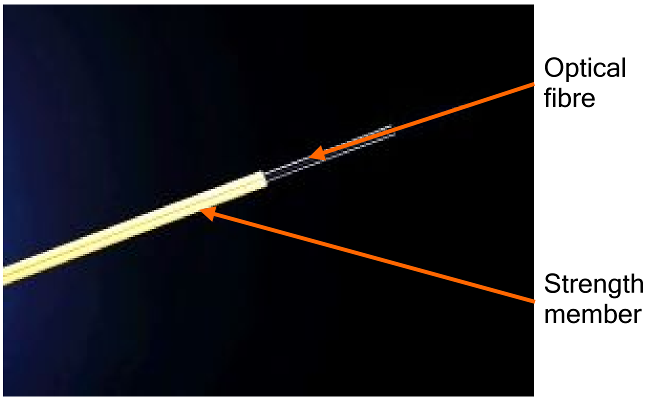

Figure 11: Flat-type Indoor Cable (1 fibre, 2 x 3mm)
(Courtesy of Furukawa Electric Co., Ltd.)

Figure 12: Low-friction Sheath Micro-indoor Cable (1 fibre, 1.6 x 2mm)
(Courtesy of Furukawa Electric Co., Ltd.)

Most indoor fibres used in FTTH networks are single-mode fibres. Other popular types of indoor fibres include multi-mode fibres and polymer fibres. Multi-mode fibres are frequently installed in data-centres for local area networking or rack-to-rack communications while plastic optical fibres are recently being proposed for high bit-rate, short-distance transmission links within the home due to their low cost.

6 Mechanical and Environmental Stresses

An optical fibre cable must be able to withstand many types of mechanical stresses, and these include tensile loading, bending, crushing, kinking and torsion. During the manufacturing, installation and operation of a fibre cable, different types of mechanical forces may be applied on the cable. The transmission performance of the optical signal may thus be degraded as these mechanical forces alter the transmission properties of the fibres inside.

Mechanical and transmission characteristics of optical fibre cables are affected by environmental conditions. Different specifications are needed for fibre cables to work properly under a variety of environmental conditions. Indoor environmental conditions are not as severe as outdoor conditions.

6.1 Bending

During the installation and operational lifetime of an optical fibre cable, the fibre may be bent by external forces. These forces may increase the fibre cable tension and bend radius, thus straining the fibre cable. A sharp bend in a fibre can cause significant losses as well as the possibility of a mechanical failure, which will reduce the lifetime of the cable. To prevent damage to the cable and reduce the possible bending losses, the minimum bend radius is always quoted in the specifications.

Fibre Microbending

If a fibre is bent from the straight position, the light may be radiated away from the guide, causing optical leakage. There are two classes of fibre losses arising from fibre bends, i.e. macrobending and microbending losses. Fibre microbending refers to a small microscopic band of the optical fibre axis that creates the local fibre axial displacement of a few micrometres and spatial wavelength displacements of a few millimetres.

Microbending is caused by the manufacturing process and mechanical stresses, and it may also occur during the installation and operational lifetime of the fibre. Another possible cause of microbending is temperature changes.

Fibre microbending can result in attenuation losses due to nanometre-scale variations in the fibre. The following figure shows the effect of fibre microbending and illustrates how optical power leakage can occur. When external or mechanical forces are applied on a fibre cable and result in fibre microbending, the transmitted light in the fibre core will be radiated away from the core to the cladding due to refraction by Snell's law. This reflection will cause optical leakage and the power of the optical signal transmitted in the fibre is thus attenuated.

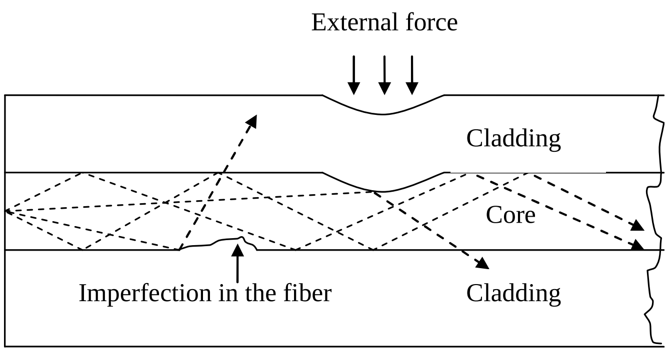

Fig.13 Effect of a Microbending

Fibre Macrobending

Fibre macrobending refers to a large visible bend in the optical fibre that can cause attenuation losses in the fibre. This type of bending occurs when the fibre is bent beyond the minimum bend radius. Such bend curvatures are obvious when the fibre is visually inspected (Figure 14).

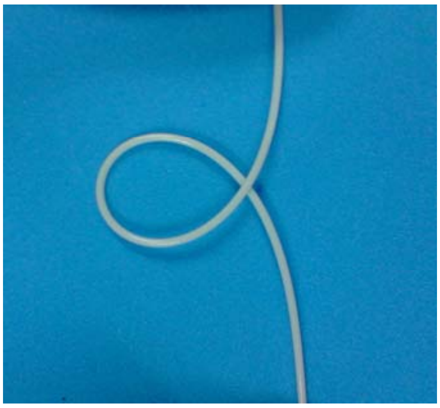

Figure 14: Example of Macrobending

To avoid macrobending-related losses, a relatively large bend is usually used in a splice organiser tray or a fibre-optic cable installation duct. If a sufficiently large bend radius is used, macrobending will not result in significant radiation losses.

Macrobending losses are normally produced by poor handling of the fibre. Generally, single-mode fibres have a low numerical aperture and are, therefore, more susceptible to bend losses than other types of fibres. The fibres commonly used in customer-premises applications typically have a relatively high numerical aperture, (approximately 0.27), and can tolerate a bend radius of an inch (2.5 cm).

Most optical fibre cable suppliers specify a minimum bend radius to limit macrobending effects (typically around 10-15 mm), although this varies with the cable type and manufacturer's recommendations. Indoor optical fibres require a higher tolerance of macrobending radius as spaces are generally tighter and fibres are more likely to be subjected to bending.

6.2 Tensile Strength

During the manufacturing, installation and operation of an optical fibre cable, a short-term load, a continuous static load and a cyclic load may be applied on the fibre cable, respectively. The fibre components may have differential movement due to the application of these loads. The maximum loading that can be applied to a fibre cable in normal working conditions is called tensile strength. Tensile strength needs to be considered when the fibre cable is designed. Excessive tensile load can increase optical loss and residual strain in the fibre. The latter may permanently damage the fibre cable. For normally coated silica-clad telecommunications fibres, the breaking tensile strength is typically on the order of 5 GPa, but the tensile strength is separately specified.

6.3 Crush and Impact

During the installation and operational lifetime of an optical fibre cable, the cable may be crushed. The optical fibre may be damaged or fractured due to the stress of the crush. In addition, heightened optical signal loss may result.

6.4 Torsion

Torsion may occur during the installation and operational life of a fibre cable. The torsion of a fibre cable may increase the residual strain of the fibre and damage the sheath of the cable. The attenuation loss in the fibre may increase due to the torsion, and, therefore, the designer of a fibre cable should consider this issue and allow a specified number of cable twists per unit length.

6.5 Impact

The cable may be impacted during both installation and operational life. The impact may increase the optical loss and lead to fibre fracture.

6.6 Kinking

The fibre cable may be subject to kinking during installation. The insertion loss of the fibre cable is increased and the kinking may lead to fracturing of the fibre.

6.7 Repeated Bending

An optical fibre may be repeatedly bent during installation. The design should guarantee that the fibres will not break easily when subjected to repeated bending.

6.8 Temperature Variations

During the operational lifetime of an optical fibre cable, the fibre can be affected by temperature variations. These temperature variations may affect the mechanical characteristics of the fibre and increase its attenuation loss. The range of temperature variation for an optical fibre cable is defined in ITU-T L.59 [3] and IEC 60794 [4].

6.9 Biotic Damage

Biotic damage refers to the damage of a fibre cable caused by biological attacks. During the operational lifetime of an indoor optical fibre cable, the fibre may be attacked by rodents, insects or micro-organisms. These attacks may permanently damage the fibre cable and severely degrade optical transmission performance. The fibre should be protected effectively against these attacks. ITU-T Rec. L.46 [8] provides more information on biotic damage.

6.10 Vibration

Vibrations may cause physical movement of fibres, especially when cables are installed vertically. These movements may affect the mechanical characteristics of the fibres and thus increase loss and degrade transmission performance. During installation, special care should be taken to ensure that the installed fibre cable can withstand vibrations.

6.11 Fire Safety

Fire safety is very important. Fire safety issues should be considered in the design and fabrication of optical fibre cables and cable elements for indoor applications. Indoor optical fibre cables should possess flame-retardant characteristics so that they cannot be easily burned. In addition, indoor optical fibre cables should not release toxic gases or smoke during a fire.

7 Test Methods for Fibre Cables

ITU-T Rec. L.59 [3] contains detailed information on the construction of indoor fibre cables as well as various mechanical and environmental tests that are applicable to such cables. It also includes recommendations for protecting the cables during storage and delivery.

The following table is a summary of commonly used test procedures or recommendations for characterising the mechanical and environmental performance of fibres and cables.

7.1 Mechanical

Standard or Test Procedure	Purpose
ITU-T G.650.1 (for SMF), ITU-T G.651.1 (for MMF)	ITU-T G.650.1 includes a test method for proof-testing single-mode fibres The parameters, test procedures, test machines and preparation techniques to measure the longitudinal tension of a cable are presented. Test methods for multi-mode fibres are covered in ITU-T 651.1. While the document provides references to these tests, it does not contain any details on the tests.
IEC 60794-1-2 E1	This document details testing of the tensile strength of an optical fibre cable. Two methods are described, one for measuring the attenuation changes and the other for measuring elongations strain. This is a non-destructive test method (the tension applied < operational values) to measure attenuation (E1A) and/or the fibre elongation strain (E1B) as a function of the load on an optical fibre cable that may occur during installation. Alternatively TIA-455-33-B can be used.
IEC 60794-1-2-E2	There are two methods for testing abrasion resistance. This test determines the ability of an optical fibre cable sheath to resist abrasion on the sheath (E2A) and cable markings (E2B). For E2A, there should be no perforation on the sheath and the optical signal transmittance should be maintained after the test is completed. For E2B, the marking on the cable should be legible after the test. For both tests, the specifications include the number of cycles, diameter of the needle and the force applied.
IEC 60794-1-2 E11	The ability of an optical fibre cable or cable element to withstand bending around a test mandrel is described in this test. The following are specifications that shall be stated: procedure used (Test method 11A or 11B), the diameter of the test mandrel, the number of turns, the number of cycles, the maximum increase in attenuation allowed during and after the test, and the temperature at which the test is conducted.
IEC 60794-1-2 E8	This is to determine the ability of an optical fibre cable to withstand repeated flexing while in service. The specifications include the number of pulleys used in the test, the mass of the weights as well as the number of cycles.
IEC 60794-1-2 E3	This test determines the ability of an optical fibre cable to withstand crushing. The specifications typically include the total force applied, the duration of the force and the number of tests, among others. The failure modes include total loss of optical continuity, a reduction of transmitted optical power or physical damage to the cable.
IEC 60794-1-2 E7	This test determines the ability of an optical fibre cable to withstand mechanical twisting. It measures the variation in the optical power transmittance of a fibre when the cable is subjected to torsional forces on the cable jacket. It also determines the possibility of physical damage to the fibres and the fibre cable. Typical failure may include loss of optical continuity, increase in fibre loss and damage to the cable jacket or core components.

IEC 60794-1-2 E4	This test will show the ability of an optical fibre cable to withstand impact. Specifications typically include the numbers and rates of impact as well as the location of the impact point on the test sample. The test is conducted using a weight or a drop hammer, and the mass and the height at which the weight is dropped shall be adjusted to compute the energy of the impact.
IEC 60794-1-2 E10	The purpose of this test is to find out the minimum loop diameter that may lead to the kinking of an optical fibre cable. The temperature at which the test is conducted shall be specified and, unless stated otherwise, standard atmospheric conditions are assumed.
IEC 60794-1-2 E6	This test determines the ability of an optical fibre cable to withstand repeated bending. In this test, the acceptance criteria are stated in the detail specifications, which may include the number of cycles and the bending radius, among others. Typical failures include loss of optical signal, reduction in a signal's optical power or physical damage to the cable.
IEC 60794-1-2-E20	This test method determines the ability of an armoured underwater optical fibre cable to be coiled and uncoiled during installation. The specifications include the length of the sample, the coil diameter, and the number of coils.
IEC 60794-1-2 E5	This document describes test methods for determining the stability of the stripping force of coated optical fibres. The tests measure the change in the fibre strippability in various environmental conditions. The change is stripping force should meet specifications for cable preconditioning, fibre conditioning, recovery time and reconditioning, as well as permissible changes in the stripping force.

7.2 Environmental

Standard or Test Procedure	Purpose
IEC 60332-1-1 or IEC 60332-3-24	This document describes test methods for determining optical fibre cable flame retardant characteristics. The various test instruments to reveal the amount of resistance that an optical fibre cable has against the propagation of fire are specified.
IEC 60754-1 or IEC 60754-2	This document describes test methods for determining the quantity of halogen acid gas and hydrofluoric acid that are produced during the burning of halogenated polymers and additive-based compounds used during the construction of optical cables.
IEC 61034-1 or IEC 61034-2	This document describes methods for measuring the amount of smoke emitted when an optical fibre cable is burnt horizontally. The amount of light transmitted when the cable is burning or smouldering can be used to compare various cables.
IEC 60794-1-2-F5	This test determines the ability of a cable to block water ingress along a specified length. The F5A test is for water ingress between the optical core and the outer sheath, and the F5B test is for water ingress over the entire cross-section of the optical fibre cable.

ITU-T Rec. L.27	Excessive levels of hydrogen in a cable can result in optical losses in the fibre. This document describes the origins of this problem and provides methods in which the concentration of hydrogen may be measured. It also includes preventive measures for the build-up of hydrogen.
ITU-T L.46	This document describes the various types of biological attacks that can occur to optical fibre cables, and provides some recommendations for protection. Typical biological attacks can come from mammals (such as rats and moles), birds, insects (termites and ants), and micro-organisms such as bacteria.
IEC 60794-1-2-F7	This test determines the degradation of the optical fibre cable when exposed to nuclear radiation. Typical changes include attenuation and physical characteristics of the materials used in the cable construction. The radiation may produce degradation in properties such as tensile strength and impact performance on the polymeric materials in the cable. These may be of vital importance in special cases like military applications and cables for use in certain areas in nuclear power stations and nuclear laboratories.
ITU-T Rec. K.25	This test includes procedures to protect fibre optic cables against lightning discharges. There are suggestions on cable materials and cable characteristics for both aerial and buried cables. The recommendation also covers the use of shield wires, earthing of the cable shield and use of surge protective devices (SPD) as well as planning considerations such as route redundancy.
IEC 60794-1-2-F1, IEC 61300-2-22 and ITU-T L.69	This test determines the stability of the attenuation of cables subjected to temperature changes. Typical changes include variation in attenuation, loss of optical continuity, degradation of optical transmittance, physical damage to the cable and increased tensioning of the fibres due to differences between their thermal expansion coefficient and the coefficients of the cable strength and jacketing members.
EIA/TIA-455-98, IEC 60794-1-2 F6	This test determines the performance of cables in freezing conditions.
IEC 60794-1-2-F8	This test determines the pneumatic resistance of optical fibre unfilled cables protected by gas pressurization. The specifications include maximum pneumatic resistance, the length of the sample and the pressure of the gas.

8 Installation Techniques

8.1 Bend Radius

One of the most important things to be considered when installing fibre optic cables is to ensure that the cable radius is always more than the minimum-bending radius recommended by the manufacturing company.

Sharp bends should be avoided at all cost along the installation route. Similarly, bends that are sharp in the cable trays or in the conduits may lead to macrobends or microbends in the fibre that, in turn, may lead to significant attenuation of the signal. Hence, care should be taken to fabricate the conduits or the cable tray without any sharp bends.

It would be preferable to lay the cables on a flat surface. Care must be taken to ensure that heavy objects do not fall or rest on the cable. It is advisable to pull the cable directly off the drum without minimum slack in the cable to avoid any kinks or twists.

Generally, a fibre optic cable with a diameter of 2 cm or less should not be more than its minimum installation bending radius if the minimum bending radius of 30 cm is maintained during installation.

8.2 Bend-tolerant Fibres

It is possible to re-engineer the single-mode fibre to make it more tolerant to macrobending, and this can be achieved through changing the mode field diameter of the fibre. ITU recommendation G.657 defines two classes of bend-resistant fibres that are suitable for home (FTTH) applications. G.657a [9]* specifies a maximum loss value at 20 and 30 mm bend diameters while G.657b [9] goes a step further to specify a maximum loss value at 15 mm bend diameter. The former is designed to be compatible with G.652 [10] fibres and is less sensitive to macrobending as compared to typical single-mode fibres. However, the latter is even more tolerant to bending, but its implementation typically requires new types of fibres such as photonic crystal fibres.

* Next Generation NBN fibre deployment in Singapore uses ITU-T G.657a fibres (for indoor environment)

Figure 15: Ultra Bend Insensitive Optical Fibre Cord (EZ-Bend (TM) Product) (Courtesy of Furukawa Electric Co., Ltd.)

8.3 Cable Tension

Fibre optic cable failure due to excess cable tension during installation could be catastrophic (i.e. fibres breaking inside the cable). Sudden, short and sharp jerks should be avoided while pulling the cable during installation. These could easily go beyond the maximum tension that the cable could withstand. Moreover, the pulling of the cable should be an easy and smooth process.

Do not allow the cable to jerk the drum around as the high moment of inertia of the drum may cause excessive tension in the cable. It is very important to minimise the stress on the cable after the installation is complete. The fibre optic cable will have a longer operating life if a slack final resting condition is provided.

Intermediate junction boxes help in reducing cable tension if there are many bends in the cable route. A little slack may be left in the junction boxes so as to reduce overall stress in the cable. Torsional forces could cause severe damage to the fibres in the cable. Twisting of cables can be caused by using improper installation techniques or due to forcing cables through tight conduits.

8.4 Installation in Trays and Conduits

Installation in Trays

If the cable is directly laid onto the cable tray from the drum, it will cause the least stress and damage to the fibres. This may not be easy due to the restriction in space around the cable trays and the tray hangers. Sometimes, the cable may need to be pulled in as there may be some difficulty in laying the cable directly onto the tray. The line for pulling a fibre optic cable should be attached to the strengthening member only. If the fibre optic cable has pre-terminated connectors, care must be taken in order to prevent the connector ends from being bent back and the optical fibres from being broken while the cable is being pulled.

Installation in Conduits

Care must be taken to ensure that both ends of the cable are properly sealed and waterproofed before installation starts. Any moisture around the fibres may lead to permanent damage in the cable. Sufficient amounts of lubricant must also be applied to the cable before it is pulled into the conduit.

Wherever possible, the cable should be pulled by hand. If a winch is being used, it is important that the maximum permissible cable tension is not exceeded. It is a well-known fact that the friction is larger if the surface area of the cable is comparable to the surface area of the conduit. Hence, care must be taken to choose the appropriate conduit diameter.

Sometimes it is possible to tie the pulling line onto the strength member for very simple pulls where there is very low resistance. This may not be true in the case of conduits as the knot may get stuck along the conduit, resulting in breakages.

The fibre optic cable may also be pulled using a 'pulling eye'. In the case where the cable has to be pulled over a long length of conduit, it is preferable to have intermediate pulling points. At these points, care must be taken to ensure that no torsion force comes into play and that the cable is well lubricated.

Figure 16: Fibre Cable in a Conduit
(Courtesy of OpenNet Pte Ltd)

Leaving Extra Cable

It is preferable to leave some length of cable (about 10 metres) at the beginning and end of every cable length and also at all termination cabinets, junction boxes, pit boxes, splicing centres, splicing trays, cable vaults and at the end equipment. This has multiple advantages. If the cable is accidentally cut or dug up, this extra length of cable can be pulled to the cut point and spliced. It could also be useful if junction/end point equipment has to be moved or there is a need for network expansion in the future.

8.5 Installation Environment

It is preferable to install cables where the ambient temperature is greater than the freezing point (0°C) or less than 65°C. The possibility of damage to the cable sheath and to components inside the cable and to the fibres themselves is quite high in cases of temperatures that are beyond these limits. High humidity levels should also be avoided (85–90%). Storage temperature and humidity specifications are normally given by the supplier.

9 Installation of Cables (Tools, Standards)

9.1 Indoor Fibres

If the indoor cables are to be installed on the floor, rubberised floor ducts should be used in order to protect the cables. Cables with strong sheaths should be used if they are to be installed under carpets. Cable clips, which are fixed onto the walls, should be used for cables that have to be run vertically up a wall.

It is more cost effective to have the cables pre-terminated in the factory for installation at the site as the lengths of cables are normally quite small. This would help in saving both time and money.

In cases where the cables are to be laid in the ceiling, care must be taken to avoid metallic members, ceiling hangers, sharp edges and corners, screws, nails, metal studs, and so on. The cable should also avoid areas that require regular maintenance like air conditioning ducts, piping for water and gas, or any other similar type of installation. If it is unavoidable, the cable could be installed in conduits.

Most fibre optic cables can support their own weight over an approximate length of over 100 metres in the case of vertical installations. Clamps on the sheath should be used at regular intervals. Moreover, care should be taken to ensure that the bending radius does not exceed the recommended limit.

In the case of installations in cable risers or in elevator shafts, the cable should be fixed using cable ties (not too tightly) at regular intervals. This will prevent the cable from exceeding its maximum tensile load and avoid movement of the cable.

If the cable has to be connected to any data equipment or patch panel, an excess length of about two feet should be provided.

9.2 Outdoor Fibres

There are quite a few important points that have to be taken into account during the installation of fibre optic cables in outdoor environments. Careful planning of the actual route for laying the cable will minimise the installation cost. Moreover, the chosen cable should be suitable for the various environmental conditions it will be subjected to. Various specifications, like the type of fibre, sheathing, overall diameter, the kind of barrier for moisture protection, strength members, connectors, and so on, should be considered very carefully.

It is better to use conduits for cables that are to be installed underground. This will provide protection, to quite a large extent, from water, rodents trying to gnaw through the cables, variations in temperature, physical stress from vehicular traffic on the surface and also from accidentally digging. If the conduit is of a larger diameter, it may also come into use at a later stage as it allows new cables to be laid without having to dig and relay the conduits and cables again. Using conduits also makes the work easier when it comes to replacing damaged or old cables.

Figure 17: Underground Conduit with Cables (Courtesy of OpenNet Pte Ltd)

If the sheath used in the cables can provide extremely good protection against rodents while having good moisture-blocking properties (e.g. jelly filled), then these cables can be buried directly in the ground. Normally, these cables have sheaths that are double jacketed with Nylon or Teflon, and they also have metal armour.

In normal circumstances, a depth of 1 to 1.5 metres is ideal for buried cables. It may be noted that the deeper a cable is buried, the lesser the temperature variations it is likely to suffer. The amount of physical stress on the cable due to vehicular traffic on the surface or attacks from rodents will also be minimal.

Extra cable length has to be provided to reduce cable tension and to allow for repairs if and when the need arises. Reconfiguration and maintenance can be carried out, if required, in termination cabinets and patch panels that could be provided at accessible places near the end of each cable length.

Aerial Fibres

Fibre optic cables, which are specially manufactured with extra internal strength, can also be installed as aerial cables hanging from poles. Some of these cables are manufactured using a design that allows it to be supported along a steel support wire. Sometimes, the fibre optic cable can be tied to the power cable line. The support wire generally provides extra strength and lessens the strength requirements on the fibre optic cable itself. The design considerations for aerial cables take into account the extreme forces that could result from strong winds along with other outdoor weather conditions including large temperature variation, moisture, and UV radiation.

Blown Fibres

This is a technique by which fibres can be installed directly within a microduct over distances of up to several kilometres. Using the aerodynamic drag of the flow of air along the duct, a small blower can produce a force of 150 psi, which draws the fibre along the microduct. This is possible due to specially designed fibres that have a rough outer coating that creates a significant drag in one direction, but is very smooth in the other direction.

Figure 18: Inserting Fibres into a Microduct
(Courtesy of OpenNet Pte Ltd)

A group of colour-coded tubes within a sheath of polyethylene forms the microduct. These tubes can then be installed into cable ducts using conventional techniques. Individual microducts are spliced together by fittings to make a continuous path from one end of the cable to the other. At any intermediate point, any or many of these tubes can be brought out from the bundle and diverted off to customers.

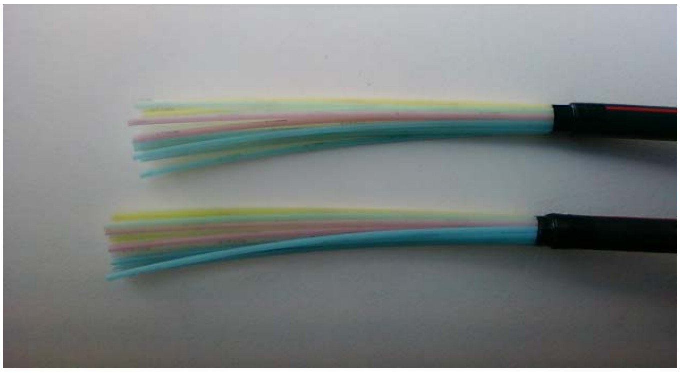

Figure 19: Microducts
(Courtesy of OpenNet Pte Ltd)

One of the advantages of this technique is that the optical fibres are relatively strain-free during installation. As a result, extra strength members are not required. Each microduct can hold about six fibres that can be blown into the duct over existing ones at any time, and this is useful if the number of users increases in the future.

This technique of installing fibres is becoming quite popular throughout the world, especially when it comes to distribution systems in buildings. Fibre cable management in buildings becomes easier as the fibres can be installed as and when they are required. The optical fibres will also have better mechanical protection as they run through risers, ceilings and under raised floors.

9.3 Termination of Fibres

Splice Trays

During field deployment, it is common to splice two sections of fibres together to produce a very low loss and reliable joint. Since a fibre cable usually contains multiple fibres, the fibres are spliced at the same time and the spliced joints are generally housed in splicing trays. The splicing tray is designed to arrange, store and to protect the cable and the splices. These trays also help in providing strain relief to the splices themselves.

Splice trays are found at points along the cabling route where two cables are required to be joined, and they are also frequently found at the termination or patch panel points. At these locations, the incoming cable is brought in and the sheath of the cable is stripped away with the bare fibres showing. The fibres are then looped around in a channel and kept in a splice tray. Using a fusion-splicing machine, the fibres from the incoming cable are spliced to the corresponding fibres of the out-going cable and protected using splice-protection sleeves. Then, the fibres are again looped around in a channel in the tray and then fed out of the tray. The fibres are looped around the tray so that if in future any changes are required, there will be sufficient fibres. It also helps in relieving the tension on the splices. Since these splices have to be protected from the environment, they are sealed inside metal cases. The metal casing usually has a screw-on lid that can be removed to help in making any changes or in order to test the cable. This casing is then completely sealed to prevent moisture ingress, and housed at outdoor junction points or buried. In situations where the fibre cable has reached a termination point, then these fibres are spliced onto fibre pigtails.

Splicing Enclosures

It is always preferable to carry out the splicing of fibres inside a building. The spliced joints should be properly stored inside an equipment rack within the same premises. But this is highly dependent on the length of each fibre cable and may not be possible every time. Hence, splicing may have to be carried out in an open space (where the two cables meet). This may lead to various inconveniences for the maintenance personnel after the cables have been installed.

The splice trays are not designed for an open environment and hence they have to be installed in a special enclosure. The design and performance specification of the enclosure largely depends on the application. A few examples of such enclosures are given below.

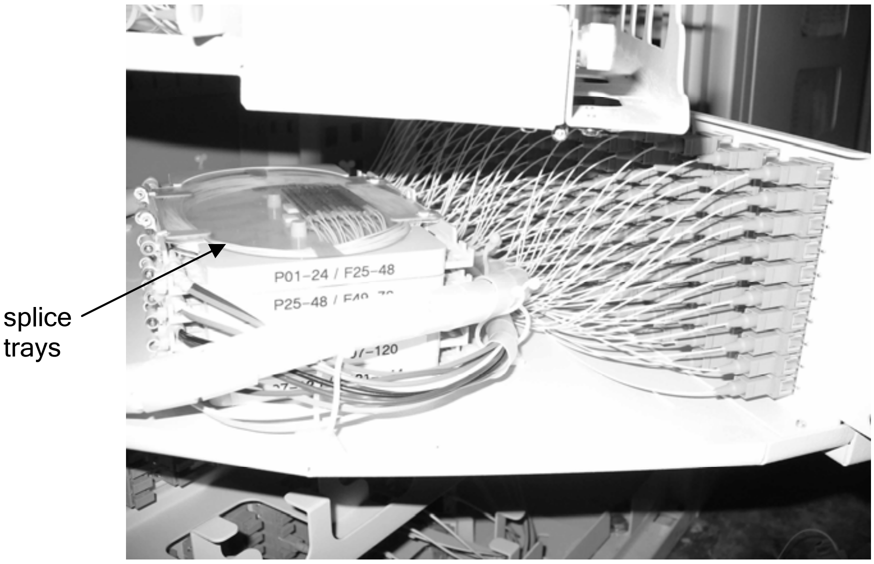

Figure 20: Splice Trays behind a Fibre Optic Patch Panel (Courtesy of OpenNet Pte Ltd)

Outdoor Cases

Buried Cylinder Enclosures

After the fibres are spliced, the splice trays are installed in a tightly sealed heavy-duty plastic or metallic cylindrical enclosure. These containers are completely sealed so as to prevent moisture ingress, and they can be equipped with packets of moisture-absorbing chemicals to absorb any moisture that may be present in the container. These cases could be stored in the junction points, which are located in pit boxes or manholes.

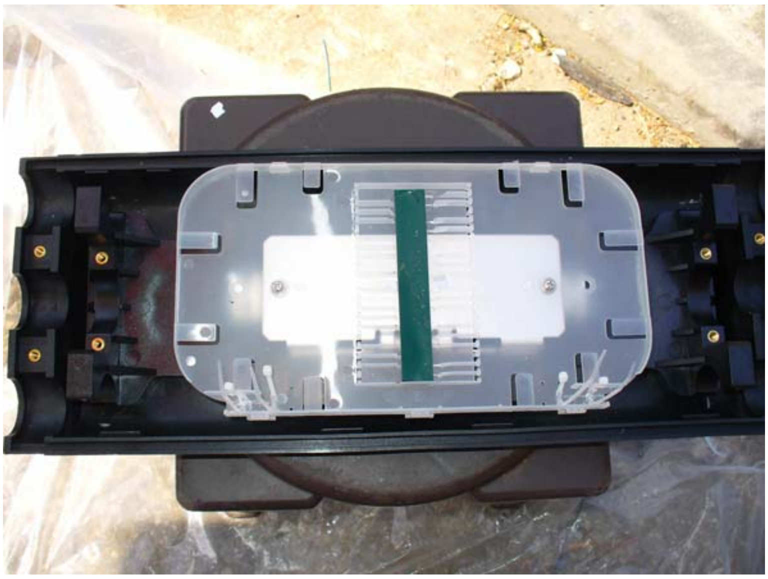

Figure 21: Interior of a Buried Enclosure (Courtesy of OpenNet Pte Ltd)

Indoor Cases

For indoor environments, the splice tray is placed inside a metal or plastic box with a lid that is screwed on. These boxes are normally attached onto a wall or are installed inside an equipment rack.

Figure 22: Photograph of a Wall-mounted Fibre Termination Box (Courtesy of OpenNet Pte Ltd)

Figure 23: A Wall-mounted Fibre Distribution Box (Courtesy of OpenNet Pte Ltd)

Termination Cabinets

At any junction point where a lot of cables come together and have to be terminated, the splice trays and/or terminated fibres are stored in a large cabinet. In cases where this cabinet has to be installed outdoors, care must be taken that the cabinet is properly protected against bad weather conditions.

Figure 24: The Interior of a Termination Cabinet
(Courtesy of OpenNet Pte Ltd)

Sometimes, splice trays may be fixed to the back of patch panels and distribution enclosures, called Fibre Optic Break-Out Tray (FOBOT), to enable the connection of patch cords to the main incoming cable.

Termination of Fibres in Patch Panels and Distribution Frames

The most common technique for connecting incoming cables into FOBOTs is to splice each fibre from the incoming cable to pre-connected fibre pigtails. This helps in reducing the stress on the incoming fibres and results in very low losses in the link.

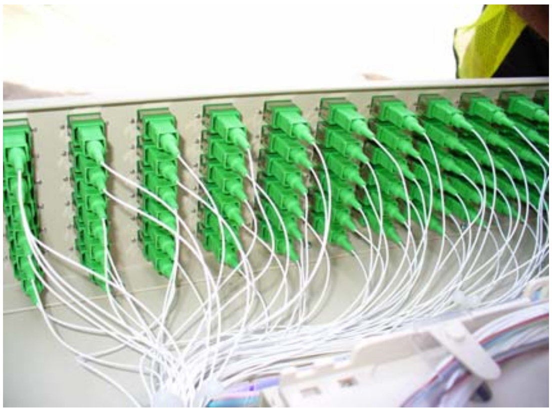

Figure 25: Photograph of a Patch Panel with Pigtailed Termination
(Courtesy of OpenNet Pte Ltd)

Another technique is to place the fibres from the incoming cable directly into a FOBOT. The FOBOT separates the fibres, and these fibres can be fitted into a plastic tube that can provide protection and strength when the fibres are looped to the front of the patch panel. In this case, the losses are even lower as there are no splices involved. The disadvantage is that this procedure is extremely time consuming and involves a great deal of manual labour and technical skill. It may lead to variations in the quality of the connectors and may indirectly introduce extra losses.

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Annex A

Corrigendum / Addendum

Changes to IDA RD OFD - Part 2 Issue 1, Jul 10			
Page	**RS Ref.**	**Items Changed**	**Effective Date**
—	—	Change of IDA's address at cover page to Mapletree Business City.	1 May 11