CHAPTER 3

OPTICAL CABLE INSTALLATION

Introduction

This Chapter is devoted to the description of the optical cable installation methods. Each type of optical fibre cable has a specific strain limit and special care and arrangements may be needed to ensure successful installation without exceeding it. Damage caused by overloading during installation may not be immediately apparent, but can lead to failure later in its service life. Also aspects related to bending during the installation may require special consideration.

In Section 1, many types of cable installation (underground duct, trenchless, mini-trench, aerial, submarine, etc.) are described. Clause 2 deals with additional safety precautions when installing optical cables.

1 Cable installation methods

Optical fibre must be protected from excessive strains, produced axially or in bending, during installation and various methods are available to do this. The aim of all optical fibre cable installation methods and systems should be to install the cable with the fibre in, as near as possible, a strain free condition, ready for splicing.

Methods and practices used in the handling of optical fibre cables during installation can, without producing any immediately evident 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, how easy it is to contravene these when installing by hand, and the difficulty of making consequential additional splices.

Ambient conditions 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 specifically for the particular product.

1.1 Installation of cables in underground ducts

1.1.1 Route considerations

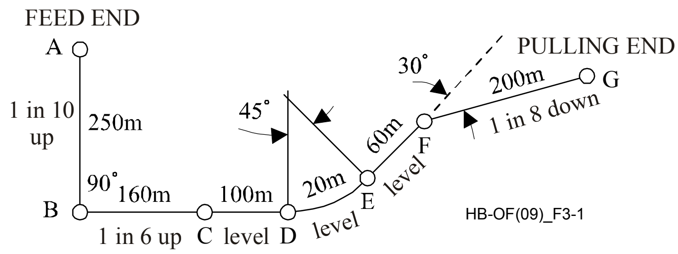
Some of the most difficult situations for the installation of optical fibre cables are in underground ducts. The condition and geometry of duct routes is of great importance. Where the infrastructure includes ducts in poor condition, contains excessive curvature, includes ducts already containing cables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

Provision of long cable lengths in underground duct situations may involve installation methods that require access to the cable at intermediate points for the application of additional winching force or figure-of-eight techniques, and 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 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 (see Chapter 10). 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 cabled than normal size duct, particularly over long lengths, and the diameter ratio between the cable and subduct should be considered. Methods have been developed that install cables into small size ducts by blowing, which leaves the cable essentially stress free (see § 1.1.8).

1.1.2 Cable installation tension prediction for cables pulled into ducts

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 safety margin 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 Figure 3-1. Here the cable is approximated as flexible, and the route between deviations and inclinations is considered straight. When taking into account cable stiffness and undulations in the trajectory, the results may differ.



T = Tension at end of section (kN)
Ti = Tension at beginning of section (kN)
μ = Coefficient of friction (between cable and duct or guide)
l = Length of section (m)
w = Cable specific mass (kg/m)
θ = Inclination (radius, + = up and – = down)
β = Deviation (horizontal plane, radians)
g = Acceleration due to gravity (9.81 m/s²)

Figure 3-1 – Cable tension calculation

The following main contributory functions need to be considered when calculating cabling tensions.

i) the mass per unit length of cable;

ii) the coefficient of friction between cable sheath and surfaces with which it will come in contact;

iii) deviations and inclinations.

Examples:

Straight sections $T = T_i + \mu lwg \times 10^{-3}$

Inclined sections $T = T_i + lwg(\mu \cos\theta + \sin\theta) \times 10^{-3}$

Curved sections $T = T_i e^{\mu\beta}$

Using the route and common tension formulae in Figure 3-1 as an example, total tension can be calculated on a cumulative basis working through each section from one end of the route to the other as indicated in Table 3-1. (For example, $\mu = 0.55$ and $w = 0.92$ kg/m.)

Table 3-1 – Example of cable tension calculation

Section	Length (m)	Tension Eqn 1 (kN)	Incl. (radians)	Tension Eqn 2 (kN)	Deviation (radians)	Tension Eqn 3 (kN)	Cum. Tension (kN)
A-B	250	–	0.10	1.47	–	–	1.47
at B	–	–	–	–	1.57	3.49	3.49
B-C	160	–	0.17	4.51	–	–	4.51
C-D	100	5.01	–	–	–	–	5.01
D-E	20	5.11	–	–	–	–	5.11
at E	–	–	–	–	0.79	7.87	7.87
E-F	60	8.16	–	–	–	–	8.16
at F	–	–	–	–	0.52	10.88	10.88
F-G	200	–	0.13	11.65	–	–	11.65

NOTE – 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 1.5-2 for two cables, 2-4 for three cables, and 4-9 for four cables.
Factors also depend on relative size; e.g. for 2 equal cables the jamming factor f_{jam} follows:

$$f_{jam} = \frac{D_d - D_c}{\sqrt{D_d (D_d - 2D_c)}}$$

Here D_d is the inner diameter of the duct and D_c the diameter of the cables.

1.1.3 Cable overload protection methods

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 is therefore necessary to provide a cable overload prevention mechanism. There are two classes of device to 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 (Figure 3-2).

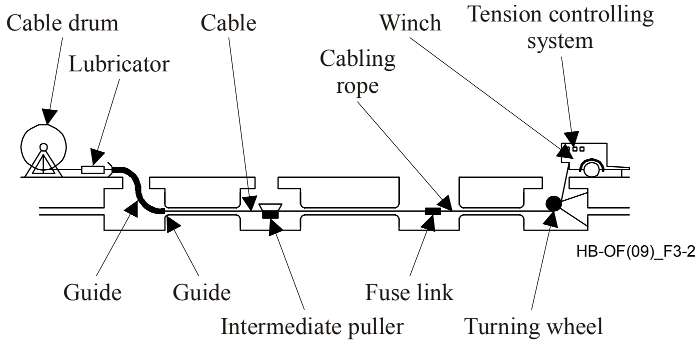


Figure 3-2 – Optical fibre cabling in underground duct

1.1.4 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; 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 using normal installation methods successively. Lines or ropes must be placed using care, where there are already optical fibre cables in a duct; knots in the lines or ropes must be avoided.

1.1.5 Guiding systems and cable bending

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 take into account cable manufacturers' stated bending criteria. In general, a minimum bending radius of around twelve times the cable diameter is considered appropriate, but when being installed under tension, it is suggested that this ratio should be doubled. Most guiding equipment can be used for both optical fibre and metallic cables, but the laying of long cable lengths may require many guiding elements and they should all have the properties of lightness and low friction.

1.1.6 Cable friction and lubrication

Special attention should be paid to friction and lubrication when installing optical fibre cables. The friction forces which must be overcome are related to several factors, primarily the materials and finishes of the cable sheath.

1.1.7 Cable handling methods to maximize installed lengths by pulling

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-of-eight system". This procedure requires the cable drum to be placed at an intermediate point and cable drawn in one direction of the route by 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 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-of-eight 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 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 coordination, synchronization 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 installation, but great care must be taken to ensure that minimum bending and other mechanical criteria are not contravened.

1.1.8 Air-assisted cable installation

Air-assisted installation is based on forcing a continuous high-speed airflow along the cable with an air source. Moving air force pushes the cable and makes it advance forward at a typical speed supported by the equipment.

Generally, the load on the cable is an order of magnitude lower than the typical force involved with other installation methods, like pulling techniques, reducing installation hazards. Additionally, with this technique, bends in duct run are not as important a matter of concern as they are in pulling techniques, so that installation speed increases and longer lengths of cable can be installed. Cables are installed without virtual stress, leaving the cable relaxed in the duct upon completion of the installation.

Different systems using blowing techniques have been developed to install bundles, cables or fibre into tubes or ducts.

The first of these consists of a two-pass process, where the tube is installed prior to the installation of the fibre. In this method, initially a bundle of tubes (micro-ducts), either loose or constructed as a cable, is installed using normal or blowing techniques. Jointing and branching of tubes within the fibre route can be easily done using simple push-fit connections. As fibres are required, either sheathed bundles of fibre (4 or 8 fibres), typically < 2 mm in diameter, or larger micro-duct cables (e.g. 96 fibre cables, typically < 7 mm in diameter) are blown by compressed air into the pre-installed tubes with an insertion speed of about 2 km/h. By this method of installation, the fibres experience little or no strain. Cable routes of up to 10 km without the need for intermediate splices can be achieved.

A second system has been developed and used in which normal, rather stiff, optical fibre cables are blown by compressed air into small pipes or ducts. Depending upon the cable characteristics (diameter, weight, flexibility), the duct diameter, the friction between the cable and the duct and the number of curves in the overall duct run, installation units may be placed every 500, 750 or 1 000 metres. No matter how many installation units are used in tandem, there is never a synchronization problem. The cable is installed at about 2 km/h. Pre-lubrication of the ducts will increase the distance over which one unit can install a cable. The cable itself can also be lubricated, with the help of an in-line cable lubricator with air-bypass.

(For further information, see Recommendation ITU-T L.57.)

1.1.9 Water pumping system

The water pumping system (floating technique) is based on forcing along the cable route, by means of a pump, a suitable water flow (Figure 3-3). The water thrust minimizes the friction effect generated between the cable and the duct during the installation process. The water pumping system can be used with or without a parachute (piston) attached to the cable end. In the first situation the water pressure exerts a pulling force on the cable end. In the latter situation this is not the case. But, here the moving water (faster than the cable) exerts a distributed action on the cable that pushes it forward at a speed in the range 30-40 m/min.

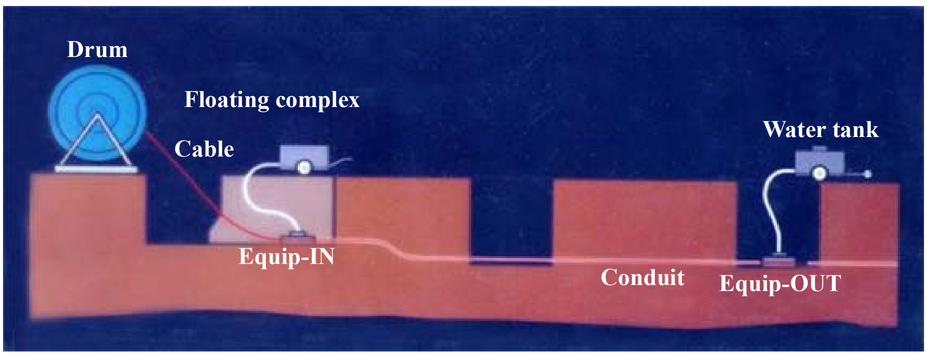


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Figure 3-3 – Schematic layout of water pumping

With this technique, the applied forces on the cable are lower than those applied in the case of the use of pulling techniques, thus reducing the installation hazards. Additionally, the presence of bends along the cable route becomes a less significant factor compared with the pulling technique. Fluid speeds of 1 m/s are advisable for heavy optical cables (around 300 kg/km).

Cables are installed without virtual stress, leaving the cable relaxed in the duct upon completion of the installation. Finally, water floating does not cause a significant increase of the duct temperature, providing another advantage over those systems that use gas as a laying element.

In the situation with parachute (piston) attached to the cable end, a piston that seals to the duct is connected to the pulling eye of the cable. The piston and the end of the cable are passed through a water injection device, which is attached to the duct. Water is than pumped into the duct through the water injection device, and pushes the piston through the duct. The cable is pulled along by the piston. The flow of the water hydraulically assists the passage of the cable through the duct and provides some lubrication. A relatively small, gasoline powered pump can install a kilometre of cable in a few minutes. Cable lengths of several kilometres have been installed using this method (Figure 3-4).

(For further information, see Recommendation ITU-T L.61.)

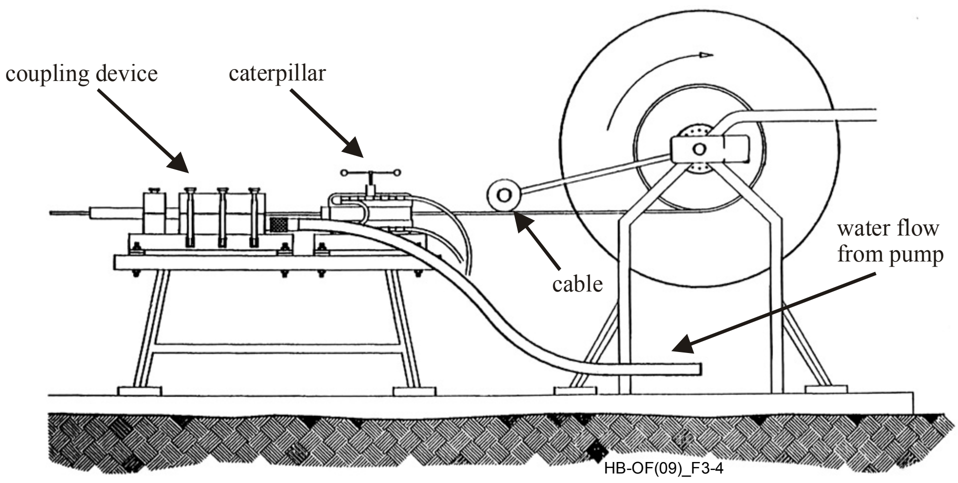


Figure 3-4 – General assembly of the floating machine

1.1.10 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.

1.2 Installation of optical cables with the trenchless technique

The trenchless techniques (or no-dig techniques) allow installation of underground optical cables minimizing or eliminating the need for excavation. These techniques create a horizontal bore below the ground in which the underground infrastructure (ducts, pipes or direct buried cables) can be placed. Trenchless techniques can reduce environmental damage and social costs and, at the same time, provide an economic alternative to open-trench methods of installation.

(For further information on these installation techniques, see Recommendation ITU-T L.38).

1.2.1 Trenchless techniques and their applications

There are several different trenchless techniques. Their classification and detailed description are in Recommendation ITU-T L.38. The scheme of one of these methods is shown in Figure 3-5.

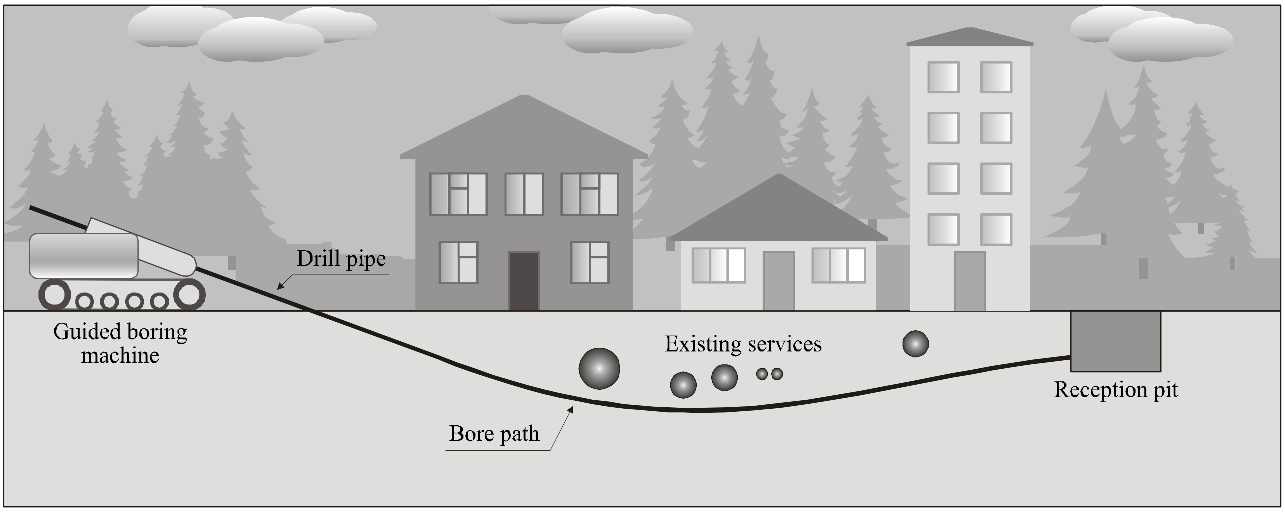


Figure 3-5 – General scheme of the directional drilling technique: drilling the pilot hole

From a general point of view, the trenchless techniques are very useful in the following situations:

i) where road surface excavation is restricted or prohibited by administrative agencies, etc. (newly constructed roads, emergency vehicle entrances/exits, etc.);

ii) where the open-cut method cannot assure safety or would cause risks to traffic and pedestrians;

iii) where noise, vibration, dust and other pollution are caused by open-cut method;

iv) where the open-cut method may impede road traffic and thus hinder the business of nearby stores;

v) where congested sections where open-cut method may damage the buried facilities of other companies or sections where the presence of buried objects causes significant lack of work efficiency;

vi) where conduits should be buried at deep locations and open-cut construction would greatly increase the amount of excavated soil;

vii) where road surfaces use high-grade material which would increase the cost of reinstatement after excavation;

viii) where road sections with high traffic volumes limit the work to the night-time hours (lower work efficiency, higher labour costs);

ix) where open-cut construction would involve extra costs to move historic remains or other items.

The choice of the most suitable technique to be adopted is related to each type of application, as outlined in the following.

Long installation lengths can be achieved (several km) by dividing the work length into shorter sections (100-200 m as an average). The length of each section will depend on the characteristics of the machines and the design requirements. Boring/directional drilling (both fluid-assisted and dry boring) machines should be used for this particular application.

River and railway crossings were the first applications of trenchless technology due to the fact that traditional digging techniques were not suitable. Surface-launched machines are often the best solution because obstacles can be crossed with a curved drilling path, thus avoiding the need to excavate deep launch and reception pits (especially in river crossings). It is possible to consider two different kinds of crossing with respect to the length and to the depth of the installed duct:

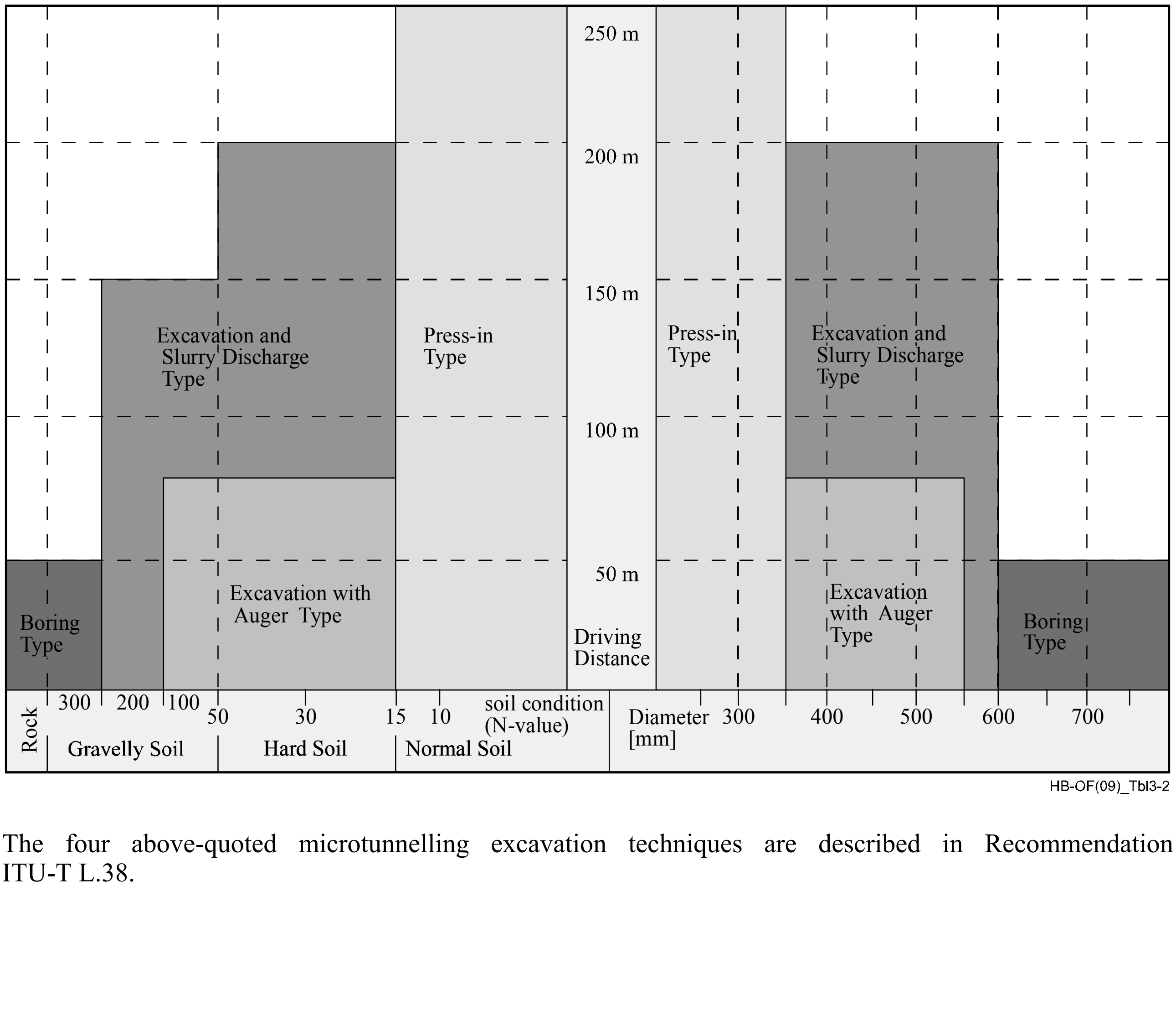
i) road and railway crossings. For both, the length of the drilling is normally not very long, so that both fluid-assisted and dry directional drilling machines can be used, or the use of micro-tunnelling systems depending on the duct diameter;

ii) river crossings. The length and the depth of the bore normally required are very long and deep, and it is important to avoid the excavation of big launch and reception pits on the opposite sides of the river. For these situations the drilling is started directly from the surface using a fluid-assisted directional drilling system.

Urban environments are also very attractive for the application of trenchless technology because it could avoid, or drastically reduce, the troublesome drawbacks normally created by digging work in urban areas. Due to the small diameters of the ducts and the short distance of each drilling section (manholes or chambers are normally very close together), a small and dry directional rig is used, in order to reduce the overall dimension of the working site, and to avoid flooding of the drilling fluid along the drilling path and the use of microtunnelling systems, depending on the duct diameter.

Moreover the choice of the trenchless technique to be adopted depends upon other elements such as the soil conditions. A general view of the impact of the soil conditions is given in Table 3-2.

Table 3-2 – Fields of application of different microtunnelling excavation techniques as a function of driving distance, tunnel diameter and soil conditions



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The four above-quoted microtunnelling excavation techniques are described in Recommendation ITU-T L.38.

Therefore, an investigation of the soil in order to get information, not only about the position of buried objects, but also on the nature of the ground is very important. There are several techniques for the investigation of the soil, which are detailed described in Recommendation ITU-T L.39. The data obtained by this investigation are necessary to plan the execution of work using trenchless techniques and to optimize the drilling path thus avoiding the risk of damage to both the existing infrastructures and the drilling equipment.

1.3 Installation of optical cables with the mini-trench technique

(For further information on this installation technique, see Recommendation ITU-T L.48).

The so-called mini-trenching technique allows the installation (in small trenches) of underground optical cables in ducts. The advantages of this technique over conventional cable laying technologies lie essentially in its speed of execution, lower cost, significantly lower environmental impact and limited disruption to road traffic and, as a consequence of the previous items, easiness in obtaining permits for the taking over of public area.

The mini-trenching technique can be applied on routes that generally involve asphalted surfaces such as roads and sidewalks with a compact soil subgrade.

It is not recommended that the technique be used on routes where the soil subgrade is sandy, gravelly or contains medium-sized cobbles (i.e., measuring 10 to 20 cm in diameter). If other underground utilities crossing a planned route already exist at a depth interfering with the depth of the mini-trench, this technology is not appropriate.

1.3.1 Traditional mini-trench (10 × 30 cm)

Mini-trenching is normally carried out by simultaneously cutting through the paving and digging a trench whose depth and cross-section vary in accordance with the number of ducts to be laid: depth is normally between 30 and 40 cm, while cross-section can vary between 7 and 15 cm. In order to guarantee a protection against impact resulting from road-repairing, the depth of the laid infrastructure shall be maintained constant at a known level that must be 5 cm deeper than the foreseen asphalt cutting depth normally specified for road surface repair works.

Figure 3-6 shows one of the possible installation configurations that can be used. Which configuration is selected will depend on the type of machinery employed and the number of ducts or cables envisaged in the project.

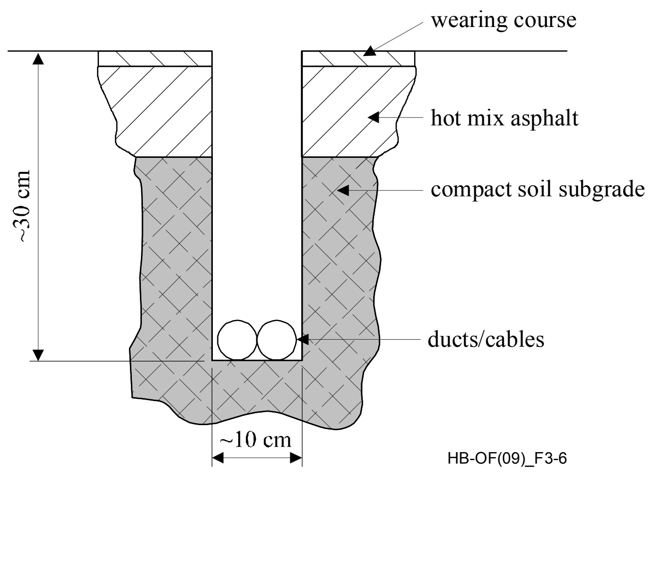

Figure 3-6 – Example of mini-trenching installation configuration

In cases where the mini-trench is dug along a road with no curb or sidewalk, the excavation shall normally be located at distance of around one metre from the edge of the road (or, if possible, just on the external side of the lateral line). In special circumstances where this is not possible, the mini-trench may be dug in the shoulder at the edge of the asphalt. Any crossings through unpaved sections (which must in any case have a compact subgrade) should be carried out using the same technique.

1.3.1.1 Traditional mini-trench preparation and duct/cable laying

The mini-trench is excavated using appropriate disc-type cutting machines.

The designed route shall be free from sharp changes in direction. Where such changes are unavoidable, they shall be made by means of cuts angled so as to comply with the minimum bend radius specified for the ducts and cables.

The location of all underground utilities must be determined in order to establish the correct route for the trench. This is normally accomplished by means of cartographic documentation provided by the administrations that own the road or by the utility company, and/or through instrumented field surveys. Where other means of determining the location of underground utilities are not available, ground penetrating radar shall be used at detection depths up to 1 metre.

The infrastructure or cables can be installed in two ways:

i) simultaneous excavation and ducts or cables laying. Reels can be mounted on board the cutting machine so that the duct or cable can be automatically fed into the trench, via a suitably shaped guide integrated into the ploughshare, as excavation proceeds. If obstacles or situations are encountered which make it impossible to proceed with the mini-trench, the reel (and thus the ducts or the cable) can be removed from the cutting machine without having to cut the ducts, thus ensuring that cable deployment can be continued using conventional methods without performing splices that are unnecessary from the technical standpoint.

ii) non-simultaneous excavation and duct- or cable-laying. After completing the excavation, ducts or cables are installed using the conventional method and in accordance with the requirements specified in the installation standard. Ducts and cables installed in trenches shall maintain their initial configuration and position in the excavation, unless special circumstances dictate otherwise.

After the ducts or cables are installed, the mini-trench is backfilled by pouring concrete (e.g. 200 kg/m^3 cement) with suitable foaming additives to ensure that a large amount of air is entrained, thus making the resulting structure mechanically as similar as possible to the soil subgrade surrounding the trench. In addition to securing the infrastructure in position at the bottom of the mini-trench, backfilling materials provide ducts and cables with mechanical protection.

Where interference with other utilities can occur and it is not possible to comply with the spacing requirements envisaged by current regulations, ducts shall be provided with mechanical protection in accordance with applicable standards and regulatory requirements.

Where the infrastructure is installed near trees whose roots could cause damage, it shall be protected by means of U-shaped galvanized steel raceways of suitable dimensions, equipped with covers and embedded in the same type of concrete backfill envisaged for the excavation.

Resurfacing should be delayed until at least 24 hours have passed from the time the mini-trench was backfilled.

1.3.2 The enhanced mini-trench

Further mini-trench technique development has resulted in a new solution in which all phases of duct/cable laying are simultaneous.

In details, the enhanced mini-trench is characterized by reduced dimensions of 5 cm wide and 30 cm deep (mini-trench 5 × 30), In the enhanced mini-trench 5 × 30 it is possible to lay one Ø 50 mm duct or two (one laid upon the other) (Figure 3-7).

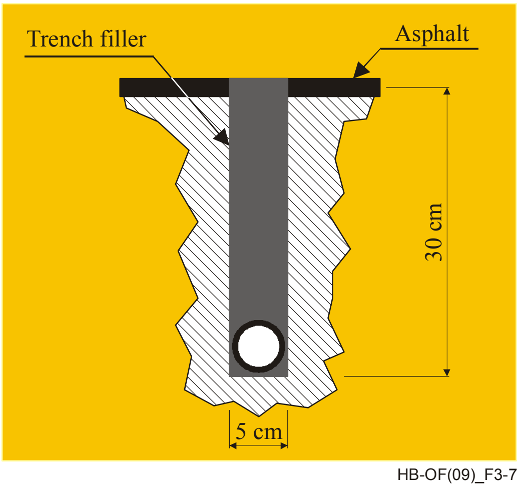

Figure 3-7 – Example of mini-trench 5 × 30 cm configuration

The enhanced mini-trench allows one to operate with smaller machinery on narrow roads, producing a lower quantity of waste material and thereby reducing operating expense. In order to execute the mini-trench 5 × 30 technique, a new digging technology can be used, characterized by the simultaneous use of a trench saw and a suction pump, by rapid excavation, and by the use of a very fast hardening material to fill-in the trench (Figure 3-8).

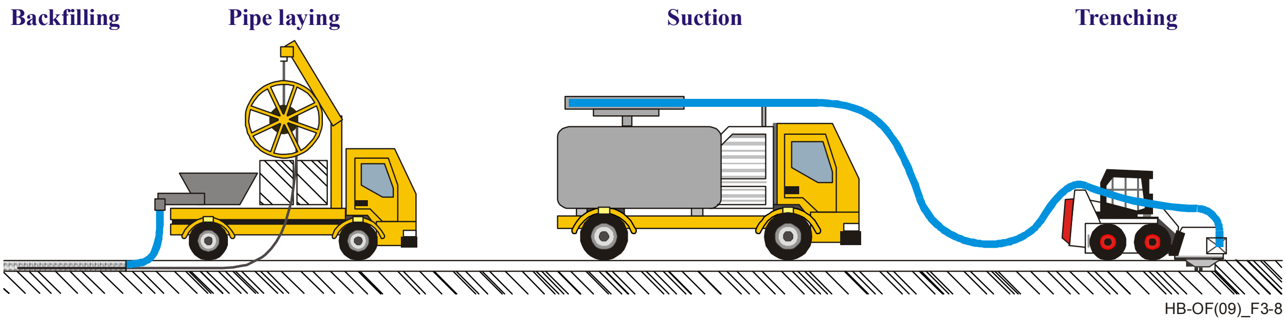

Figure 3-8 – Schematic layout of enhanced mini-trench 5 × 30 cm technology

This advanced solution allows both flexible use of smaller machines and reduction of time and space occupancy (Figure 3-9).

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Figure 3-9 – Example of application of enhanced mini-trench 5 × 30 cm technology

So, this solution can operate both in urban and in non-urban environments. All the construction activities are split into separate operational steps involving subsequent phases:

i) trenching dig phase, characterized by small size saw disks, allowing utilization of small operating machines;

ii) material debris suction phase, characterized by innovative operation(sawing and debris suction/ removal carried out at the same time), sharp and clean trench, debris suction and immediate loading on a debris removal truck;

iii) backfilling phase (after cable/duct laying), characterized by use of highly resistant and fast hardening material, no waste of back filling material, lack of bitumen materials, vehicle traffic restoration within 1 to 2 hours, high compatibility with mechanical and visual characteristics of existing pavement surface.

1.4 Installation of optical cables with the micro-trench technique

(For further information on the installation with the micro-trench techniques, see Recommendation ITU-T L.49.)

The micro-trenching technology can be applied on routes that involve asphalted surfaces, such as roads or sidewalks with a base of compact material (asphalt or concrete).

Its advantages over conventional cable-laying technologies lie essentially in its speed of execution, major reduction in infrastructure deployment costs, and significantly lower impact on the environment and on road traffic.

Protection against breakage from road reparation is not possible due to the shallow depths used in micro-trenching techniques. It is therefore essential to carefully plan the routes on which these techniques are to be used, in order to provide long-term stability of the routes.

Micro-trenching is normally carried out by cutting a shallow groove in the asphalt (better if not less than 7 cm), but without penetrating past the asphalt layer. Care must be taken to avoid cutting entirely through the asphalt, as this could cause the pavement along the sides of the groove to crack or split.

This precaution must be borne in mind in all cases where there is no lateral protection on one or both sides of the groove, which can prevent the asphalt layer from shifting, and particularly in cases where micro-trenching is performed along the edge of a road with no curb or sidewalk. In such cases, the groove shall normally be located at a suitable distance (e.g. at least one metre) from the edge of the road.

Groove width may vary (e.g. 10-15 mm) in accordance with the diameter of the cable laid.

The cable should meet exacting demands as to crush resistance and, in particular, temperature resistance, which is needed when sealing the cable in the groove with hot bitumen. The bitumen temperature during the sealing operation can reasonably vary between 100° C and 170° C.

The optical fibres are preferably enclosed in a metallic (e.g. copper) tube filled with a suitable filling compound and surrounded by a polyethylene jacket. There are currently in use different cable types, containing varying numbers of fibres and with different outside diameters.

The cable can be manufactured and supplied in long lengths; in city networks it is, however, often convenient to use short or matching lengths, particularly for crossing under road or rail.

1.4.1 Micro-trench preparation and duct/cable laying

As is customary, a detailed survey of the route must be carried out, the purpose of which is to identify the work required to be done before starting cable installation operations. Such work could include, for instance, the preparation at bridges, or at road or rail crossings. Furthermore, it is necessary to determine closure locations and section ends.

The route subsoil, i.e., asphalt thickness, road or sidewalk composition may have to be investigated by test drillings.

Micro-trenching is performed using an asphalt cutting machine. Cutting speed will depend on the type of machine used. The route shall be free from sharp changes in direction. Where such changes are unavoidable, they shall be made by means of cuts angled as illustrated in Figure 3-10.

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Figure 3-10 – Sharp change in route direction

The cable can be installed manually in the micro-trench, laying it gradually off the reel and into the bottom of the groove with the aid of a reel trolley.

While changes in direction are permissible, care must be taken not to exceed the minimum cable bend radius.

A retaining strip (e.g. an expanded polyethylene strip) shall be run into the groove, above the cable, to fix it in place inside the groove. The retaining strip shall then be covered by a highly water-repellent filling material (e.g. a rubber strip), whose dimension shall be slightly greater than the groove cross-section. Each strip shall be fixed in place using a suitable roller.

In addition to securing the cable to the bottom of the groove, the primary function of these filler materials is to provide mechanical protection for the cable. The rubber strip also provides thermal protection.

After the cable and protective strips have been installed, the groove shall be closed with hot liquid bitumen. To ensure that the bitumen adheres to the side walls of the groove and creates an effective seal, a liquid bonding agent (primer) shall be first applied to the entire length of the groove and the groove edges. Liquid bitumen shall be applied using an appropriately sized nozzle. This operation shall be performed in a way (e.g. two consecutive passes) to ensure that the groove is filled uniformly up to road level. To ensure that the groove is correctly filled and sealed, the primer and bitumen shall be compatible.

At the end of the operations described above, measurement shall be carried out (e.g. by means of a wheel track) in order to ensure that there are no uneven edges, steps or irregularities along the cable groove as a result of overfilling with liquid bitumen. These conditions must be maintained over a long period of time.

The micro-trenching cable laying technique is typically used for customer drop connection to the distribution network (connections to existing networks).

These connections shall normally be routed along two physically separate paths.

In addition to the information which is normally required (cable route, type of installation, installation in road, sidewalk, etc.), cartographic documentation for cables installed using the micro-trenching technique shall also indicate reference depth relative to known datum points.

1.5 Installation of aerial cables

1.5.1 Installation methods

Installation methods of optical aerial cable include the normal practices for both self supporting cables (all-dielectric or including a metallic element) and lashed cables (e.g. attached to a pre-installed tension strand).

The mechanical stresses and, therefore, strain experienced during aerial cabling are generally less than those induced during underground placing and in a mixed underground/overhead route underground cable may, with care, be used for overhead sections.

1.5.2 Cable protection methods

In general, where end-pull or distributed pull methods are used, the various types of systems indicated in the above clauses to protect the cable from excessive strain during installation may be employed for aerial cable and it is good practice also 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 must be constructed to withstand lashing. The lashing-wire tension must also be carefully controlled. Great care must be exercised when handling cable in aerial route installations.

1.5.3 Winching and guiding systems

Provided the need to protect from overload and over-bending is borne in mind, most normal aerial cable installation winching equipment including end-pull winches, intermediate winches, controlled cable feeding devices, etc., can be used (Figure 3-11). For long length installations, where end-pull or distributed-pull systems are used, it is very important that proper guiding equipment is provided at positions where sharp changes of direction occur, and every effort should be made to ensure pulling-in at an even speed.

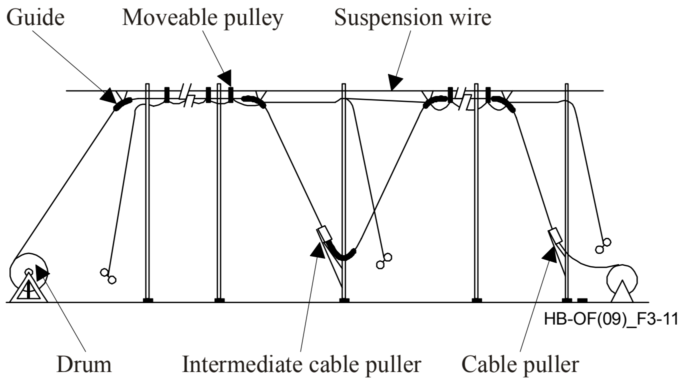

Figure 3-11 – Aerial cable pulling through system

1.5.4 Methods to maximize lengths

Where relatively unrestricted access to the route is possible, it is feasible in many cases to install, using a variety of normal methods, very long lengths of aerial optical fibre cable with the main limitation being only 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 must 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. A way of reducing or limiting the strain in the cable during installation is to use the moving reel method, i.e. the cable is attached to the strand as the cable reel is moved along the pole line.

1.5.5 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. This length at each end of the cable must 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.

1.5.6 In-service considerations

Great care should be taken during cable installation to minimize fibre strain, and with aerial routes in particular, steps to ensure that strain levels remain within manufacturer's recommendations during service. All types of movement, whether produced by cable weight, thermal changes, ice loading, or wind dancing, produce strain that must be taken into account and minimized where possible.

Where wind and/or ice and snow loading is anticipated or for long spans it may be necessary to use a higher strength strand than normal to prevent excessive strains due to sagging. Furthermore, the possibility of excess induced strain must be considered if an optical fibre cable is lashed to an existing cable. Cable dancing due to wind can cause excessive fibre strain in an aerial optic cable. Methods should be employed, such as dampers and springs, to reduce cable dancing.

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.

1.6 Installation of buried cables

1.6.1 Installation methods

Normal buried cable installation methods, including ploughing (direct, vibratory or winched), trenching and moling, can, in general, be used for direct burial of optical fibre cable, provided the cable is specifically designed for this type of application (Figure 3-12). 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, back filling materials and practices may require particular consideration so that fibre strain limits are not reached during this operation.

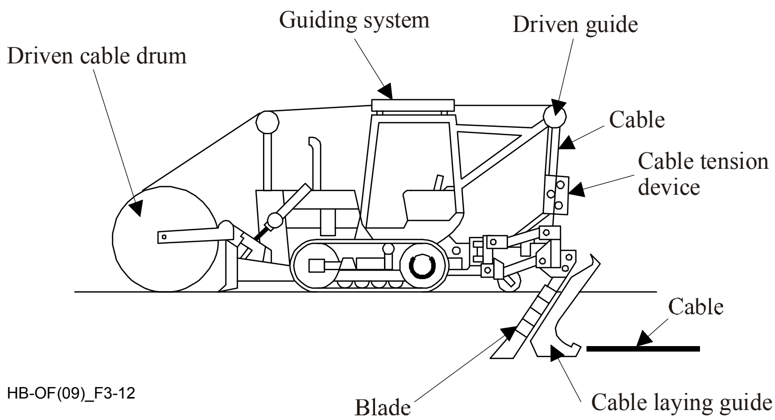

Figure 3-12 – Installation by cable ploughing

1.6.2 Cable guiding and protection

When ploughing methods are used the design of the guiding equipment between the cable reel and the cable laying guide must take careful account of specified cable bending criteria and have a low friction value to prevent fibre overstrain. Cable 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.

1.6.3 Methods to maximize 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 slitting or trenching can be beneficial. A moving reel technique may also be used to maximize lengths installed.

1.6.4 Jointing length allowance

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

1.7 Installation of cables in tunnels and on bridges

Winching optical fibre by end-pull or distributed methods in tunnels can be considered a special case of cabling in ducts, and those methods and considerations indicated above for ducts apply. However, where cable is laid out and manually inserted onto trays or bearers, care must be taken to ensure that support geometry and handling operations do not contravene the specified bending criteria. Cleating and fixing systems must be suitable for use with optical fibre cables.

The normal considerations for placing metallic cable also apply to optical fibre cable to be laid on bridges, 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, could lead to excessive fibre strain and suitable cable restraints should be used.

1.8 Installation of optical fibre ground wire (OPGW) cable

(For further information on this type of installation, see Recommendation ITU-T L.34.)

Optical fibres are particularly suitable for use on the aerial power lines in high-voltage networks, because they are immune by electromagnetic influences. There are several types of cable and installation technology.

Among them, Optical Fibre Ground Wire (OPGW) cable technology is specifically designed for high-voltage power line installations. OPGW has the advantage of using the ground wire of a power line also for communications. However, users of OPGW need to be aware that if the cable fails it may not be repaired quickly. Therefore, an alternative routing for the optical circuits needs to be considered.

These cables consist of a nucleus containing optical fibres and an armour, generally composed of one or more layers of aluminium wire, steel wire or aluminium-coated steel wire. The additional features of these cables compared to others types of cable are basically as follows:

i) greater tensile strength;

ii) protection of fibres against excessively high temperatures when high current densities occur in the cable.

The following factors should be considered in determining the type of cable, maximum tension and the installation plan:

i) maximum short-circuit current through the cable;

ii) disconnection time of a short-circuit to earth;

iii) sag of the phase conductors;

iv) spans;

v) positions in relation to poles;

vi) maximum wind speed;

vii) maximum ice load;

viii) other aspects such as: risk of atmospheric discharge, fire, discharge of bird-shot, saline fog, aggressive chemical agents in the atmosphere.

The following installation materials and equipment should be used:

i) anchoring units. Used to lash the cable to the poles where necessary, they should be able to withstand installation tensions even under the worst working conditions envisaged (wind, ice), without damaging the cables or affecting their useful life;

ii) suspension units. Placed on poles that do not have a cable anchorage to support them. Their characteristics should be the same as those of the anchoring units;

iii) vibration suppressors. Used to absorb vibrations produced by the wind;

iv) pole clamp element. Used to fasten the cables and splice cases to the poles;

v) payoff reel with a brake in the spin axis. Used to maintain a certain tension in the cable to be installed;

vi) cable grips with anti-rotational device. Used to attach the OPGW cable to the pulling rope;

vii) sheaves. Located at the poles and used to guide the pulling rope and the cable during the installation procedure. To prevent damage to cable during installation, a minimum sheave diameter is needed. That diameter depends on the type of cable, the tension applied to it and the degree of deflection (typically 25 times the diameter of the cable or as recommended by the cable manufacturer);

viii) capstan. Used to pull the draw rope;

ix) splice cases. Used to house the fibre splices.

Recommendation ITU-T L.34 outlines the precautions that should be taken when handling the reels, all the steps necessary to string the cable, and what should be borne in mind for splicing.

1.9 Installation of optical cables along railways

(For further information on this type of installation, see Recommendation ITU-T L.56.)

Railway companies have become interested in laying optical cables along their own infrastructures. These installations could be used for internal communications of the railway companies, or be offered to other customers for public telecommunications.

Moreover, telecommunication companies could use the railway facilities to provide telecommunication services to their clients.

Types of cable and infrastructures used in these installations can be very different.

The cable core may have different configurations: tight tube, loose fibre in tube, loose fibre in groove and ribbon. Usually, the most common configuration is loose fibre in tube.

The type of sheath and armouring of the cables depends on several factors: design of the cable, method of installation and kinds of infrastructures to be used. Generally, totally dielectric cables or armoured cables with corrugates steel tapes, can be used in direct burying and in ducts installations. In aerial applications, totally dielectric cables are recommended. Another alternative to these aerial cables are Optical Fibre Ground Wire (OPGW) cables (see § 1.8). In this case, caution must be taken in order to avoid problems in the signalling system or traction line of the railway.

Several types of installations can be used: ducts, directly buried or aerial. In case of metallic armouring, periodic ground feed-through should be implemented. Recommendations ITU-T K.33 and ITU-T K.53 give guidance of this issue.

The choice of one among various types of infrastructures depends on the environment (urban area or rural area). Existing infrastructures should be used wherever possible. A study of environmental impact, regulations in each region and economic factors should be carried out in order to decide on the type of installation.

1.9.1 Duct installation

In duct installations, different cable designs can be used: totally dielectric cable, or metallic armoured cable.

Depending on the cable design, they should be installed in the duct by any of the traditional or blowing methods. In any case, all the precautions about handling cable, splice boxes, storage of excess length of cable and personal security should be taken into account.

In the case where the cable is laid into a concrete trench, which is then covered with plates, armoured cable is recommended.

1.9.2 Directly buried cable installation

In directly buried cable installation, it is recommended that a cable designed to protect optical fibres from external shocks, attacks from rodents, or any other harsh environmental conditions, should be chosen. Armouring with corrugated steel tape or any other type should be considered.

Any of the traditional methods of installation should be used, depending on the cable design.

1.9.3 Aerial installation

In aerial installations, the use of totally dielectric cables, is recommended. In some cases, armouring the cable against hunters, squirrels or birds might be necessary depending on the environmental conditions.

An alternative to the use of totally dielectric cables, could be the use of Optical Fibre Ground Wire (OPGW) cables. When using this type of cable, care must be taken to avoid any trouble with the signalling system or traction line. The aspects raised in Recommendation ITU-T L.34 should be taken into account.

Usually, poles of the railways power supply line shall be used for suspending or anchoring the cable. Another possibility is to use additional line poles, which could belong to the telecommunication provider.

Pole material for railways power supply can be concrete or iron. Additional line poles should be made of wood, concrete, steel, fibre or plastic, depending on the costs and environmental impact study.

1.9.4 Cable installation along existing railway poles

(For further information on this type of installation, see Recommendation ITU-T L.56.)

When using the railway's power supply pole line in the installation of the optical cable, cable can be suspended from the field side or from the railway side.

Minimum vertical distance from ground level (when cable is installed on the field side) or from the top of the rail (when cable is installed on the railway side) to aerial cable shall be more than 5 metres and less or equal to 10 metres. Horizontal separation from the live conductor will depend upon the design of the pole line, taking into account the safety requirements for workers.

Span length (distance between poles) depends on the laying characteristics and the cable design.

A nominal cable sag not exceeding 3% is recommended.

Cable should be suspended on all the poles in the appropriate way, depending on the cable design and the laying characteristic. A common way to do it is using clamps or pulleys.

At special positions (splice points, end of the route, every given number of poles, etc.), the cable should be fixed to the pole.

1.9.5 Particular cases

Cable installation through singular points, like tunnels or bridges, requires some additional protection or special precautions (e.g. fire retardant sheaths).

In case the cable is installed in tunnels, it shall be bound in an appropriate way: fixing it on a support, on the wall with staples or using ducts.

In case the cable is installed on bridges, it is recommended to use ducts.

1.9.6 Splice points along railways

When splices are installed in manholes, the suitability of making the splices inside or outside the manhole should be considered, as well as the characteristics of the splice box, cable, manhole and personal security. In any case, a length of cable should be stored in the manhole in order to allow the correct fulfilment of the splice. Usually, a minimum length of 5 metres from each end is recommended when splicing takes place inside the manhole. When splicing takes place outside the manhole, a minimum length of 10 metres is recommended. Anyway, stored cable length will depend on the characteristics and dimensions of the manhole and the splice box.

In aerial installations, splicing can take place on the top of the pole or on the ground. As in the previous case, a length of cable should be stored in the pole for cable splicing purposes. Stored cable length will depend on the position of the splice box and the place where the splice is carried out. The suitability of making the splice at the top of the pole or on the ground should be considered, according to personal security and the characteristics of the cable and the splice box.

In any case, cable should be wound and fastened in such a way that the minimum bending radii indicated by the manufacturer is respected.

Inside the manhole, the splice box should be fixed directly on the wall or using an appropriate support, depending on the box design.

In aerial installations, it is recommended fixing the splice box on the pole, avoiding fixing it in line with the cable.

It is recommended to avoid the installation of the splice box inside tunnels or bridges. If it is not possible to avoid its installation inside a tunnel, the splice box should be fixed on a support or directly on the wall.

1.10 Installation of cables in sewer ducts

(For further information on this type of installation, see Recommendation ITU-T L.77.)

Optical cable installation in sewer ducts presents many advantages compared with traditional trench installation techniques, such as: less time for cable laying, not limited by weather conditions, increased protection of cable against damage, no traffic disruption, no noise pollution, no excavation, no damage to road surfaces and underground installations, no heavy equipment, no inconvenience to businesses or to citizens.

In general, there are two categories of sewers: man-accessible and non-man-accessible sewers.

The definition of whether a sewer is man-accessible or not depends not only on national regulations, but also on the individual regulations of different sewer network operators. Usually, non-man-accessible sewers have diameters between 200 mm and 700 mm.

Installation in non-man-accessible sewers is carried out with the help of robots. In man-accessible sewers, both robot-assisted and manual installation of cables is feasible.

Basically, there are three different methods to install optical cables into sewer ducts:

i) traditional optical cables or micro-cables, designed to be installed in protective ducts which have to be installed before the cable installation;

ii) self-supporting optical cables, designed to be directly suspended at the top part of sewers;

iii) special armoured optical cables, designed to be directly installed at the bottom of the sewers.

The sewer optical cables and/or related infrastructure should be designed and manufactured for an expected operating lifetime of at least 15 years. It should be possible to install or remove the cable to/from the sewer throughout the operation lifetime. The materials in the sewer optical cable and/or the related infrastructure shall not present a health hazard within its intended use.

1.10.1 Sewer assessment

Exact information about the structural condition of the sewer networks in which cable systems are to be installed is to be considered as a prerequisite. It must be clarified whether the pipes are suitable with respect to their structural/operating condition, capable of being used for the installation of an optical cable. Furthermore, in the case of non-man-accessible sections, it must be determined whether these are suitable for installation by a robot. Thus, for example, significant structural changes in the sewers (collapse) or promontory pipe junctions can hinder the use of robots or even make their use impossible if other remedial measures are unable to solve the problem.

The static bearing capacity of the sewers and their suitability for rehabilitation measures must be estimated using the results of the assessment. Equally important to the assessment of the static bearing capacity, the hydraulics must be checked with respect to the reduction of the section caused by installation of the cable. This will determine whether one or, if necessary, even several cables can be installed in a pipe or sewer. In planning the cable routes, the experience of the sewer network operator with respect to loading and strategic planning for the future, additional discharges into the sewer must be taken into account.

The operation of the sewer networks must not be affected by the installation of cables. The cables must adhere as much as possible to the pipe ceiling. The technology used must also ensure that the sewer ducts are not damaged during the installation or the operation of the cable network. In the area of the manholes, the cables must be laid so that solids cannot be caught on them and in such a way as to ensure safe accessibility to the manhole.

A suitable grounding system is documented to avoid the formation of high induced voltage and sparking, which is absolutely not acceptable in locations with explosion hazards, such as the sewer systems. At the entry and exit of sewer pipes, a connecting point for equipotential bonding between all the metallic parts of the infrastructure and the cables must be provided, measured and documented.

1.10.2 Installation in non-man-accessible sewers

Installation in non-man-accessible sewers is made by robots and shall be damage-free when using all types of pipe material (vitrified clay, plastics, concrete, etc.). 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. Later alterations and extensions of manhole installations and/or of the telecommunications network shall be possible.

The optical cable infrastructure consists of protective conduits fixed, by using a robot, to the sewer duct by special clamps equipped with clips. All the materials used for the infrastructure in the sewer pipes must be of stainless steel type to ensure the mechanical protection in the sewer environment and the protection against rodents for the optical cable.

Protective conduits shall be corrugated tubes. The corrugated steel tubes are available with an outer diameter of 11.5 mm or 15.5 mm in order to cause only a negligible reduction of cross section.

Flexible cable trays can be used to guide and protect the optical cables in sewer manholes if the protective conduits cannot pass the manhole or if an over-length storage box or a cable closure has to be installed in the manhole.

All the parts shall be designed to guarantee the minimum allowed cable bending radius on the entire network installed into the sewers.

The optical cables are blown into the conduits. The necessary equipment and procedures are similar to the standard installation of optical cables outlined in § 1.1.8.

It is recommended that the maximum diameter of the cable be 70-80% of the corrugated steel tube diameter. For example, for the installation in a 11.5 mm corrugated steel tube, the maximum diameter of the cable is 9.2 mm; for a 15.5 mm tube, the maximum cable diameter is 11.5 mm.

1.10.3 Installation in man-accessible sewers

The optical cable infrastructure consists of protective conduits fixed to the sewer wall by special clip holders equipped with clips, in which protective conduits can be fitted. All the materials used for the infrastructure in the sewer pipes must be of stainless steel type to ensure mechanical protection in the sewer environment and protection against rodents for the optical cable.

The clip holders are straps fixed by the operators with expansion bolts. The wall thickness in sewers with a nominal diameter of 800 mm and above allows for the holes drilled to accommodate expansion bolts without causing any problems. The maximum number of protective conduits to be installed depends on the clip holder size. In general, each clip holder allows the operator to install up to four clips and conduits.

1.10.4 Installation of special armoured optical cables into the sewer ducts

The installation of an optical cable pulled in and laid on the pipe invert is the easiest solution to deploying an optical cable. Fastening the cable into sewer pipes is not necessary because gravity keeps the cable on the floor. The condition of the pipe is not very important. Future development of the optical network and of the sewer system must be carefully taken into account, as their upgrade is quite difficult after installation. Access to the cable in every manhole is important in order to fix and survey the installation process, as well as for maintenance purposes.

As the cable lies on the invert of the sewer pipe, it is also recommended to plan maintenance operations and eventual pipe rehabilitation with liners, as in small pipes the cable might cause wrinkle formation in the invert area.

Bonding methods (fixing cables or conduits to the sewer by means of plastic bonding) are not recommended since a lasting bonding of the adhesive cannot be guaranteed, costly surface treatment would be required to prepare the bonding; later damage-free removal or adding of the conduits would not be possible, and the sewer pipes concerned would need to be completely drained.

Tightening methods (cable wound under high tension from manhole to manhole at the sewer top, a high tensile load of several tons is created by means of tension fixtures) are not recommended for several reasons: the tension fixtures exert tremendous tensile loads on the manhole shafts, which are usually not capable of taking such loads; rehabilitation with liners is difficult; and it can happen that the cable runs in front of a tap, which might cause a blockage of that tap.

1.10.5 Guidelines for the selection of the most appropriate installation method

The criteria reported in Table 3-3 shall be observed to select the appropriate method for the installation of optical cables in sewer ducts.

Table 3-3 – Comparison of installation methods

No.	Requirement	Special armoured optical cables	Infrastructure and conventional optical cables	Self-supporting optical cables
1	Applicable sewer pipe diameter	No limitations	From DN 200	From DN 300
2	Position in the sewer	Bottom	Top	Top
3	Sewer visual inspection before installation	Optional	Mandatory	Optional
4	Maintenance of the sewer	To be planned before installation	To be planned before installation	To be planned before installation
5	Risk of blockage	Depending on the water level and on the water flow	No	No
6	Upgrading of the optical network	Very difficult	Possible	Possible
7	Maximum number of cables and fibres	Maximum one cable (i.e., 144 optical fibres)	Up to nine cables (one in each corrugated steel tube)	Maximum two cables (i.e., 216 optical fibres each)
8	Flexibility of the optical network	Only for point-to-point connections	Very high	Medium
9	Access to optical network	No	Yes	Yes
10	Cable type	Special armoured	Standard	Self-supporting
11	Installation cost	Low	Medium	Low

Note – DN is Nominal Diameter.

1.10.6 Pressure washing and finishing brush

In general, sewer ducts must be cleaned every two years. Pressure washing using a high-pressure water washer and vacuum cleaning system are adopted. Therefore, any cable or conduit placed into a sewer must withstand the rigors of the pressure washing as frequently as every two years.

A finishing brush attachment is also used for detailed cleaning work. Since the brush is a little smaller than the sewer pipe, it can be pulled along the sewer pipe, loosening any debris that remains after the high-pressure washing. Cables and infrastructure must withstand the action of the finishing brush without damage.

1.10.7 Safety

Safety practices should follow the guidelines of local regulations and/or the state laws. Guidelines shall be observed that address confined spaces, hazardous underground utilities, trench safety, traffic safety, equipment safety and safety training. Personnel must be trained for those guidelines and regulations. There must always be a competent person trained to recognize dangerous conditions, to protect the personnel, and to manage the traffic with appropriate resources. All construction equipment and personal protective gear must meet guidelines and be kept in good condition. Prior to starting a project, a safety plan should be prepared and documented by the installer or the owner's designated representative. This plan should be implemented and followed by the personnel involved in the installation process.

1.11 Installation of marinized and submarine optical cables

(For further information on this type of installation, see Recommendations ITU-T G.971, ITU-T G.972, ITU-T G.976, and ITU-T G.978; Supplement 41 to the ITU-T G-series Recommendations and the ITU-T Handbook, *Marinized Terrestrial Cables*.)

As outlined in Chapter 2, underwater optical fibre cables are classified in this Handbook (according to the ITU-T Recommendations), in the three following categories:

i) marinized terrestrial cable;

ii) repeaterless submarine cable;

iii) repeatered submarine cable.

Marinized terrestrial cables are generally used for crossing lakes and rivers. Repeaterless submarine cable is suitable for use in both shallow and deep waters for lengths up about 300 km. Repeatered submarine cables can be used in all underwater applications, mainly for deep waters on lengths that require the deployment of submerged repeaters.

The installation aspects of these three types of cables have many points in common, so that a unique description is made in the following, while specific requirements for each type are given where necessary.

1.11.1 Survey and route planning

Prior to any marinized/submarine system implementation a survey normally is conducted in order to find the optimum route and to give the cable the optimum protection along this route. This survey is usually divided several phases.

1.11.1.1 Desk route study

The purpose of a desk route study is to assess the factors affecting the selection of a marinized/submarine cable route between the terminal stations.

The following items are investigated, as appropriate:

i) land routes and landfalls (suitable places for the beach closures or manholes);

ii) study of existing nautical charts;

iii) study of existing data over tide and sea currents, wrecks, other underwater cables (planned, existing, power or telecom) in the neighbourhood of the planned cable route. The same apply also for pipeline or over seabed installations;

iv) fault history of nearby located cables;

v) shipping activities;

vi) navigation restriction and military exercise areas;

vii) contact and cooperation with authorities and other interested parties (i.e. defence, port, maritime, public works and any other cable owners, etc.) in order to get permissions or relevant information;

viii) fishing activities, in particular in areas where the trawl nets and other fishing devices represent a risk for the integrity of the cable.

The desk route study for international submarine links should also determine all political, economic and practical aspects related to the presence of landing points placed in different countries.

All the above information put together results in a tentative route which can be further investigated, depending by the characteristics of the link, e.g. by its length. Such further investigation (route survey) is normally carried out with a small boat or with a special survey ship, once again depending on the link characteristics.

1.11.1.2 Route survey

Route survey is performed prior to cable laying so as to select the cable route and means of cable protection (lightweight protection, armour, burial). The route survey consists of studying the sea depth profile, the sea bottom temperature and seasonal variations, the morphology and nature of the sea bottom, the position of existing cables and pipes, the cable fault history, fishing and mining activities, sea current, seismic activity, laws, etc.

The route survey may not be required if a comprehensive desk study has been carried out, including site visits, or the proposed route is a short, shallow route (e.g. river crossing).

In a route survey it is essential to have high accuracy of navigation along the route. Today this is normally achieved by means of differential Global Position System (GPS) receivers or other high precision radio navigation methods interfaced to a PC calculating the position. Such equipment can have a typical horizontal accuracy better than ± 5 m.

The bathymetric investigation normally is carried out using an echo-sounder (sometimes with multi beam or rotating) along a pre-selected cable route in a corridor manner of an adequate width. In areas with steep slopes or very rugged seabed, the density of survey lines can be increased so that the result covers all possible hazards.

In order to be able to find obstacles along the route, side scan sonar is used. If the route is investigated with side scan sonar, it is sometimes favourable to have an overlap of the survey lines along the route corridor. Also, the width of the corridor must be such that a cable normally can be laid within the pre-selected width.

Especially close to the landfalls, but also in other cases, it could be useful to have a visual inspection and this can be performed using Remotely Operated Vehicles (ROVs). For very shallow water, a diver inspection should give the same result in a cost-effective manner. Divers can also sometimes provide some assessment of burial, e.g. by obtaining core samples.

In order to ascertain results from the route survey and determine the "burial feasibility", seabed samples (grab or core ones) are usually taken on sites where the geophysicist, in charge of the survey, deems it necessary. Taking the samples which have been analyzed (bulk density, water content, undrained shear strength, etc.), it can be easier to judge if a slope is stable or not, and to evaluate the cable protection and burial feasibility.

1.11.1.3 Route planning

The results of the desk study and of the electronic route survey, if necessary, are used to finalize the cable route planning. Before the manufacture and installation of the cable, the chosen protection is summarized in a Straight Line Diagram or presented in the form of a diagram or scheme accompanied by the appropriate list of positions (way points).

1.11.2 Characteristics of vessels

1.11.2.1 Survey vessels

A survey vessel is only normally required for long or complex routes, as highlighted in the desk study and agreed by the parties concerned.

The definition of a suitable survey vessel is very much dependent on where and when the survey has to be made. In protected waters quite a small vessel-of-opportunity might do, but for surveys off the coast, a conventional survey vessel may be necessary. The choice of vessel will depend upon the application.

The season is also of great importance. If the survey vessel must be used during a rough season, it must be of a bigger and sturdier kind.

In general, when the survey requires more than one day in open water, more requirements are usually necessary for survey vessels (room for equipment, adequate working space, communication facilities, good power supply, etc.).

1.11.2.2 Laying vessels

Generally, it can be said that important parameters for the vessel are:

i) cable handling according to the manufacturer's specifications;

ii) precise navigation equipment (differential GPS);

iii) professional manning.

Data on cable ships and submersible equipment (ROV Remotely Operated Vehicle, submersible ploughs, etc.) used worldwide are listed in Recommendation ITU-T G.971, together with their geographic areas of work and their owners. A representative drawing of one of these cableships is shown in Figure 3-13.

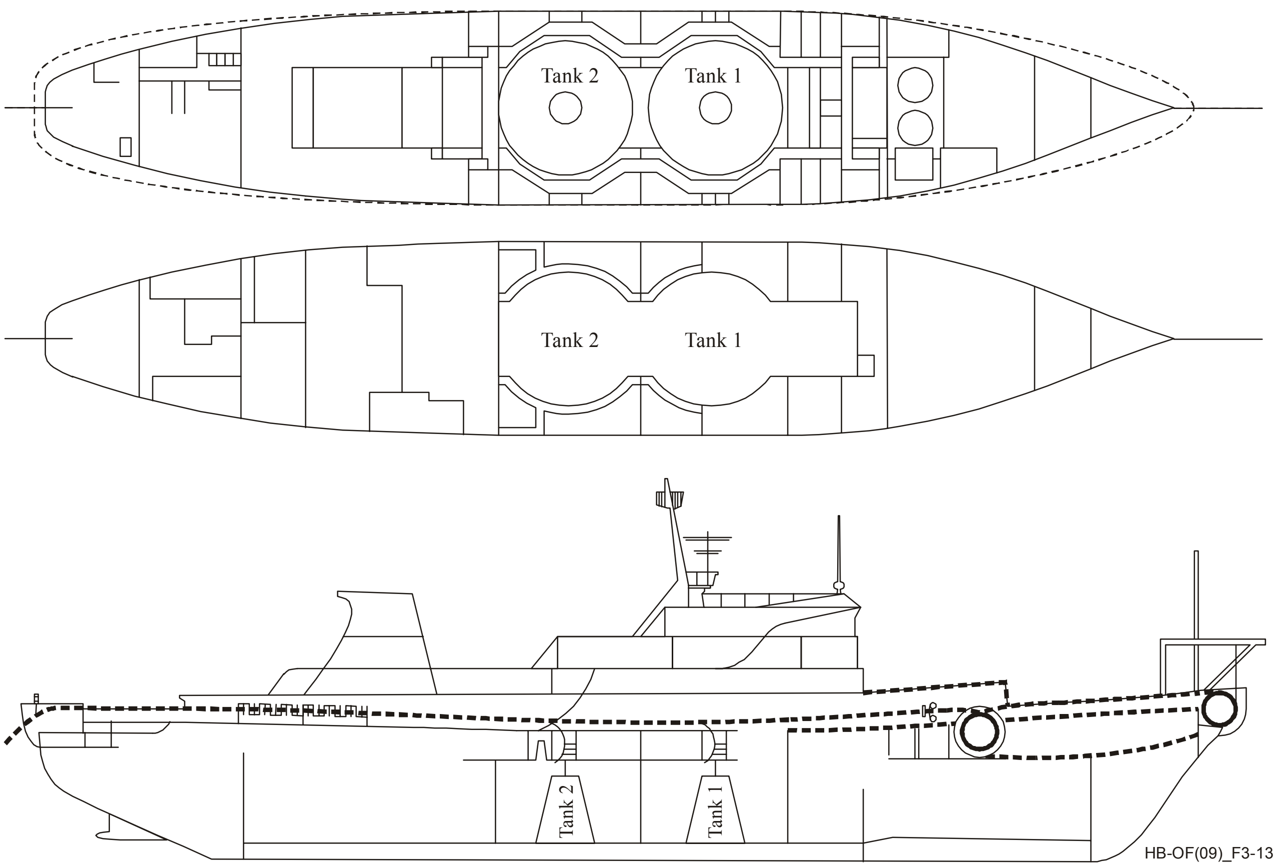

Figure 3-13 – Cableship suitable for laying long submarine cables

Depending on the application, vessels' general characteristics include, among others, the following: containerized equipment and control rooms, jointing and storage space, open cable tanks with elevated cable track ways.

1.11.3 Installation

The cable installation should follow approved procedures in order to guarantee the required lifetime performance of the complete system.

Installation techniques are different for various environments such as sea, river or lake.

1.11.3.1 Cable loading

Usually a submarine cable is manufactured in cable plants close to the beach in order to facilitate the loading aboard of a vessel. For marinized cables to be installed in rivers or lakes, with the cable to be delivered by terrestrial transportation, the loading method adopted is the same as that for terrestrial cables.

For this reason, only the loading technique for sea-going vessels will be presented in the following.

Before the loading, the whole cable length of the marinized and repeaterless submarine cables to be laid is jointed in order to cover the total link length. For the repeatered submarine cables the single elementary factory lengths are prepared in the factory. The cable, usually stored in coils, in pay-off tanks or turntables, is transferred aboard the vessel by means of a specially designed path passing through crane wheels, a pier and a system of driving rollers. In practice, a rope, having an outer diameter similar to that of the cable, is pulled up to the pier end. From that point the rope is removed from the cable end and another one, coming from the vessel, is fastened to the cable end. The cable is then pulled by the vessel machinery forming a catenary, to be controlled, between the pier end and the vessel. The pulling machine aboard of the vessel can sometimes be a linear cable engine.

The cable is then stored in coils in the tanks of the vessel having the two, or more, cable ends available for testing.

During loading, the control of such parameters as attenuation regularity, ohmic continuity (if applicable), pulling load, etc., should be monitored.

Care must be taken when storing the cables into the tanks in order to avoid uncoiling conditions, kinks, etc. During the loading, counter metres must be available along the cable gangway, both from the factory and from the vessel, in order to monitor the length of cables or the closure positions (if any) along the cable sections.

The loading speed depends on the tank size, vessel equipment, cable structure and weight. As an example, the speed for single armoured cables is typically 2-2.5 knots, and for double-armoured cables 1-1.5 knots. For closures, the maximum speed is typically 0.5 knots.

For the repeatered submarine cable systems, after the loading, the single elementary factory lengths are jointed to the submerged repeaters and to all the other submerged equipment in order to form on the cable ship the link to be laid without stopping the ship (Figure 3-14).

These systems should be tested during the laying and at the end of laying, so as to ensure that no significant system degradation has been induced. Laying testing includes transmission and functional tests, and may include tests on redundant subassemblies. To permit test during cable-laying, the link may be powered, provided that safety regulations are respected.

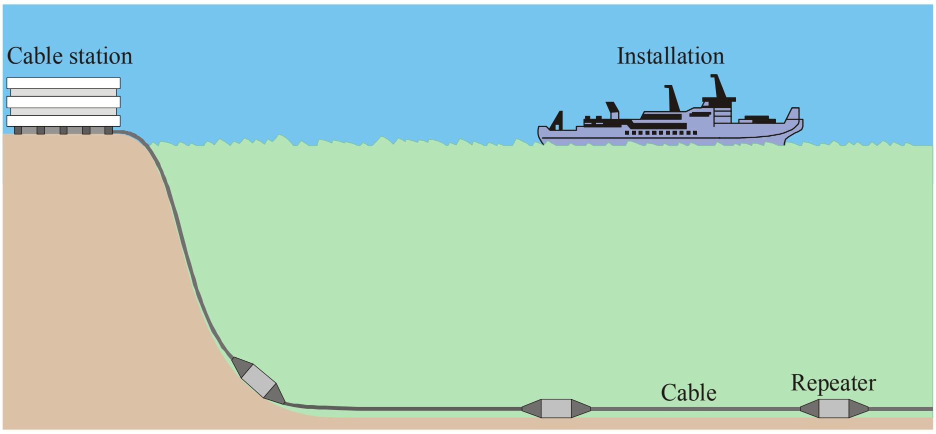

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Figure 3-14 – Laying of repeatered submarine cables

1.11.3.2 Shore-end operations

The shore-end operations are those performed to lay the first cable portion close to the coast. The laying activities must ensure the foreseen reliability and the lifetime of the link.

Usually, in repeaterless systems, the shore end is not separated from the main laying in order to avoid the so-called initial or final splice operations.

Taking into account the results of the survey, the vessel is positioned on the foreseen cable route, by means of previously calibrated radio-positioning system, at a distance from the beach suitable to guarantee safe activities.

When all the equipment and personnel are ready for the laying, the cable is drawn out of the vessel by a service boat and is floated by means of balloons. Such balloons are distributed at regular intervals depending on the cable weight and length.

The boat moves towards the beach assisted by divers and other boats in order to correct deviations from the route due to currents. When the cable is closer to the beach (about 100 m), a rope will be moored to its end to pull it up to the beach manhole, or directly to the station (if it is very near), by means of roller guides.

As soon as the cable is set on the landing route, the balloons will be taken off by the divers between the vessel and the beach. If it is included in the technical requirements, the cable will afterwards be protected by means of burial, articulated pipes, etc. Starting from the completion of the shore end operation, the main laying will start.

In the shore ends the cable may be buried in the seabed to increase cable protection. Burial can be undertaken during laying using a sea plow towed by the laying cable ship, or after laying using a self-propelled submersible robot or other means.

1.11.3.3 Sea laying operations

Laying is normally undertaken only when weather and sea conditions do not create severe risk of damage to the submarine portion, cable ship and laying equipment, or of injury to the personnel.

During laying, all appropriate measures should be taken to control the vessel's route, speed, and laying slack, together with the pulling tension applied to the cable. During the laying, an echo sounder is used in order to compare data related to the structure of the seabed in comparison with those resulting from the survey. With such elements, the required slope, slack and vessel speed can be adapted for the necessary laying conditions.

At constant vessel's speed, the cable is laid in a straight line and the slope depends on the cable type and vessel's speed. To adapt the speed to the seabed profile, the slope must never be less than that of the bottom. Otherwise, suspensions and risks of faults could occur.

Usually armoured cables are laid at a speed of 2-3 knots. In some cases it is necessary to reduce the speed due to particular bottom conditions. Anyway care must be taken in order to avoid the risk of kink formations.

During the laying, the slack parameter is under appropriate control in order to allow the cable to cover the bottom irregularities. Such slack is the percentage of the excess cable length laid with respect to the geographical distance covered by the vessel and allows the recovery of the cable for maintenance purposes. The slack to be adopted is usually decided on the basis of experience and any requirements arising from the desk study/survey reports (if applicable).

1.11.3.4 Laying in lakes

The procedures for laying in lakes do not differ much from those adopted in the marine sector. The main differentiation factors are:

i) it is impossible to load the cable on the lay vessel directly from the manufacturer and, therefore, it is necessary to transport the cable by land, on a spool, to the final location of the lay;

ii) it is more convenient to employ vessels already present in the basin and adapt them for the purpose or, if this fails, to utilize modular pontoons;

iii) particular attention would have to be given to the slack allowance of the cable because the slopes in the lake bottom may be higher than those in shallow sea water.

1.11.3.5 Laying in rivers

The laying of optical cables in rivers is undertaken only in situations where an aerial crossing is not possible, because river environments present complex problems. The laying itself is similar to that shown for short sections in lakes.

Actually, the stability of the cable and the stress and tension applied to it by the current, presents greater limitations in this kind of installation.

Particular attention is given to the type of cable protection adopted, and also to the considerable variability of sedimentary dynamics on the river bed.

An alternative to an aerial or submerged installation could be the construction of the crossing in a drilled tunnel under the riverbed, with techniques analogous to those used for oil and gas pipelines drilling.

1.11.4 Controls after the laying

After the completion of the laying, a check of the optical parameters of the cable is carried out in order to ensure that the design technical requirements are met, with particular attention to the total attenuation and cable margin. Moreover, an insulation test, made in order to verify the integrity of the cable sheaths, could be advisable. Such tests can be performed only if in the cable structure a suitable metallic element is available, which could be used for electroding purposes, if necessary, to help locate the cable.

The final as-laid report is intended for area operating companies of the cable network (for telecommunications and other services), for national hydrographic institutes and other interested authorities.

To allow other systems installers and operators to properly design routes for future submarine services, and to carry out safe maintenance over existing lines, the final report should contain, as a minimum, a general layout map with the whole cable route and a detailed landing point map.

1.12 Installation of indoor cables

Within buildings various types of optical fibre cable construction can be used and it is important to ensure that the most appropriate type for each part of the indoor network is employed. It may be that the bending criteria of the incoming cable is more stringent than internal types and it may be advantageous, where possible, to site line terminating equipment near the building cable entry or a cable riser.

Where cables are routed along the floor, a short straight route is preferable with cable passing through, rather than around, walls to avoid sharp bends. For under floor installation, computer type flooring is normally satisfactory. Non-ruggedized cable is best run in conduit, racks or trays, but care must be taken to ensure that turning points are properly constructed so that cable bending criteria can be satisfied.

Where cable is fitted directly to walls, care must be taken to ensure proper cleats and straps are used and that they are not over tightened. Much internal optical fibre cable installation is done by hand; therefore, the possibility of fibre overstrain during this handling should be borne in mind.

2 Safety, in-service protection and location

2.1 Safety

Additional safety precautions when installing optical fibre cable in duct, by direct burying, or in an aerial route relate mainly to proper handling and disposal of broken fibre. The fibre should be handled very carefully, because broken fibre can be very sharp and must be kept well away from eyes. Small pieces of cable or fibre must be collected and disposed of in suitable containers. Technicians must be made aware of the dangers associated with handling optical fibres.

2.2 In-service protection

Optical fibres are not susceptible to lightning surges, but they are usually incorporated in cables with a metallic content. Therefore, apart from the possibility of adopting non-metallic cable designs, the methods used to protect optical fibre cables are of the same type used for metallic cable adapted to suit the longer lengths, and the guidance of Recommendation ITU-T K.25 should be observed.

2.3 Location

Where optical fibre cables, with little or no metallic content in their construction, are directly buried, the question of location at a later date should be considered at the time of installation. It may be appropriate to use an over ground post marking system, or to bury a locating wire with the cable and use discrete buried markers at the splice points.