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Edition 2.0 2016-06

TECHNICAL REPORT

Optical fibre cables –
Guidelines to the installation of optical fibre cables

colour inside

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

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INTERNATIONAL
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OPTICAL FIBRE CABLES –

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FOREWORD

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IEC TR 62691, which is a Technical Report, has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics.

This second edition cancels and replaces the first edition published in 2011. It constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) more details have been added on cables for lashed applications (transferred from IEC 60794-3-10);
b) more details have been added on cables for storm and sanitary sewer applications (transferred from IEC 60794-3-40);
c) more details have been added on cables for high pressure gas pipe applications (transferred from IEC 60794-3-50);

d) more details have been added on cables for drinking water pipe applications (transferred from IEC 60794-3-60);

e) a reference to IEC TR 62263 has been included, concerning optical cables installation on high voltage power lines;

f) a revision, and an update when applicable, has been done on the referred documents.

The text of this Technical Report is based on the following documents:

Enquiry draft	Report on voting
86A/1721/DTR	86A/1730/RVC

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

Optical fibre cabling provides a high performance communications pathway whose characteristics can be degraded by inadequate installation. This Technical Report provides guidance to assist the user and installer with regard to the general aspects of the installation of optical fibre cables covered by the IEC 60794 series, and the particular aspects of the "blowing" technique.

Optical fibre cables are designed so that normal installation practices and equipment can be used wherever possible. They do, however, generally have a strain limit rather lower than metallic conductor cables and, in some circumstances, special care and arrangements can be needed to ensure successful installation.

It is important to pay particular attention to the cable manufacturer's recommendations and stated physical limitations and not exceed the given cable tensile load rating for a particular cable. Damage caused by overloading during installation may not be immediately apparent but can lead to failure later in its service life.

This document does not supersede the additional relevant standards and requirements applicable to certain hazardous environments, for example electricity supply and railways.

OPTICAL FIBRE CABLES –

Guidelines to the installation of optical fibre cables

1 Scope

IEC TR 62691, which is a Technical Report, gives recommendations for handling and installing optical fibre cables on metropolitan communication networks. Installation methods covered by this document include underground ducts, trenchless technique, blowing in microducts, aerial installation on poles, lashed aerial in metropolitan networks, direct buried and use of trenches.

Special installation situations such as tunnelling and lead-in installations, on-bridges, underwater, use of sanitary sewers, high pressure gas pipes and drinking water pipes are commented and detailed.

Installation and maintenance of optical fibre cables on overhead power lines including the following are not covered by this document and are referred to in IEC TR 62263:

- optical ground wire (OPGW) fibre cable;
- optical phase conductor (OPPC) fibre cable;
- optical attached fibre cable (OPAC);
- all dielectric self-supporting (ADSS) optical fibre cable.

IEC TR 62263 includes an extensive coverage on recommendations to ensure the safety of personnel and equipment when installing or maintaining these types of optical fibre cables on overhead power lines.

2 Normative references

There are no normative references in this document.

3 Installation planning

3.1 Installation specification

The successful installation of an optical fibre cable can be influenced significantly by careful planning and assisted by the preparation of an installation specification by the user. The installation specification should address the cabling infrastructure, cable routes, potential hazards and installation environment and provide a bill of materials and technical requirements for cables, connectors and closures.

The installation specification should also detail any civil works, route preparation (including drawpits, ductwork, traywork and trunking) and surveying that are necessary, together with a clear indication of responsibilities and contractual interfaces, especially if there are any site or access limitations.

Post-installation requirements for reinstatement, spares, ancillary services and regulatory issues should also be addressed.

3.2 Route considerations

Whilst optical fibre cables are lighter and installed in longer lengths than conventional metallic cables, the same basic route considerations apply.

Route planning and cable handling methods shall carefully take into account the specified minimum bending radius and maximum tensile loading of the particular optical fibre cable being installed so that fibre damage, giving rise to latent faults, can be avoided.

Some of the most difficult situations for the installation of optical fibre cables are in underground ducts, and the condition and geometry of duct routes are of great importance. Where the infrastructure includes ducts in poor condition, excessive curvature, or ducts already containing cables or access points with abrupt changes of direction, the maximum pull distance will be reduced accordingly.

As provision of long cable lengths in underground duct or aerial situations may involve installation methods that require access to the cable at intermediate points for additional winching or blowing effort, or "figure-8" techniques, these sites should be chosen with care. Consideration should also be given to factors of time and disturbance. Installation equipment may be required to run for long periods of time, and the time of day, noise levels, and vehicular traffic disruption should be taken into account.

Because the condition of underground ducts intended for optical fibre cable is of particular importance, care should always be taken to ensure that ducts are in sound condition and as clean and clear as possible. Consideration can also be given to the provision of a subduct system, either in single or multiple form, to provide a good environment for installation, segregation of cables, extra mechanical protection and improved maintenance procedures. Subducts can be more difficult to rope and cable than normal size ducts, particularly over long lengths, and the diameter ratio between the cable and subduct should be considered. Note that in ducts or subducts, bundles of microducts can also be installed, for example by pulling or blowing.

For overhead route sections, a very important consideration is the need to minimise in-service cable movement. Movement of the cable produced by thermal changes, cable weight, ice loading, wind, etc. may have a detrimental effect. A stable pole route, with all poles set as rigidly as possible, is therefore an important element in reducing possible movement, and consideration should be given to purpose-designed, optical fibre-compatible, pole top fittings and attachments.

Although optical fibre cables are generally light in weight, their addition to an existing suspension member can take the optical fibre beyond its recommended strain limit, and the added dip and extension should be calculated before installation.

Where it is planned for long lengths of optical fibre cable to be directly buried or ploughed, those sections involving ploughing can, with advantage, be pre-prepared using specialised slitting or trenching equipment.

3.3 Cable installation – Tension considerations

The potential for providing very long lengths of optical fibre cable can lead to the need for confidence that a particular installation operation will be successfully achieved, particularly in underground ducts, and a good indication can be provided, in some cases, by calculating the maximum cable tension. This maximum tension can be compared with the stated mechanical performance of the cable and, where these values are close, consideration can be given to methods for providing a greater margin of safety such as an alternative cable design, shortening the route, changing the route or direction of cabling, provision of intermediate winches, or by taking special precautions at particular locations. Calculation considerations are indicated in 3.4 and 3.5.

Cable tensions in ploughing or trenching are generally minimal, much smaller than the rated tension of the cable. Momentary tensions and jerking due to cable reel inertia when paying off cables, which result in tensions in the immediate area being installed, should be considered. In ploughing, frictional tension through the plough chute shall be considered, but is generally small.

Cable compression and buckling in pushing and blowing should also be considered. Cable compression less than a critical maximum value generally has no effect on cable performance. Excessive pushing – either due to pushing or blowing – may cause the cable to corkscrew in the duct or fold over, which will damage the fibre. Considerations to be taken in account are:

- cable with smaller diameters will require a lower maximum push force;
- the maximum cable push force will also decrease with larger duct inside diameters.

In either case, a crash test per the cable and installation equipment manufacturers' procedures should be performed to determine the maximum push force.

See 3.5 and 3.6 for guidance on friction forces consideration during installation.

3.4 Duct installations – Cable tension predictions

It should be noted that the tension calculations for duct installations are of inexact necessity since the actual geometry and characteristics of the ducts are seldom well known. The calculations, therefore, should be utilized with regard to experience and empirical data from similar installations.

Two sets of equations are presented below. The first, presented in 3.5.2, is used to calculate cable tension in pulling applications. The second, presented in 3.5.3, is used to calculate cable tension in cable pushing and blowing applications; it may also be used for pulling. Note that the first set, for pulling only, is much simpler and neglects cable weight in Equation (3). The second set, for any of the duct installation methods, comprises very complex equations involving much more data, including amplitude and frequency of innerduct undulations. Much of this data is generally not known and shall be estimated from cable experiments and empirical data from similar installations.

3.5 Maximum tension or compression force exerted on cable

3.5.1 General

The following main contributory functions need to be considered when calculating cable forces-tensions or compression:

- the mass per unit length of cable;
- the diameter of the cable;
- the stiffness of the cable;
- the coefficient of friction between cable sheath and surfaces with which it will come in contact;
- the inner diameter of the duct;
- deviations (bends and undulations) and inclinations.

3.5.2 Total cable tension – pulling applications

The calculated cable tension or compression force should be evaluated with respect to the maximum rated cable tension (for pulling) or the maximum pushing force or crash force (for pushing or blowing) for the cable being installed according to the cable specification or the manufacturer's declared rating.

Figure 1 shows an example of routes and common tension formulae (see Equations (1) to (3)):

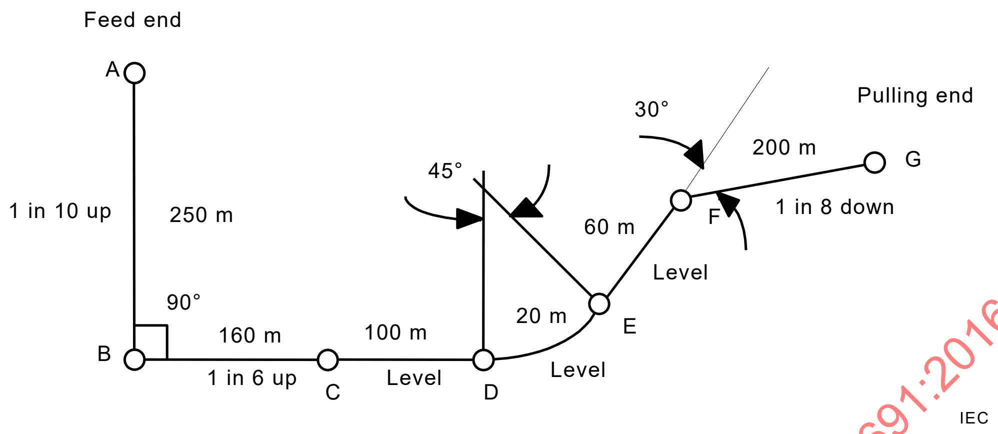


Figure 1 – Cable tension calculations (Equations (1) to (3))

Equation (1) is used for straight sections, Equation (2) for inclined sections and Equation (3) for deviated sections and bends.

$$T = T_i + \mu lwg \tag{1}$$

$$T = T_i + lwg\,(\mu \cos\theta + \sin\theta) \tag{2}$$

$$T = T_i \exp\,(\mu\theta) \tag{3}$$

where

T is the tension at end of section (N);

T_i is the tension at beginning of section (N);

μ is the coefficient of friction (between cable and duct or guide);

l is the length of section (m);

w is the cable specific mass (kg/m);

θ is the inclination (radians, + up, – down) or deviation (radians, horizontal plane);

g is the acceleration due to gravity (9,81 m/s^2);

The resulting total tensions calculations are shown in Table 1:

Table 1 – Calculation for total tension

Section	Length	Tension at beginning of section T_i	Inclination	Deviation	Equation	Tension at end of section (cumulative) T
	m	N	rad	rad		N
A	–	0	–	–	–	0
A – B	250	0	0,100	–	2	1 460
B	–	1 460	–	1,571	3	3 464
B – C	160	3 464	0,165	–	2	4 484
C	–	4 484	–	–	–	4 484
C – D	100	4 484	–	–	1	4 980
D	–	4 980	–	–	–	4 980
D – E	20	4 980		0,785	3	7 669
E	–	7 669	–	–	–	7 669
E – F	60	7 669	–	–	1	7 967
F	–	7 967		0,524	3	10 628
F – G	200	10 628	0,124	–	2	11 390
Where more than one cable per duct is installed, tension can be greatly raised, and it is necessary to take account of this by applying a factor before the deviation calculation. Factors vary with the number of cables, sheath/cable materials, cable/duct sizes, cable flexibility, etc. Values can be in the order of 1,5 to 2 for two cables, 2 to 4 for three cables and 4 to 9 for four cables.						

3.5.3 Total cable tension – pushing, blowing, or pulling applications

3.5.3.1 General

Total tension can be calculated on a cumulative basis working through each section from one end of the route to the other. Calculation is done using the common tension and blowing formulae listed below:

$$F = \frac{WP^2}{8\pi A}\sinh\left[\frac{8\pi A f l}{P^2} + \sinh^{-1}\left(\frac{8\pi A}{WP^2}F_i + \frac{3AB}{2W(P/4)^4}\right)\right] - \frac{48B}{\pi P^2} \qquad \text{(4) (horizontal pulling)}$$

$$F = \left(F_i \pm \frac{WP^2}{8\pi f A} + \frac{48B}{\pi P^2}\right) e^{\frac{8\pi f A}{P^2} l} \mp \frac{WP^2}{8\pi f A} - \frac{48B}{\pi P^2} \text{ (+ .. – for upwards)} \qquad \text{(5) (vertical pulling)}$$

$$F = F_i e^{f\theta} + \frac{2Bf}{\sqrt{6(D_d - D_c)R_b^3}} \qquad \text{(6) (deviations and bends)}$$

$$\frac{dF}{dx} = f\sqrt{(W\cos\alpha)^2 + \left[\frac{3AB}{2(P/4)^4} + \frac{8\pi A}{P^2}F\right]^2} + W\sin\alpha \qquad \text{(7) (inclined pulling)}$$

$$\frac{dF}{dx} = f\sqrt{(W\cos\alpha)^2 + \left[\frac{3AB}{2(P/4)^4} + \frac{8\pi A}{P^2}F\right]^2 + \left(\frac{D_d - D_c}{\pi^2 B}F^2\right)^2} + W\sin\alpha \qquad \text{(8) (inclined pushing)}$$

$$\frac{dF}{dx}=f\sqrt{(W\cos\alpha)^2+\left[\frac{3AB}{2(P/4)^4}+\frac{8\pi A}{P^2}F\right]^2+\left(\frac{D_d-D_c}{\pi^2 B}F^2\right)^2}+W\sin\alpha-\frac{\pi D_c D_d\left(p_i^2-p^2\right)}{8l\sqrt{p_i^2-\left(p_i^2-p^2\right)\frac{x}{l}}}$$

(9) (blowing; inclined)

where

F is the force at end of section (N);

F_i is the force at beginning of section (N);

f is the coefficient of friction, COF (between cable and duct or guide);

m is the cable specific mass (kg/m);

l is the length of duct (m);

W is the cable specific weight = gm (N/m);

g is the acceleration of gravity (9,81 m/s^2);

B is the cable stiffness (Nm^2);

D_c is the cable diameter (m);

D_d is the duct inner diameter (m);

A is the amplitude of duct-undulations (m);

P is the period of duct-undulations (m);

R_b is the bending radius of bend (m);

θ is the deviation of bend (radians, horizontal plane);

α is the inclination (radians, + up, – down);

p_i is the air pressure (absolute) at beginning of section (N/m^2);

p is the air pressure (absolute) at end of section (N/m^2);

x is the position in the section (m).

Equations (4), (5) and (6) are analytical solutions; Equations (7), (8) and (9) have to be solved numerically.

Figure 2 shows an example of a cable with diameter of 18 mm, weight of 2 N/m and stiffness 5 Nm^2, which is installed in a 40/33 mm duct of 2 000 m total length laid in the trajectory below (the red sections are vertical):

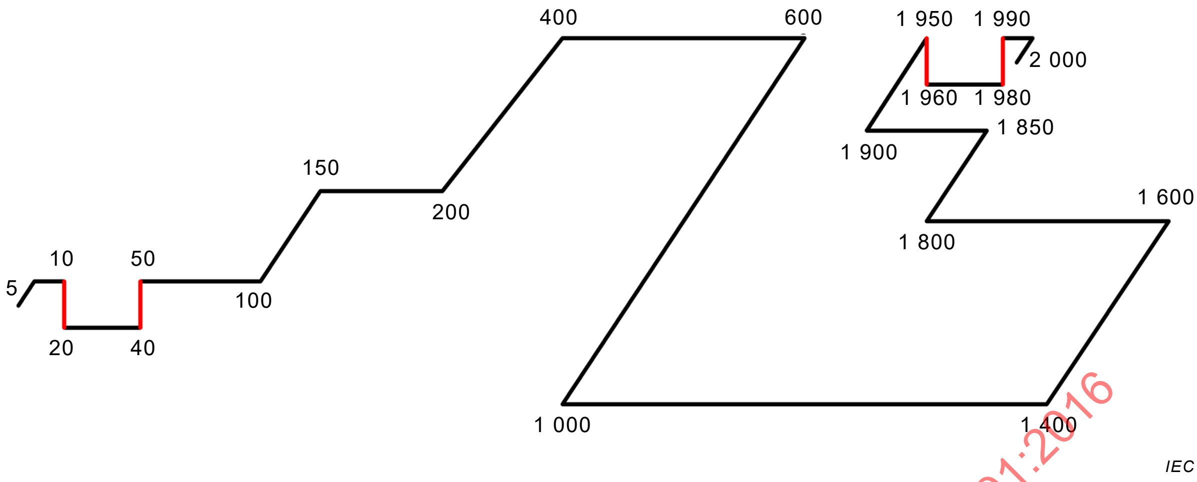


Figure 2 – Cable tension calculations (Equations (4) to (9))

The coefficient of friction (COF) between cable and duct is 0,1, the (right-angled) bends in the trajectory are of radius of 1,2 m and the straight sections still make undulations with amplitude of 5 cm and period of 8 m.

IEC TR 62470 describes techniques to measure the coefficient of friction between cables and ducts.

3.5.3.2 Pulling force

The pulling force is calculated for the situation where the winch is placed at the beginning of the trajectory. The cable is placed somewhere in the field. The pulling force is calculated for one location of the cable, at 1 100 m, with the boundary condition that the cable enters the duct without any tension as shown in Table 2.

Table 2 – Calculation for pulling force in Figure 2

Position m	Pulling force N
1 100	0
1 000, before bend	20
1 000, after bend	26
600, before bend	127
600, after bend	151
400, before bend	236
400, after bend	279
200, before bend	421
200, after bend	495
150, before bend	547
150, after bend	642
100, before bend	709
100, after bend	833
50, before bend	920
50, after bend	1 079
40, before bend	1 080
40, after bend	1 266

Position m	Pulling force N
20, before bend	1 317
20, after bend	1 544
10, before bend	1 595
10, after bend	1 869
5, before bend	1 887
5, after bend	2 210
0	2 232

In Figure 3, the pulling force is also plotted for other lengths.

3.5.3.3 Pushing force

The pushing force is calculated for the situation where the pushing device is placed at the beginning of the trajectory. The cable is placed at the same location. The pushing force is calculated for one location of the cable, at 450 m, with the boundary condition that the pushing force at the cable end is zero as shown in Table 3.

Table 3 – Calculation for pushing force in Figure 2

Position m	Pushing force N
450	0
400, before bend	10
400, after bend	14
200, before bend	59
200, after bend	72
150, before bend	86
150, after bend	103
100, before bend	131
100, after bend	156
50, before bend	202
50, after bend	239
40, before bend	282
40, after bend	333
20, before bend	415
20, after bend	488
10, before bend	558
10, after bend	655
5, before bend	720
5, after bend	845
0	950
NOTE The available software only gives the end-result of 950 N.	

In Figure 3, the pushing force is also plotted for other lengths.

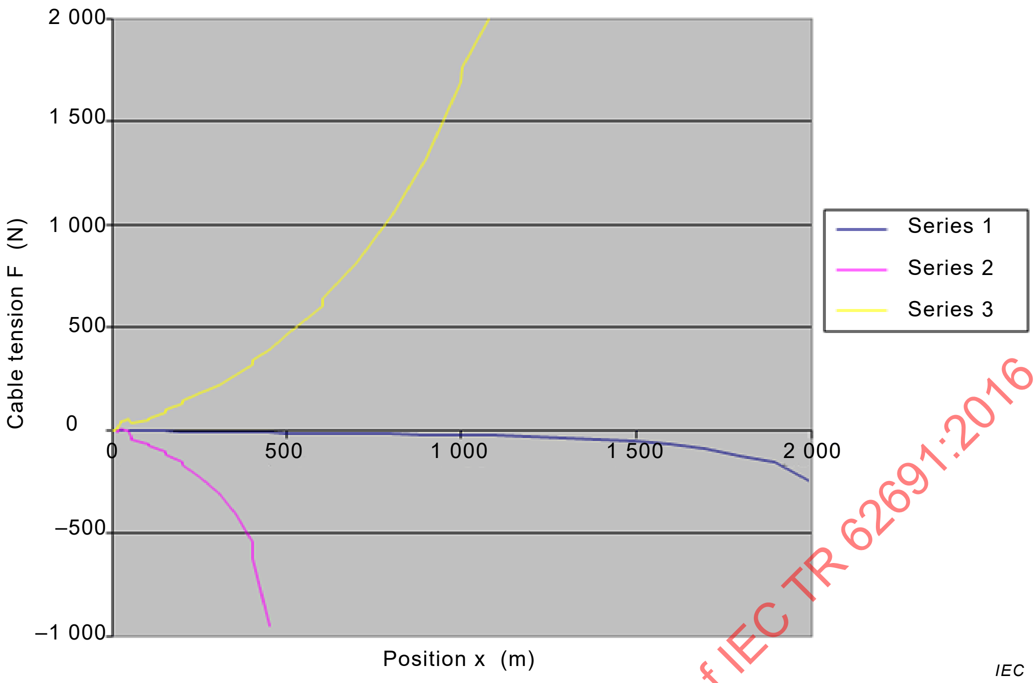
3.5.3.4 Blowing force

The blowing force is calculated for the situation where the blowing device is placed at the beginning of the trajectory. The cable is placed at the same location. The calculation is done for a pressure at the cable inlet of 12 bar relative to atmosphere (13 bar absolute) and the duct open at 2 000 m. Note that the calculation starts with the cable-end at the "critical point", the position where the pushing force reaches a maximum, at the bend at 1 000 m (beyond this position, the airflow propelling forces become larger than the friction forces). The calculation does not take into account the effect of the filling of the duct with cable on the airflow (which shifts the critical point to a position further in the trajectory), which makes the calculation worst case. In this example, the full 2 000 m can be bridged by blowing. This is illustrated in Table 4.

Table 4 – Calculation for blowing force in Figure 2

Position m	Pushing force N
1 000, before bend	0
1 000, after bend	2,5
600, before bend	5
600, after bend	8
400, before bend	13
400, after bend	18
200, before bend	26
200, after bend	34
150, before bend	38
150, after bend	47
100, before bend	52
100, after bend	64
50, before bend	70
50, after bend	85
40, before bend	108
40, after bend	130
20, before bend	136
20, after bend	161
10, before bend	142
10, after bend	169
5, before bend	171
5, after bend	204
0	208

In Figure 3, the pushing force is also plotted for other lengths. Note that calculation is still done with the duct open at the corresponding lengths. Also note that the plotted pushing force in Figure 3 is a little higher than the force in the Table 3. The forces plotted in Figure 3 are obtained with software that also takes into account that the cable end needs a little higher pushing force when exactly in the bend than when passed. This is why a bend is picked as the critical point, while the airflow propelling forces are already a little higher than the friction forces.



Series 1 blowing

Series 2 pushing

Series 3 pulling

Figure 3 – Cable tension calculations

3.6 Installation temperature

Installation temperature may affect installation procedures and it is good practice to install optical fibre cables, particularly in long lengths only when the temperature is within the limits set by the particular cable manufacturer.

The mechanical properties of optical cables are also dependent on the temperature and the materials used in their construction. Typically, cables containing PVC in their construction should not be installed when their temperature is below 0 °C, whilst cables incorporating polyethylene can be installed when their temperature is down to –15 °C. For most cables, the upper installation temperature limit is +50 °C. Unless special measures are taken, cables should not have been exposed to temperatures outside the specified installation temperature range for a period of 12 h prior to installation.

NOTE Polyethylene which is used as a common sheath material starts softening around 50 °C. Thus, the coefficient of friction increases remarkably. This will impact installation performance (pulling, pushing, blowing) negatively. In general, PVC sheathed cables have a poorer installation capability than PE cables, especially at elevated temperature.

3.7 Information and training

Methods and practices used in the handling of optical fibre cables during installation can, without producing any immediately obvious physical damage or transmission loss, affect their long-term transmission characteristics.

Technicians involved in installation procedures should be made fully aware of the correct methods to employ, the possible consequences of employing incorrect methods, and have sufficient information and training to enable cables to be installed without damage to fibres.

In particular, installation crews should be made aware of minimum bending criteria, and how easy it is to contravene these when installing by hand.

4 Cable installation methods

4.1 General considerations

Optical fibre cable can be installed using the same or similar general methods employed for metallic cables but with more attention required to certain aspects such as long lengths, cable bending and cable strain. It may be necessary to employ particular methods and equipment in some circumstances. Optical fibre shall be protected from excessive strains, produced axially or in bending, during installation; various methods are available to do this. The aim of all optical fibre, cable-placing methods and systems should be to install the cable with the fibre in an as near as possible strain-free condition, ready for splicing.

Other general precautions:

- delivery of cable to site should be monitored to ensure that no mechanical damage occurs during off-loading from vehicles;
- storage conditions should be suitable, taking into account mechanical and environmental considerations;
- documentation should be checked to ensure that cable delivered is in accordance with the procurement specification;
- suitable protective caps should be fitted to the exposed ends of the optical cable. End caps should be handled carefully to avoid damage during installation, and any damaged caps should be repaired or replaced.

4.2 Safety in confined spaces

During the installation of optical fibre cables, it may be necessary to work in confined spaces such as manholes, underground passageways, tunnels and cable ways and areas where air circulation is poor or where entry and exit is difficult.

Where the possibility of working in confined spaces exists, it is necessary to consider any health and safety hazards that may be present, such as explosive, asphyxiating or toxic gases, lead, asbestos, and ensure that any additional safety equipment and/or instruction is provided prior to the commencement of work.

4.3 FTTX installation

Along the network, several branching points can be found. The diagram in Figure 4 illustrates different types of infrastructure in a typical metropolitan optical network. The last distribution point, the one that delivers the service to the user, closes the gap between distribution cables starting at the network access point (NAP)) and the user´s home (FTTH), multi dwelling units (FTTMDU), buildings (FTTB), or other premises. Drop cables are used for this application and may be deployed as aerial cables, duct cables, direct buried cables, as well as on facades, on either outside the building or inside the building, being sometimes of indoor/outdoor type. Details on the application spaces, the selection and the performance requirements for drop cables can be consulted in IEC TR 62901. Also, the cell tower (FTTT) and cell antenna (FTTA) are being considered as last distribution point for fibre.

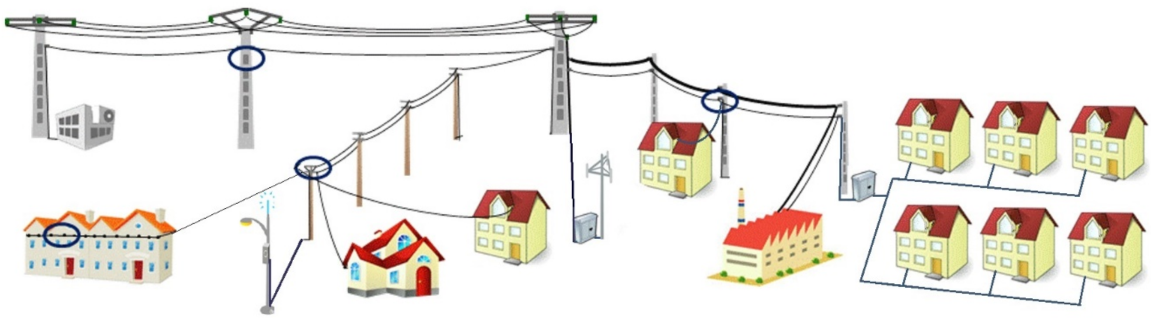


Figure 4 – FTTX applications

4.4 Pre-installation procedures

Before installation commences, the installer should carry out the following checks.

- establish that the routes defined in the installation specification are accessible and available in accordance with the installation programme. The installer should advise the user of all proposed deviations.
- establish that the environmental conditions within the routes and the installation methods to be used are suitable for the design of optical cable to be installed.
- determine any measures necessary to prevent the optical fibre within the optical cable from experiencing direct stress following installation. Where long vertical runs are proposed, optical cables may need to deviate from the vertical at intervals as recommended by the manufacturer (by the inclusion of short horizontal runs, loops or support arrangements).
- determine the proposed locations at which drums (or reels) shall be positioned during the installation programme and establish the accessibility and availability of those locations.
- make sure the pay-off will be positioned in such a manner that the cable will be de-reeled at right angles to the axis of the drum spindle (parallel to the drum flanges).
- identify proposed locations of service loops and establish their accessibility and availability in accordance with the installation programme.
- ensure that all necessary installation accessories are available.
- identify proposed locations of closures and establish their accessibility and availability in accordance with the installation programme.

The closures should be positioned so that subsequent repair, expansion or extension of the installed cabling may be undertaken with minimal disruption and in safety.

4.5 Installation of optical cables in underground ducts

4.5.1 Application

Outside-plant optical cable is usually installed by trenching technique. Trenching involves digging along the path, placing the optical cable in the hole and refilling it to set the cable protected. A variation consist in laying a conduit in the trench to then pull inside the optical cable. The availability of a duct between locations enables to later pull additional cables without the need of trenching again. A typical underground duct installation is shown in Figure 7.

As trenching is not a quick process and usually implies traffic for several days when deploying in metropolitan areas, some variations have been proposed to deploy optical cables with reduced dimensions, at lower cost, more efficiently and faster, such as micro-trenching which involves the use of a saw to create a typically 1,5 cm to 3,0 cm wide per 6 cm to 12 cm depth narrow trench in the sidewalk or street asphalt. A fibre optic cable of reduced dimensions can be laid directly into the saw cut, or a mini-conduit can be buried to air-blow micro-fibre units into the conduit. Additional information on micro-trenching technique can be consulted in ITU-T L.48. Fibre blowing is commented in 4.5.9 and 4.10.

4.5.2 Installation using trenchless technique

Installation of ducts using trenchless techniques allow installation of underground telecommunication network infrastructures minimizing or eliminating the need for excavation. Trenchless techniques can reduce environmental damage and social costs and, at the same time, provide an economic alternative to installing ducts by digging methods.

Available trenchless techniques comprise:

- guided boring/directional drilling;
- impact moling;
- pipe ramming;
- pipejacking;
- microtunnelling.

These techniques are described in detail in ITU-T L.38.

4.5.3 Cable overload protection methods

A general guidance instruction for optical cables installation is to attach the strength member of the cable, if existent, to the pull line. Where all actions and precautions have been taken to protect the cable and its fibres from excessive load as far as suitability of route, guiding etc. is concerned, then there still remains the possibility, in the dynamics of an installation operation, for high loads to be applied to the cable, and it may be advisable to provide a cable overload prevention mechanism. Two classes of device provide this protection: those situated at the primary or intermediate winch and those at the cable/rope interface. Those at the winch include (depending on winch type) mechanical clutches, stalling motors and hydraulic bypass valves, which can be set to a predetermined load, and the dynamometer/cable tension monitoring type systems to provide feedback for winch control. Those at the cable/rope interface include mechanical fuses (tensile or shear) and sensing devices to provide winch control information. All these systems have a common aim of limiting or stopping the winching operation when loads applied on the cable approach a damaging level.

4.5.4 Cable bending and guiding systems

To avoid subjecting cables and optical fibres to unacceptable bending stresses, the cable manufacturer's recommendations regarding bending diameters should be observed during pulling and installation. Guiding equipment should be used at bends in the cable route and at duct entrances so that the minimum bending diameter recommended for the particular cable type is observed.

Bending optical fibre cable under tension during installation should be undertaken with care. Guiding systems and equipment should be examined for their suitability for purpose and properly take into account cable manufacturer's stated bending criteria. In general, a minimum bending diameter of around 20 times the cable diameter is considered appropriate but when being installed under tension, it is suggested that this ratio may be doubled. Most guiding equipment can be used for both optical fibre and metallic cables but long length placing may require many guiding elements, and they should all have the properties of lightness and low friction.

4.5.5 Winching equipment and ropes

Provided the need for overload protection is borne in mind, most normal, speed-controlled cable winching equipment and systems are suitable for installing optical fibre cables in ducts. These include end-pull winches, with various types of primary mover, intermediate winches for longer length schemes and, where necessary, powered cable feeding equipment. Where intermediate winches (capstan or caterpillar) and/or powered cable feeding equipment are used, a method of synchronization, to prevent excessive fibre strain, should be employed, and it should be borne in mind that some intermediate capstan type winches can introduce a twist into the cable. Ropes or lines of low specific weight and a high modulus of elasticity are necessary for optical fibre cabling. Placing long lines or ropes can be difficult but can usually be accomplished by successively using normal installation methods. Lines or ropes shall be placed with care where there are already optical fibre cables in a duct, and knots shall be avoided.

Cable winches should be capable of providing varying rope speeds, particularly with regard to low starting speeds, and should be equipped with a calibrated winch-line dynamometer (or a tension sensor or mechanical fuse can be fitted at the beginning of the cable). The maximum installation force shall be limited to the safe working load of the cable as measured at the winch-line dynamometer or the tension sensor at the beginning of the cable. The winch shall be provided with a tripping device that automatically stops the winch if the installation force exceeds the pre-set tension limit. If a mechanical fuse is used, it shall be designed to break at the maximum safe working load of the cable.

If a capstan type intermediate puller is used, the diameter of the capstan should be greater than or equal to the minimum bending diameter of the cable.

To reduce twisting during installation, the pulling end of the cable can be connected to the end of the winch rope via a twist compensation device, for example a rotary shackle or a rope socket with a swivel. When pulling the cable with a winch, the pull should be started with a low rope speed. Pulling speed can be gradually increased up to the maximum speed of 75 m/min when there is no danger that the maximum permissible tensile loading for the cable will be exceeded.

Factory-fitted "pulling eyes" should be capable of pulling a cable at its rated tensile load without failure. If the cable is not already provided with a pulling eye, a cable sock-type grip shall be fitted to the pulling end of the cable, whose eye shall be fitted to the winch rope by means of a rotary shackle, and whose minimum safe working load is greater than the maximum allowable cable tension. The cable grip can be fitted directly onto the outer sheath when the latter is secured internally to the strength members, as illustrated in Figure 5. Strength members which are not sufficiently coupled to the outer sheath shall be provided with a connection for high tensile loading when such loading is anticipated.

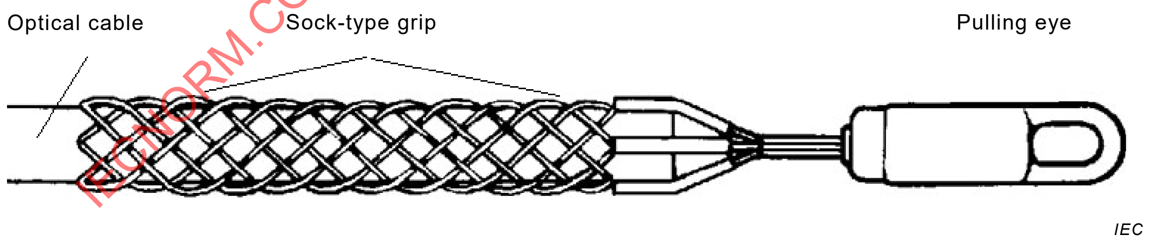


Figure 5 – Cable with fitted sock-type grip

Factory-fitted pulling eyes and cable grips intended to protect pre-connectorized cable should not pass around capstans or pulleys whilst the cable is under tensile load. Sock-type grips installed on the cable sheath may be pulled around capstans and pulleys unless prohibited by local practices.

4.5.6 Cable friction and lubrication

Special attention should be paid to friction and lubrication when installing optical fibre cables. The friction forces which shall be overcome are related to several factors, primarily the materials and finishes of the cable sheath, duct, cabling rope or line and guiding elements, and all can contribute significantly to the total installing force required. Lubrication can have beneficial effects in reducing the total installing force needed, and attention should be paid to both the rope/duct and cable/duct interfaces, and steps taken to ensure that the rope/cable attachment point presents a smooth profile. Any lubrication system employed shall have long-term compatibility with cable, rope and duct material and be safe from an occupational health point of view.

4.5.7 Cable handling methods to maximise installed lengths

Where it is not possible, because of load limitations, to install long length optical fibre cables using a single end-pull, it may be necessary to employ a method of dividing the load along the cable length, and this can be done, depending on circumstances, by either static or dynamic methods.

The most common static method is known as the "figure-8" system. This procedure requires that the cable drum be placed at an intermediate point and the cable drawn in one direction of the route using normal end-pull techniques. The remaining cable is then removed from the drum and laid out on the ground in a figure-of-eight pattern. The figure-of-eight pile shall be flipped over for access to the outside end.

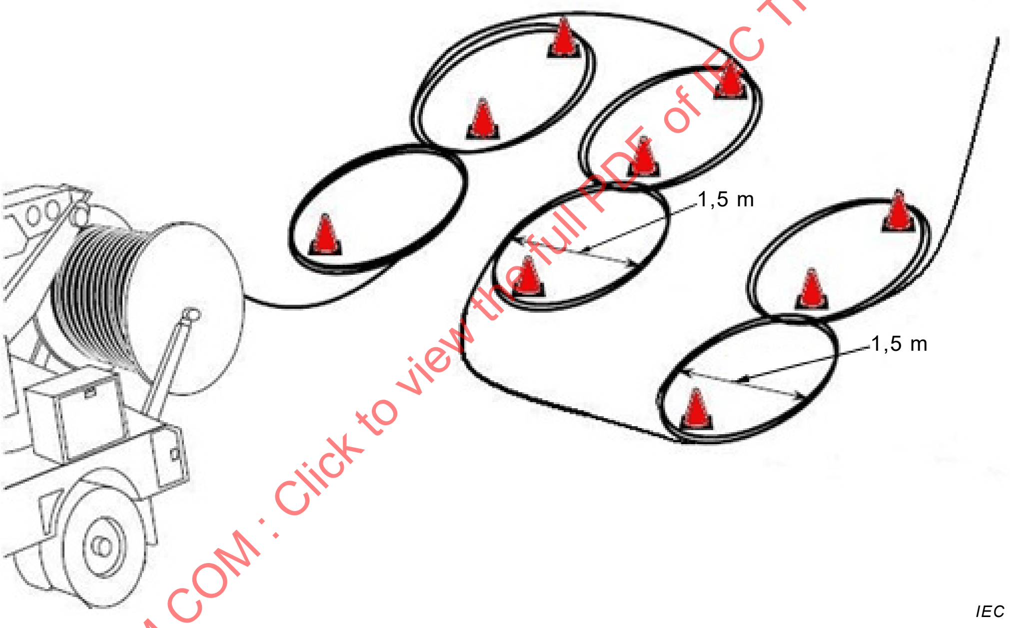


Figure 6 – The "figure-8" system

For long pulls, an intermediate pulling and "figure-8" operation may be performed using a capstan winch at intermediate points (see Figure 6). As the cable is pulled off from the low-tension side of the capstan winch, it is laid out on the ground in a figure-of-eight pattern. At the end of the pull, the figure-of-eight shall be flipped over to access the outside cable end. The winch is then moved to the next pulling point, and the operation repeated as many times as necessary. At the final section, the winch is moved to the other end of the section and the laid out cable is drawn in for the final time.

The winch is then moved to the other end of the section and the laid out cable is drawn in using the same end-pull method. This method requires appropriate space at the "figure-8" point.

Dynamic load sharing is more complicated and requires more equipment and setting-up; however, it has the advantage of allowing installation in one direction straight from the drum. In this process, special cable winches or urgers are employed at intermediate points, and the maximum load on the cable is related to the distance between these intermediate points. It should be borne in mind that with intermediate winching, all the installing forces are transmitted through the cable sheath, and the design of a particular cable being placed by this method should take this into account. Intermediate or distributed winching systems require good co-ordination, synchronisation and communication between the intermediate points. Capstan-type intermediate winches may introduce additional cable twisting.

Hand-pulling methods can be employed at intermediate points on long length optical fibre cable installations, but great care shall be taken to ensure that specified bending and other mechanical criteria are not contravened.

4.5.8 Jointing length allowance

It is important, when installing optical fibre cable lengths in underground ducts, to make proper arrangements for an adequate extra length of cable at the access point for testing and jointing. This additional length, at each end of the cable, is normally greater than that allowed for metallic cables and should not include that part of the cable used for the rope attachment which is not suitable for jointing. The additional length may be established by the splice or closure manufacture or by the splicing procedure, especially if the splicing is carried out in an adjacent vehicle.

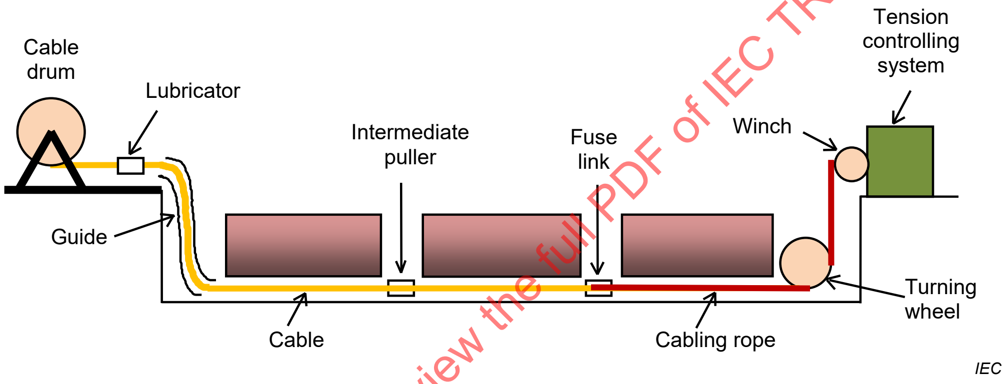


Figure 7 – Optical fibre cabling in an underground duct

4.5.9 Blowing techniques for the installation of fiber optic cables into ducts

Cable installation equipment should either contain a sensing mechanism to limit the applied push force or a "crash" test should be performed previously and the result of this used to set a limit on push force. This is especially important for smaller cables, typically those below 6 mm in diameter. The equipment has to be adjusted for not to damage the cable because of too high traction forces in the blowing equipment.

Additional recommendation for installation by blowing technique is given in ITU-T L.57.

4.5.10 Optical fibre cable installation by floating technique

The floating technique is based on forcing along the cable route, by means of a pump, a suitable water flow which exerts a distributed pushing force along the cable length moving it forward with minimal tension. No pulling action is necessary to be applied at the front end of installed cable. For uphill routes with significant height change, the weight of water should be considered as well as the duct resistance to pressure.

Additional recommendation for installation by floating technique is given in ITU-T L.61.

4.6 Installation of aerial optical cables

4.6.1 Application

Some examples of applications covered by this document are shown in Figures 8 to 12.

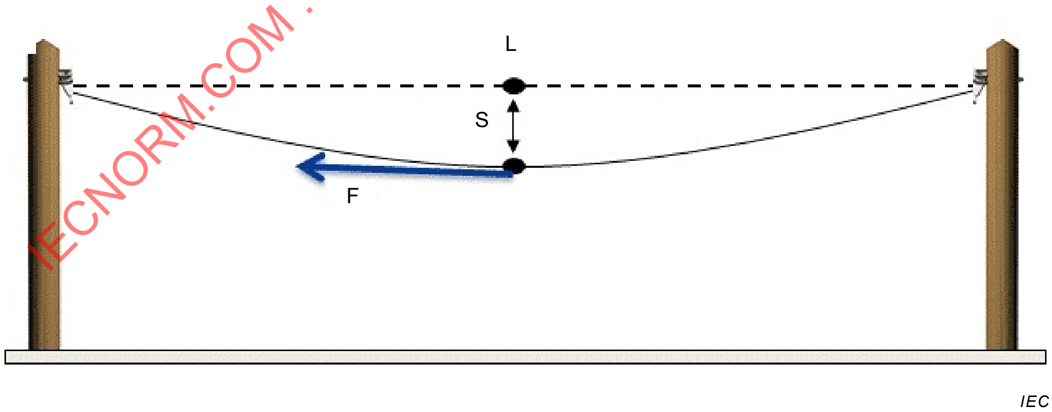
Cables for installation on high voltage lines, such as composite overhead ground wires with optical fibres (commonly known as OPGW) and all-dielectric self-supported (ADSS) optical cables, are excluded from the scope of this document. IEC TR 62263 covers as a primary concern the necessary precautions to ensure the safety of personnel and equipment, as well as guidance and procedures for the installation and maintenance of optical cables on overhead power lines.

The main constrains for aerial cable installation and operation are of topological and climatic type. The combination of the following constraints, if not adequately taken in account for a proper cable selection, can lead to consequences that can compromise the security, the trustability and the longevity of the optical network.

Topological parameters

- span: distance between two poles
- sag: the maximum distance measured vertically from the cable to the straight line joining two points of support, as indicated in Figure 8, generally expressed as a percentage of span
- level change: vertical distance between two adjacent points for cable fixation
- climatic parameters
- wind force
- ice formation over the cable
- temperature change

The influence of the listed parameters define the maximum tension level to which an aerial cable will be summited during short periods of time, as illustrated in Figure 9. So, the wind velocity and predominant direction information should be available for the area where the aerial optical cable will be installed in order to select a cable design of such mechanical characteristics to support the action of this parameters without loss of optical performance nor affection of the cable longevity. This means to define not only an adequate rated tensile strength (RTS) for the aerial cable, but also define a maximum allowable tension (MAT), which is also known as maximum operation tension (MOT) and a maximum installation tension (MIT) with a fibre strain level that does not compromise the expected lifespan of the network.



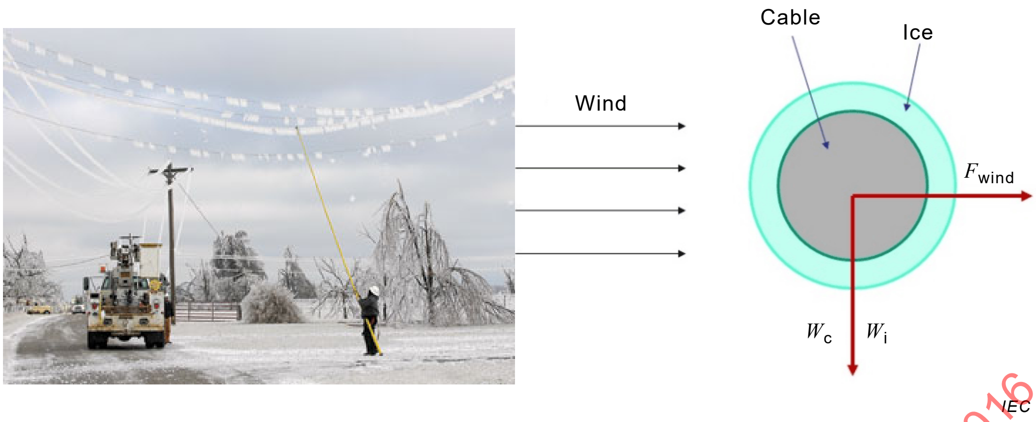
Key

L span length

S sag

F traction force

Figure 8 – Aerial cable parameters



W_c Vertical force due to cable weigth

W_i Vertical force due to ice/snow formation over cable

F_{wind} horizontal force due to perpendicular incidence of wind on the cable section

Figure 9 – Analysis of forces acting on an aerial cable with ice formation

In a simplified analysis of forces, the horizontal component of the tension to which the aerial cable is subjected, as illustrated in Figure 9, can be approximated by the following parabolic equation

$$T = \frac{Pt \cdot l^2}{8 \cdot S} + \frac{Pt \cdot H}{2} \qquad (10)$$

where

T horizontal vectorial component of tension;

Pt resultant of cable weight, ice load and force of wind;

l span length;

S sag;

H level change (vertical distance between two adjacent points for cable fixation).

Vectorial forces analysis should be considered to include wind contribution on Pt value. In order to predict a more precise cable behaviour, a sag-tension model should consider the following factors:

- tension increase due to ice and wind loading;
- cable length change with temperature variations;
- elastic cable length change associated with tension changes;
- permanent increase in cable length over time (creep effect).

Literature can be found for theoretical models approach to evaluate tension and sag of aerial cables, such as [23][1] or [24].

For each design of cable, a table of calculated forces should be provided, considering different span, wind speed and sag values. The calculated tensions to which the aerial cable could be submitted should be lower than the maximum operation tension (MOT) declared for that specific cable design (see Figure 10).

1 Numbers in square brackets refer to the Bibliography.

DESCRIPCTION: AERIAL CABLE

CABLE CHARACTERISTICS

Diámeter (mm)	Weight (kg/km)	Tensión (N)		Número de Tubos		Fibres per tube		Mòdulo elástico compuesto (Gpa)	Coeficiente de expansión térmico (10-5/ºC)
		Operación	Rupture	Corona 1	Corona 2	Corona 1	Corona 2		
12.19	114.05	5,980	17,690	6	0	6	0	2.60	4.10

AERIAL CABLE TENSION PERFORMANCE UNDER DIFFERENT ENVIRONMENTAL CONDITIONS

Wind speed (km/h) : 65.00; Ice= 0 mm			NESC Light Wind = 95 km/h; Ice = 0 mm		NESC medium Wind = 40 km/h; Ice = 6.35 mm		NESC Heavy Wind = 40 km/h; Ice = 12.70 mm	
Span (m)	Sag (%)	TENSION (N)	%	N	%	N	%	N
10	1.5	200	1.5	393	1.5	470	1.5	947
20	1.5	399	1.5	785	1.5	939	1.5	1893
30	1.5	599	1.5	1178	1.5	1409	1.5	2840
40	1.5	799	1.5	1570	1.5	1879	1.5	3787
50	1.5	999	1.5	1963	1.5	2349		
60	1.5	1198	1.5	2355	1.5	2818		
70	1.5	1398	1.5	2748	1.5	3288		
80	1.5	1598	1.5	3140	1.5	3758		
90	1.5	1797	1.5	3533				
100	1.5	1997	1.5	3925				
110	1.5	2197						
120	1.5	2396						
130	1.5	2596						
140	1.5	2796						
150	1.5	2996						
160	1.5	3195						
170	1.5	3395						
180	1.5	3595						
190	1.5	3794						
200	1.5	3994						

IEC

Figure 10 – Example of calculated forces for an aerial operation cable design

There is a third type of constrains that could affect the aerial cables performance. It includes:

- the presence of induced electrical field due to electrical conductors proximity; and
- corrosive atmospheres (salty environment, chemical pollution, etc.).

The induced electrical field produced by an electrical conductor is an issue on high tension lines. Recommendation to prevent damage on the dielectric optical cable jacket due to dry band arcing is covered in IEC TR 62263. Dry band arcing and tracking (electrical field erosion) effects can be accelerated by a saline atmosphere.

4.6.2 Installation methods

In general, regarding optical "figure-8" type, lashed and wrapped cables, the methods used and considerations made in the installation of metallic aerial cables can and should be employed for optical fibre aerial cables. These include the normal practices of lashing or attaching hanger rings to a pre-provided tension strand, self-supporting systems, lashing to an existing aerial cable or, with a special design of cable and equipment, using the optical fibre cable itself as the lashing medium. The mechanical stresses and therefore strain experienced during aerial cabling are generally lower than those induced during underground placing and, in a mixed underground/overhead route, underground cable may be used for overhead sections.

Where end-pull and/or intermediate pullers are used, care should be taken to ensure there are sufficient devices of adequate power available to pull the very long continuous sections, possible on aerial routes.

4.6.3 Cable protection methods

In general, where end-pull or distributed pull methods are used, the various methods as in underground duct installations (see 4.5) to protect the cable from excessive strain during installation may be employed for aerial cable. It is also good practice to ensure that cable back-tension is always carefully controlled.

Where lashing to pre-tensioned support wire or existing metallic cable is employed, the optical fibre aerial cable shall be constructed to withstand lashing. The lashing-wire tension shall be controlled. Care shall be exercised when handling cable in aerial route installations.

4.6.4 Winching and guiding systems

Provided the need to protect from overload and over-bending is borne in mind, most normal aerial cable installation and winching equipment, including end-pull winches, controlled cable feeding devices, can be used. For long length installations where end-pull or distributed-pull systems are used, it is important that proper guiding equipment is provided at positions where sharp changes of direction occur, and every effort is made to ensure pulling-in at even speed.

4.6.5 Methods to maximise lengths

Where relatively unrestricted access to the route exists, it is feasible in many cases to install, using a variety of normal methods, very long lengths of aerial optical fibre cable, the only limitation being the capacity of the cable drum. However, where road or other crossings are involved and extra splices are not acceptable, a system of pulling through this section shall be devised. Also, where winching methods are used, cumulative friction effects limit the installation length and, as with underground systems, intermediate winching systems may be employed.

4.6.6 Jointing length allowance

It is important when installing aerial optical fibre cable lengths to make proper arrangement for an adequate extra length of cable at a pole position for testing and jointing (see Figure 11). This length at each end of the cable shall be sufficient to enable construction of joints and sheath closures at a convenient work position and it may be necessary to allow extra length for ground level operations. Also, for the construction joint, the pistonning effect (movement of the cable elements in relation to the cable sheath) should be taken into account, which could occur in case of extreme weather conditions such as the combination of ice and strong incidence wind. The resulting effect may lead to the optical fiber breakage in the joint. To prevent it, tight loves of cable is a proved solution. Practically four loves at each end of the cable at the minimum static bending radius is efficient enough. Sufficient cable length should be allowed for this purpose.

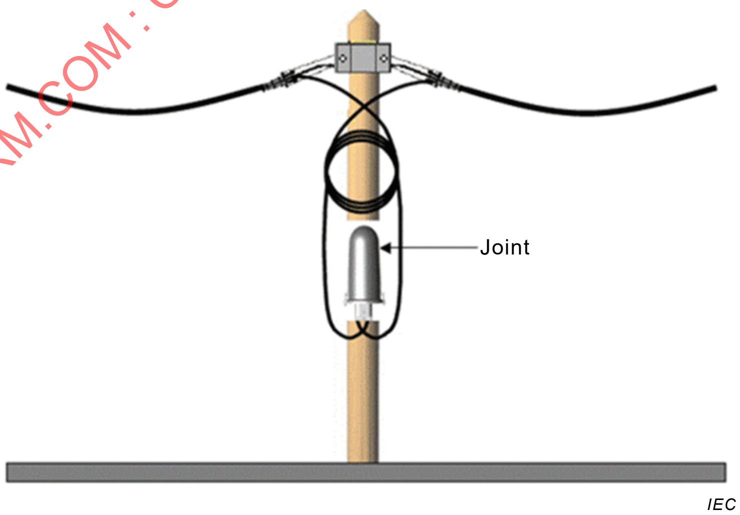


Figure 11 – Aerial cable joint point

4.6.7 In-service considerations

Care should be taken during cable installation to avoid exceed fibre strain limits stated by the relevant cable specification and, with aerial routes in particular, steps to ensure that strain levels remain within the manufacturer's recommendations during service are necessary. All types of movement, whether produced by cable weight, thermal changes, ice loading or wind, produce strain and shall be taken into account and minimised where possible. In particular, proper optical-fibre pole fittings to provide movement damping over a longer length than metallic types should be employed.

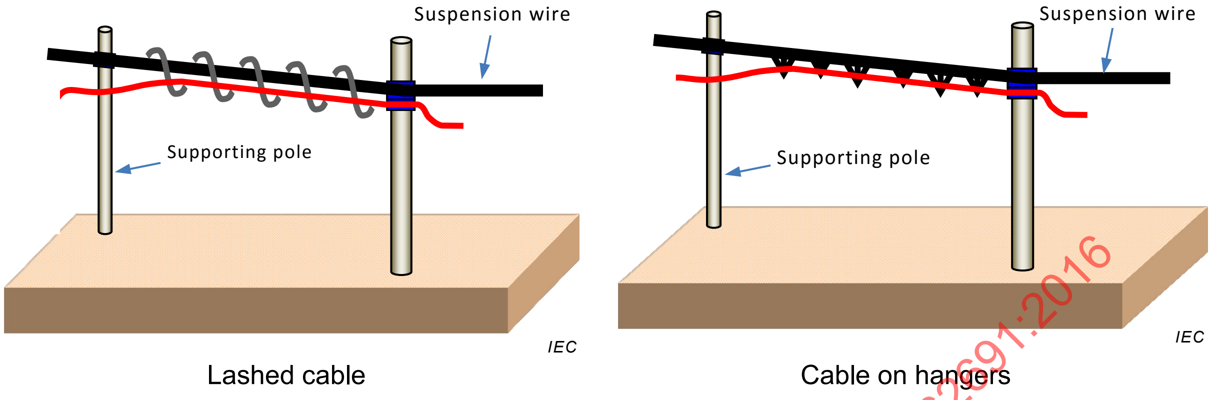


Figure 12 – Aerial cable applications

4.6.8 Lashed aerial applications

4.6.8.1 General

Lashing fibre optic cables in aerial applications is a common method of cable installation in North America (see Figure 12). As with many metallic communication cables, fibre optic cables used in aerial applications frequently rely upon dedicated stranded steel wires known as messengers for support. Furthermore, "overlashing" installations in which a fibre optic cable is lashed to a copper or fibre optic cable already in place on a strand is also common practice in North America.

There are two basic methods of lashed aerial plant installations:

- the drive-off or moving reel method; and
- the back-pull, pull-in, or stationary reel method.

4.6.8.2 Drive-off (moving reel) method

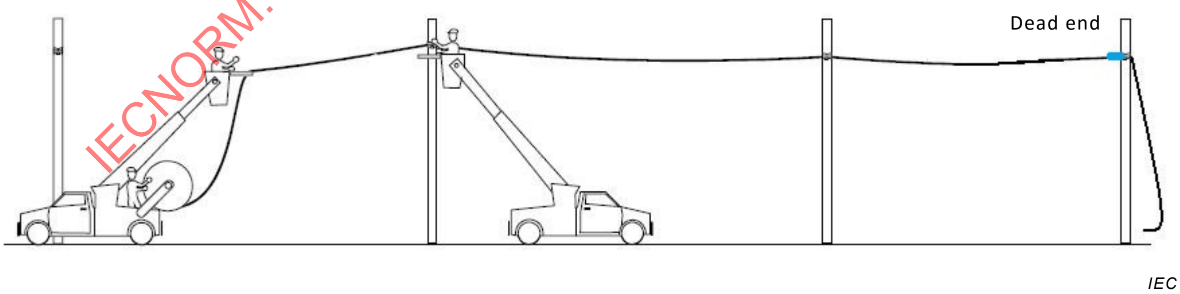


Figure 13 – Drive-off (moving reel) method

The drive-off method is used when the entire route can be traversed by reel-carrying vehicles (see Figure 13). The fibre optic cable is raised to strand level and lashed to the strand in one operation as the placement vehicle(s) move(s) along each span.

This method requires vehicle access to the placement side of the pole line, and the cable route shall be away from tree limbs, guy wires, and other obstructions. If the cable route has significant elevation changes, it is preferable to lash downhill.

The drive-off method offers production and cost advantages over stationary reel methods as no cable blocks or other temporary support hardware are required. In addition, fewer crew members on the ground with two-way communications devices (e.g. radios) are required.

4.6.8.3 Back-pull, pull-in, or stationary reel methods

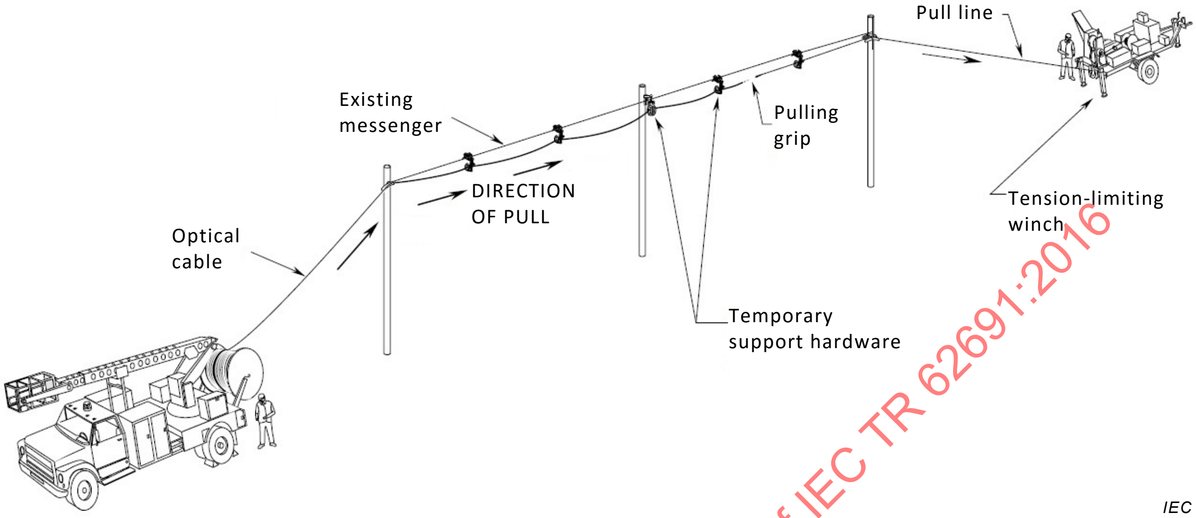


Figure 14 – Stationary reel method

The back-pull, pull-in, or stationary reel method is used for cable routes which are inaccessible to vehicles. The cable is placed with the following operations (see Figure 14).

- Station the reel and the tension device a distance of 3 to 4 times the structure height to minimize the cable angle and compression on the entering and exiting sheaves which are designed to have proper size.
- Cable is pulled into place beneath the strand and suspended there by cable blocks.
- Flashing then begins at the far-end of the cable run, the lasher is pulled back down the cable route towards the fixed-location cable reel.

While the methods used for placing aerial fibre optic cable are essentially the same as those used for placing copper cable, there are important differences which shall be recognized by the craftsman. Fibre optic cable is a high capacity transmission medium whose qualities and characteristics can be degraded when it is subjected to excessive pulling tension, sharp bends, and crushing forces (see the specification sheet for the cable being used).

Similar to placing copper cables, one shall also plan for pole usage, receive the proper authorizations and obtain the proper right-of-way clearances.

Some of the elements of lashed aerial plants regardless of the installation method (drive-off or back-pull) used are:

- suspension strands (messenger wires);
- overlashing;
- bonding and grounding;
- pulling grips;
- lashers:
  - lasher operation;
  - transferring lashers around poles.
- dead ends and crossovers.

4.6.8.4 Suspension strands (messenger wires)

Suspension strands are the steel wires supported between two poles. This wire provides support for the fibre optic cable and is what the cable is lashed to. Suspension strands used in telephony are classified by rated breaking strength and the type of steel used in their construction.

Note that when a suspension strand is specified for a fibre optic cable, the most important considerations are that the strand is strong enough, and that excess cable strain does not occur. When the diameter of a strand is enlarged to increase its strength, its weight and the effect of wind and ice loading is affected, which increases cable strain. Normally, the "best" strand is not the question, but rather if the normal strand is satisfactory. Technically, the smallest messenger with a satisfactory strength is best.

4.6.8.5 Overlashing

An alternate to lashing a fibre optic cable to a dedicated messenger is to lash the cable to an existing lashed fibre optic or copper cable. This method of aerial cable placement, called "overlashing", is attractive because the expense of providing a separate suspension strand for the fibre optic cable is avoided.

4.6.8.6 Bonding and grounding

In order to maintain a high degree of safety and reliability in overhead plant construction, standards regarding grounding should be defined and followed. Grounding of all metallic cable elements at splice points and building entry points are recommended; however, the company's normal specifications concerning the grounding of messenger wire and associated hardware/equipment may be followed.

4.6.8.7 Pulling grips

Pulling grips provide effective coupling of pulling loads to the jacket, aramid yarn, and central member of fibre optic cables. Wire-mesh pulling grips may be either factory or field-installed. The use of a swivel between the pull-line and pulling grip is required to prevent the pull-line from imparting a twist to the cable.

4.6.8.8 Lashers

A lasher is used to secure fibre optic cable to a strand by wrapping a small continuous lashing wire around both the strand and the cable in a spiral manner. Lashing wire may be made of steel or contain dielectric materials such as aramid yarn. Fibre optic cables shall be installed without loose lashing, twisting, or weaving along the strand. Rippling, kinking, or any kind of deformation of the cable can require replacement of the cable by the responsible contractor.

When lashing fibre optic cable to the support strand (messenger), there shall be at least one wrap of lashing wire per linear 30 cm. To determine the correct size of standard lashing wire for the cable and the strand, consult the lasher instruction manual.

Fibre optic cable can be lashed to a messenger wire with one or two lashing wires. Double lashing provides an added measure of security against vibration and other stresses. Double lashing fibre optic cable is recommended in the following situations:

- when overlashing over existing aerial cables;
- when placing cable over railroads and roadways.

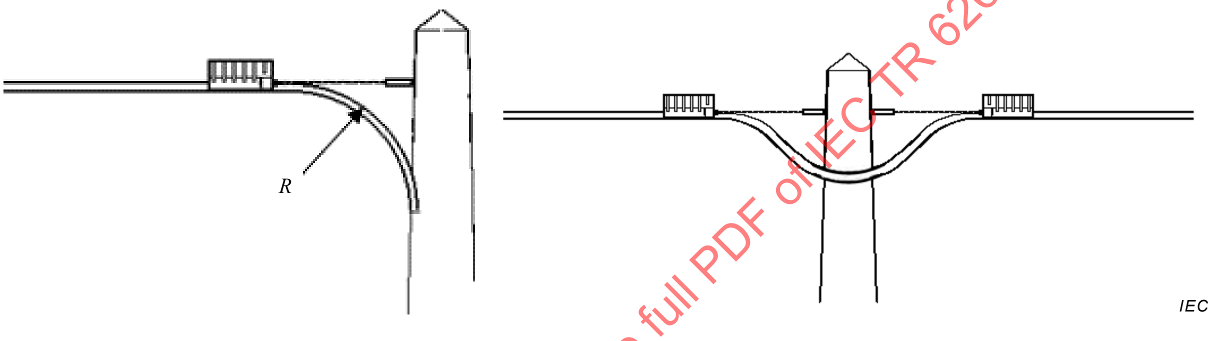
The lasher and its accessories shall be manually transferred each time they reach a pole along the route.

4.6.8.9 Dead ends and crossovers

As with copper cables, fibre optic cables should be routed on the inside of messenger intersections at dead ends and aerial crossovers. The accessories selection shall be done under a qualification process to guarantee the compatibility with the optical cable simulating the climatic conditions and network parameters. The following tests, defined in IEC 60794-1-21, are the minimum recommended to be evaluated in order to guarantee the compatibility of the aerial cable with dead ends and suspension accessories:

- tension test at maximum operation test (MOT), method E1;
- galloping test, method E26;
- aeolian vibration test, method E19.

Routing the cables on the inside of messenger intersections, along with drip loops, will minimize the risk of damage in the cable route. Be sure to respect the cable's minimum bend radius whenever the span makes a directional change.



Key

R bend radius

It is important to respect the minimum bend radius for the optical cable at dead ends (single fixing) and at directional changes (double anchorage) situations

Figure 15 – Minimum bend radius for the optical cable at dead ends (single fixing) and at directional changes (double anchorage) situations

4.7 Installation of buried cable

4.7.1 Installation methods

Normal buried cable installation methods including ploughing (direct, vibratory or winched) and trenching can, in general, be used for direct burial of optical fibre cable, provided the cable is specifically designed for this type of application. The same depth of cover as for metallic cables is usually adequate, but traffic capacity or other considerations of security may indicate a requirement for greater depth. Where a trench method is used, backfilling materials and practices may require particular consideration so that fibre strain limits are not reached during this operation.

4.7.2 Cables in trenches

When installing cables in trenches, the following precautions should be observed.

- The bottom of the cable trench shall offer a firm base, such as compacted soil and be free from stones. If stones are present, an approximately 15 cm high layer of sand or finely sieved granular soil should be added.
- Installation depths (to the foot of the trench) are shown in Table 5 and reflect the risk associated with the application and the cost of replacement.
- The direct burial of cables under roadways in the longitudinal direction is permitted only in exceptional cases. At the crossings of roadways or installations longitudinally under roads,

cables shall be protected by cable duct. When cables run almost parallel to a road, the duct between trenches should cross the roadway at an angle of about 45° in order to reduce the pulling forces.

- When the cable trench is free of obstacles and where local conditions allow, the cables can be unrolled from the cable transport trailer driven along the trench and laid in the trench. The unrolling of the cable from the coil should correspond to the forward movement of the vehicle and a suitable braking device can ensure that not too much cable is unrolled. As it is unrolled, the cable should be moderately tensile loaded, in order to straighten it on the bottom of the trench.
- If, because of location conditions, the cable is laid on the ground prior to trenching, the cable should be laid out in sufficiently large curves, to ensure that no undue bends, twists, kinks, compression or abrasions occur.
- If the cable is drawn into a cable trench using a cable winch, the cable will graze the foot of the trench or trench walls in virtually all cases. Significant abrasion of the cable may occur. Therefore, this method is discouraged.
- Special measures shall be taken in areas where earth settling may occur. In those areas where cables enter buildings or ducts, there is the danger that cables could be kinked or sheared off in the building or duct if the soil surrounding the cable settles. Such damage can be prevented by precautionary measures such as making cable loops, padding, junction boxes or compacted backfill.
- Stone-free or slag-free filler (earth or sand) may be tipped onto the cable lying flat on the foot of the trench up to a depth of at least 15 cm above the cable, and lightly tamped and levelled.

Sand-encased cables in built-up areas or in areas of increased hazard can be protected against damage with cable protection covers or cable cover plates.

When the cable trench is filled, compacting machinery shall be employed only when coverage of the cable is at least 30 cm deep. For filling cable trenches within roadway zones, compliance with local regulations should be ensured.

A warning strip of corrosion-proof material, for example soft PVC, should be placed at a distance of 30 cm to 40 cm above the cable.

Table 5 – Minimum installation depths

Application	**Installation depth** m
High data rate/heavy concentration (trunk)	0,8
Medium data rate/medium concentration (distribution)	0,6
Low data rate/low concentration (service/drop)	0,5
The installation depth may be shallower in certain locations, where particular obstacles or ground conditions cause considerable difficulties and where there are no justifiable objections. Where depths are less than as shown above, the cables shall be provided with special protection (e.g. by means of cable duct).	

On routes that involve asphalted surfaces such as roads or sidewalks with a base of compact material (asphalt or concrete), the micro-trenching technology may be applied with considerable reduction in infrastructure deployment cost and lower impact on the environment. Micro-trenching involves cable designs for high crush level and temperature resistance. A typical application consists of protecting the fibres inside a metallic tube filled with water blocking compound covered by a PE jacket; cutting a groove in the asphalt to a depth not less than 7 cm, but without penetrating past the asphalt layer to prevent asphalt layer cracking with time. The cable is installed at the bottom of the micro-trench and then, covered with a sealant material to provide mechanical protection. Additional information and recommendations on micro-trench installation technique is referred to in ITU-T L.49.

4.7.3 Installing cables by ploughing

When ploughing methods are used, the design of the guiding equipment between the cable reel and the cable laying guide shall take careful account of specified cable-bending criteria and have a low friction value to prevent fibre overstrain. Cable tensile overload protection systems are not normally necessary, but where a large ploughing machine is used and there are driven cable reels and guide wheels, a tension device can be incorporated. In-service mechanical protection at road or service crossings or in situations of high vulnerability may be felt to be necessary.

Generally, a ripping pass or passes should be made to ensure that the path is clear and the required depth can be attained. The minimum cable depth is as shown in Table 5.

A warning strip of corrosion-proof material, for example soft PVC, should be laid simultaneously at a distance of 30 cm to 40 cm above the cable.

4.7.4 Methods to maximise lengths

Provided proper preparations are made, direct buried installation of optical fibre cable is normally only limited by obstructions and, to a lesser extent, the reel capacity. However, where some parts of a long length ploughed installation involve difficult ploughing through stony or rocky sections, preparation by trenching can be beneficial. A moving reel technique may also be used to maximise lengths installed.

4.7.5 Jointing length allowance

It is important, when installing directly buried optical fibre cables, to make proper arrangement for an adequate extra length of cable at both ends of a section for testing and jointing. This length shall be sufficient to enable construction of joints and sheath closures at a convenient work position.

4.8 Installation in special situations

4.8.1 Tunnel and building lead-in

Winching optical cable by end-pull or distributed methods in tunnel or building leads-ins can be considered a special case of cabling in duct, and those methods and considerations indicated in 3.4 apply. However, where cable is laid out and manhandled onto trays or bearers, care shall be taken to ensure that support geometry and handling operations do not contravene specified bending criteria. Cleating and fixing systems shall be made-suitable for use with optical fibre cables.

4.8.2 Bridges

The normal considerations for placing metallic cable also apply to optical fibre cable but with additional care required to counter cable movement in steep approach sections or vertical sections. This type of movement, which can be produced by traffic vibrations, can lead to excessive fibre strain, and suitable cable restraints should be used.

4.8.3 Underwater

Where it is necessary to place optical fibre cable underwater in river crossings or in lakes, the cable shall be constructed for this purpose. Often, standard outdoor cables can be suitable for immersion in less than 10 m water depth if benign conditions exist and sufficient burial depths are employed. A continuous length should be provided where possible to avoid underwater joints. In addition, the gradient of the cable route down the river bed or lake shore should be as gentle as possible to avoid the fibre moving within the cable. Underwater cable can be subjected to large degrees of movement on all planes, producing fibre overstrain, and measures to restrict this movement by the use of trenching, sandbagging, ducts, etc., should be taken. Consideration of bottom erosion by currents, dragging anchors, bottom scouring, etc., should be part of the planning for route planning, burial depth, or special armouring.

4.8.4 Storm and sanitary sewers

4.8.4.1 General

A sewer cable should be suitable for installation in non-man-accessible storm and sanitary sewers by the following installation methods, also applicable for man-accessible sewers and for lateral sewer systems:

– blowing and/or pulling into a conduit, previously fixed to the sewer wall or, for laterals, placed in between the lateral sewer wall and the in-liner system;
– direct installation into the sewer duct, according to the following applications:
  - drilling and screwing to the inner wall;
  - spanning between manholes, etc., similarly to aerial cables;
  - laying on the ground of the sewer.

Installation in sewers should have no adverse effects on the efficiency of the sewer system. Cables are generally placed manually in pre-installed trays or ducts by end-pulling or blowing. They may also be secured to the sewer wall by means of hooks, adhesive beds, sewer pipe liners, or the like, by manual, pre-engineered, or robotic means. Such methods may require intermittent tensioning in order to maintain the duct or cable out of the flow within the sewer. Application of cables into existing sewer systems requires detailed surveys and planning and frequently requires prior maintenance or rehabilitation of the sewers.

Cables for sewer installation are the subject of IEC 60794-3-40. Sewer cable and conduit constructions have to meet the different requirements of the sewer operating companies and/or associations regarding chemical, environmental, operational, cleaning and in general maintenance conditions.

It shall be possible to install or remove the cable in or from the sewer throughout the operational lifetime. Upon removal of the cable or conduit, no remnants which would snag normal sewage debris or which would affect laminar sewage flow shall remain. The materials in the sewer, cable and/or accessories including fixing elements and conduits shall not present a health hazard within its intended use. All the materials used for the infrastructure in the sewer pipes shall be of stainless steel type to ensure the mechanical protection in the sewer environment and the protection against rodents for the optical cable. Rodent protection is generally needed but there is presently no standard test to measure the protection level. Rodent protection can be provided by the cable or by the duct.

Recommendations for such applications are also described in ITU-T L.77.

4.8.4.2 Installation within conduits

Installation in non-man-accessible sewers is made by robots; anchoring installation methods in non-man-accessible sewers are not recommended as the sewer pipe wall thickness is weakened by drilled holes and might break due to the heavy load or pipe sagging. Conduits are fixed, for example by clamps, to spring loaded stainless-steel rings installed into the sewer tube using a special designed robot (see Figure 16).

Sewer cables will be blown or pulled later within such conduits.

Figure 16 – Conduit robotized installation

4.8.4.3 Spring loaded stainless-steel ring

To install a clamp, the spring box on the clamp is unlocked, so that the clip ring is expanded against the duct wall and tightly fixed to the inside sewer wall without drilling, cutting or screwing (see Figure 17).

Figure 17 – Spring loaded stainless-steel ring – Conduit fastening

4.8.4.4 Installation directly into the sewer

4.8.4.4.1 Cable screwed to the inner sewer wall by means of an installation robot

Prior to cable installation, an inspection should be performed to verify the good condition of the sewer section, register the joints location and defining the optimum position of the clip holders. The sewer wall thickness should be thick enough to allow drill holes for the installation of expansion bolts and nuts which fix the clip holders to the inside sewer wall. For small diameter cables, protective conduits are preferred to be pulled into the sewer pipes. If the optical cable is rough enough to support the pulling force during installation, then the cable is pulled directly into the sewer and a robot presses the cable sections into the clips of the previously installed clamps (see Figure 18). Optical fibre cables for direct installation inside sewer ducts shall guarantee maximum robustness and corrosion resistance since they are laid directly into bodies of water and will be exposed to chemically corrosive elements.

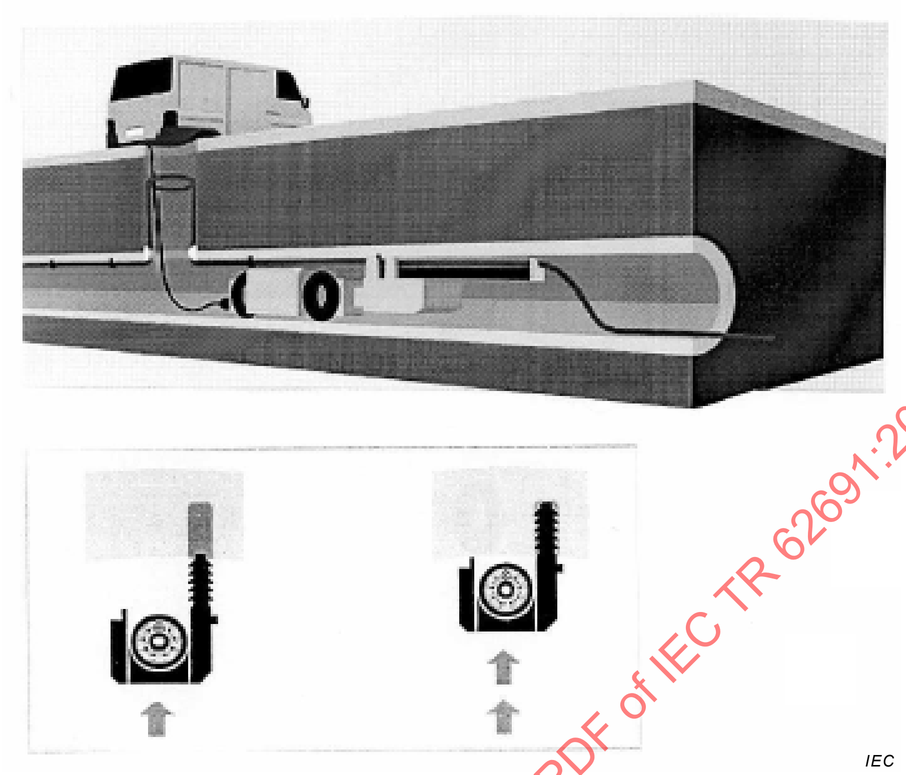


Figure 18 – Schematic drawing robotized installation – Drilling

4.8.4.4.2 Cable spanned between manholes, similarly to aerial cables

For optical cables installation, it is recommended to provide an over-length section of cable to prevent excessive tension on the cable, to keep the adequate radius bend and to allow for latter branching on the route if necessary.

When it is defined that the optical cable should be fixed to the top wall of the sewer, the whole cable length is divided into several segments according to the quantity of manholes. Each segment is suspended in the sewer between two adjacent manholes by hardware and fittings (see Figure 19). Each section of cable is fixed to the manhole wall, and the cable is tensioned at the other end of the section to a sag not less of 3 %. By achieving this sag value, the cable is fixed and secured to the next manhole wall to suspend the cable section in the sewer upper wall between two adjacent manholes. For this technique, it is recommended not to exceed 50 m span to avoid high tensions that could put the fibers on risk. For sewer sections longer to 50 m, an intermediate fixing point should be provided in the sewer section.

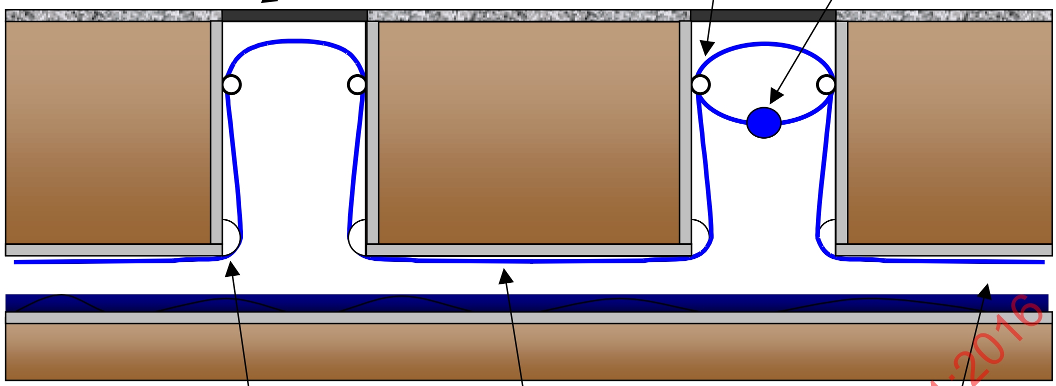


Figure 19 – Schematic drawing – Spanning of optical fibre cables within sewers

4.8.4.5 Cable laid on the ground of the sewer

A simple installation method consists of laying the optical cable on the ground of the sewer pipe. The fastening of the cable to the pipe wall is not necessary as the weight of cable keeps it on the floor by gravity, requiring fixing the cable only in the manhole area (see Figure 20). Minimum cable's bending radius shall be strictly observed and an adequate protection should be provided to prevent damage to the optical fibres due to rodents attack and during sewer cleaning when done with high-pressure washing.

Additional information about safety and recommendations on installation of optical fibre cables inside sewer ducts can be consulted in ITU-T L.77.

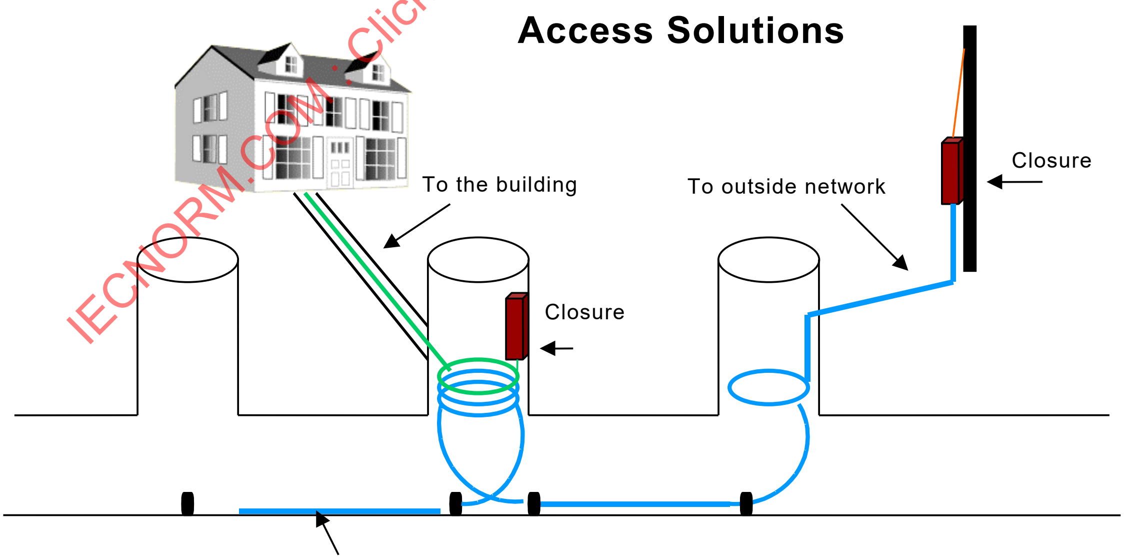


Figure 20 – Schematic drawing – Laying on the ground of optical fibre cables within sewers

4.8.5 High pressure gas pipes (fiber-in-gas)

4.8.5.1 General

A gas pipe cable should be suitable for installation in high pressure gas pipes by the following installation methods, also applicable for the access gas pipe network:

- blowing and/or pulling into a subduct, previously installed into the high pressure gas pipe between two I/O-ports;
- direct installation into the gas pipe in between two adjacent I/O-ports.

Placing optical fibre cables in high pressure gas pipes requires especial consideration of safety issues regarding gas leaks where cables enter and exit the gas pipe. Due to the relatively small size of gas pipes, microcables or microducts are suitable for installation in gas pipes. The ducts or cables, as appropriate, shall withstand degradation by or contamination of the gas within the gas pipes.

Cables for gas pipe installation are the subject of IEC 60794-3-50. Gas pipe cable and subduct constructions have to meet the different requirements of the gas-companies and/or associations regarding chemical, environmental, operational interactions and in general maintenance conditions.

It shall be possible to install or remove the cable in or from the gas pipe throughout the operational lifetime. The materials in the gas pipe cable and/or accessories including fixing elements, i.e. I/O-ports and subducts, shall not present a health hazard within their intended use.

In case of use, the subduct with outer nominal diameters ranging from 10 mm to 100 mm shall be able to resist pressure differences needed for installation by blowing and able to withstand the gas pressure within the gas pipe. The subduct shall be circular, and the outer and inner surfaces shall be of low coefficient of friction. The material shall withstand all possible chemical attacks by the natural gas itself.

4.8.5.2 Steel gas pipe access

The cable inlet and outlet are typically of a steel construction, installed by hot tapping, together with a sealing device placed between the gas pipe cable and the steel-tubing of the I/O-port pipe. The sealing system has to ensure absolute gas tightness, preventing any gas from escaping out of the I/O-port (see Figure 21 and Figure 22).

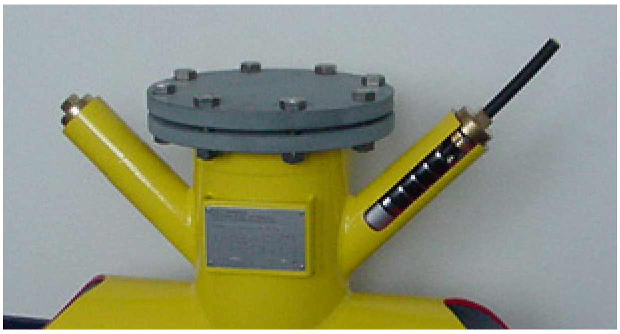


Figure 21 – Picture of an the I/O-port