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WORKSHOP ON OPTICAL FIBER COMMUNICATION
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CONSIDERATIONS ON OPTICAL CABLE DESIGN.

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1) OPTICAL CABLE DESIGN

It is well known that optical fibre is a transmission medium capable of extremely high capacity, but to make use of this capacity the fibre must be protected from stresses which may cause it to break or change its transmission characteristics. Optical fibre does in fact have a high inherent strength, but the presence of microscopic flaws within the material can trigger breakage when subjected to quite limited tensile or bending stresses. These flaws, which are absent from the fibre when it is first produced, are rapidly initiated and subsequently grow due to mechanical abrasion and humidity. To inhibit this, a primary protective coating (for example acrylate, silicone rubber, or epoxy resin) is applied to the fibre during its manufacture. When coated with these materials the inherent strength of the fibre is preserved, even in a wet or damp environment. On average, the short-term breaking load is around 60 N in the case of a primary coated 125 um diameter fibre. However, over an extended period of time, the application of a tensile load to the fibre would cause a gradual growth of any existing flaws and consequently reduce its tensile strength.

With regard to transmission properties, optical fibre is particularly susceptible to a type of deformation which permits optical energy to escape from the core of the fibre. This deformation (micro-bending) will occur when a fibre is pressed against rough surfaces and causes an increase in transmission loss which may be substantial if it is spread throughout most of the length of the fibre.

Thus it is clear that to make effective use of optical fibres it is necessary to protect them from the effects of axial stress and microbending. This requirement, which must be met under all operating conditions and throughout the life of the system, is accomplished by the secondary protection of the fibre and the structure of the cable. To provide strain relief, the structures of all optical cables include strengthening elements. These elements (either metallic or non-metallic) are characterised by high mechanical strength and low coefficients of expansion, and their function is to restrict the deformation of the cable due to the installation or operating conditions, or the effects of distortion of the plastic materials in the cable structure through long-term exposure to heat.

1.1) Fibre protection

In an optical cable, special attention must be paid to the surface of materials which are in contact with the fibre, since the protective action of the cable structure depends to a large degree on the nature of these surfaces. Because of the importance

of this aspect, the components of the cable which actually contain the fibre are described as the secondary protection of the fibre.

Two general methods of providing secondary protection may be identified namely tight protection and loose protection. In the first method, protection is achieved by using suitable materials in intimate contact with the fibre. This coating has the twin task of substantially reinforcing the strength of the fibre and of protecting the fibre from the lateral stresses which could cause micro-bending. To carry out both tasks satisfactorily the coating often consists of two layers. Fig. 1 shows and example of this form of tight protection in which the fibre is coated with an inner layer of soft material to alleviate the effects of lateral stress, and an outer layer of material with a high modulus of elasticity to improve the strength and flexural rigidity. An alternative type of tight protection is the optical fibre ribbon. The ribbon is comprised of a number of fibres which are arranged in parallel and then sandwiched between layers of suitable plastic material.

The other method of secondary protection is loose protection. In this method the fibre is protected from any external stress, either axial or lateral, by being loosely contained by a structure which has a high degree of mechanical strength. An example of this is a tube, made of high modulus of elasticity plastic, with an inside diameter much greater than that of the fibre (typically 5-10 times). One or more fibres are arranged helically within the tube so that it is adequately protected from external stresses (Fig. 2).
Another example of the loose protection method consists of a plastic extrusion with a number of helical grooves which contain one or more fibres.

The protective tubes or the grooves may be filled with soft tight materials which still maintain the primary coated fibres in a loose like environment.

In the following we describe the criteria adopted for bothfilling and loose protection of optical fibres.
The cable designs are then completed, using correctly dimensioned reinforcing elements and suitable protective sheaths, to take account of the mechanical and thermal conditions encountered during installation and operation.

a) Tight Protection

In the case of stranded cables using tight protected fibres, the fibre is integral with the structure of the cable so that all the mechanical stresses applied to the structure, and those induced in the structure by changes in temperature, are transmitted to the fibre. It is therefore necessary to reduce the effect of these stresses on the fibre to the fullest possible extent. As regards axial stresses, causing elongation of the fibre due to installation tension or high operating temperatures, the effect may only be reduced by strengthening the cable reinforcing elements (metallic and non-metallic).*

By using a suitable secondary coating for the fibre it is possible to reduce the effect of lateral stresses which may cause an increase in attenuation due to micro-bending. However, it is also necessary to limit the negative effect of axial contractions of the protective materials at low temperatures. The following example demonstrates how a tight protection coating, which comprised several layers of materials, as in the construction type developed at Pirelli Group.

The aim of the design was to obtain a structure having geometrical and physical parameters capable of providing the coated fibres with the best possible protection against lateral compression, together with the required stability of their optical characteristics, in the widest temperature range. However, since the two requirements are intrinsically conflicting, a compromise is the only practical approach.

The design of such a sophisticated structure required optimisation by computer after theoretical models (verified by experimental trials) had been developed to define the effect of the different structural parameters on lateral protection and thermal behaviour.

A secondary coating, with the required characteristics, was developed by the Pirelli Group using a fibre which had a composite primary coating of acrylate resin. The secondary coating is applied in a single operation and comprises an inner layer of silicone rubber under an outer layer of nylon.

Using fibres coated in this way, it is possible to construct cables by traditional laying-up techniques, either in concentric or group formation, without degrading the optical performance of the fibres. It is also possible to further improve the resistance to lateral stress and temperature change, by using materials which have high rigidity and low coefficients of expansion for the outer protection of the cable.

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* Where the protection consists of extruded plastic materials it is also necessary to take into account the compression exerted on the fibre by the shrinkage of these materials after extrusion.

b) Loose protection

In the loose protection method, the fibre is protected from lateral stresses until the protective structure collapses. By the correct choice of material and dimensions for the structure, it is therefore possible to protect the fibre against lateral stresses of practically any intensity. The types of stress of greatest significance for the loose structure are axial compression and tension. A loose structure does in fact allow the fibre a range of paths whose lengths can be less than, or greater than, the length of the neutral axis of the cavity containing the fibre. Thus for each type of loose structure there exists a range of axial extension and compression which can be tolerated by the structure before the fibre comes under stress. This range is determined by two factors: firstly, the conditions adopted when applying the protection, which govern the initial path of the fibre within the loose structure; and secondly, the geometry of the loose structure within the finished cable. It is therefore not possible to separate the design of the fibre protection structure from the design of the cable itself when loose protection is employed. However, by taking account of the performance required from the cable it is possible to define the overall characteristics (geometric and technological) of the whole structure.

It is worthwhile to analyse the two types of axial stress separately. In the case of tensile stress the maximum elongation that the structure will tolerate, before the fibre comes under stress, can be unambiguously identified from the characteristics of the structure. In fact, assuming a knowledge of the initial position of the fibre inside the protection,* it is possible to calculate the maximum elongation applicable to the cable structure without the fibre being subject to axial tensile stress and lateral compressive stress against the walls. This elongation is reached when the fibre takes up the minimum length path inside the structure.

Unfortunately, the study of a cable in axial compression cannot be made so unambiguously because, when the structure is compressed, the path taken up by the fibre is random and essentially depends on local friction between the fibre and the walls of the structure.
The problem may only be tackled by recourse to parameters determined experimentally and specific to the various structures and technological processes used. For ease of calculation it is, however, possible to refer to a geometric model of the structure (compression is assumed to result in the fibre occupying a specific path) and then apply correction coefficients obtained by experiment. From the foregoing it is apparent that cables

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* This parameter is determined from subsequent tests on the finished cable

employing loose protection cannot be designed solely from theoretical considerations, and must take into account the experience acquired from tests on completed cables.

Loose protection cable designs include:- stranded assemblies of tubes containing one or more fibres; plastic cores with helical grooves containing one or more fibres; and single tubes containing a number of fibres.

The following example demonstrates the design criteria adopted for fibres which are individually protected by a loose tube and are then laid-up helically to form a concentric cable. The fibre is inserted into the tube during the extrusion process and the length of fibre incorporated, relative to the neutral axis of the tube, depends on the technological conditions employed for the operation (in particular, the output winding tension and the cooling conditions). By altering these conditions it is possible to obtain a fibre length which is greater or smaller than the neutral axis of the tube. Fig. 3 gives a schematic representation of the relationship between cable lay pitch and the range of possible paths, parallel to the neutral axis, that the fibre can assume without coming under either tensile or compressive stress. The diagram also illustrates the maximum and minimum path lengths that the fibre can initially assume, dependent upon the conditions adopted for the extrusion process. The maximum cable elongation value (ΔP_e) and the maximum cable compression value (ΔP_c) correspond respectively to the minimum and maximum path length that the fibre can take up without altering its own length. These values are obtained from the geometrical parameters of the optical core (central element diameter, loose tube dimensions, tube stranding pitch) and the fibre quantity put into the tubes. It should be noted that the minimum path considered is the absolute minimum inside the tube, whilst the maximum path is relative only to the family of curves examined (parallel to the neutral axis) and will not be obtained in practice.
As regards tensile stress, the elongation value $\mathcal{E}_e = \Delta P_e / P$ represents the effective permissible elongation for the cable; but for compressive stress the value $\mathcal{E}_c = \Delta P_c / P$ is assumed to be a reference only, and to this it is necessary to apply correction coefficients obtained by experimentation. Therefore, with simple geometric considerations for a specific cable structure, it is possible to obtain an analytical relationship between the elongation and compression values, the geometric characteristics of the tube, the laying-up pitch, and the initial position of the fibre with respect to the neutral axis of the tube. Figs.4 and 5 show qualitatively the maximum permissible elongation and compression values of the cable without stressing the fibre, and indicate the effects of changes in the internal diameter of the tube and the initial position of the fibre.

It can be seen how, when the pitch is increased, and when the diameter of the tube is reduced, the range of permissible axial deformation is restricted. However, provided that the range of deformation is sufficient, it is possible to improve the performance of the cable, either in compression or in tension by changing the initial position of the fibre.

By the use of diagrams similar to those illustrated, and by taking account of the performance required from the cable as regards tensile and compressive stress, it is therefore possible to define technological and geometric parameters for the type of loose protection adopted. Designs have been developed using the techniques described, and to date the most widely adopted solution has used a plastic (e.g. polypropylene) tube which has the dimensions up to 2 mm (Fig. 6). This type of coating offers protection against very high lateral stresses (Fig.7) and cables employing it have been produced using traditional laying-up techniques (either in concentric or group formation). The behaviour of the cables during changes in temperature, and when under tension, depends on the type of strengthening elements employed as well as on criteria previously discussed. In every case it has been found that absolute stability of the optical characteristics has been maintained throughout a specific temperature range. Outside this range random increases in loss or attenuation are experienced (Fig.8). Additionally, the tensile stress behaviour is characterised by a range of elongations throughout which the fibre is not stressed and its optical characteristics remain stable (Fig.9).

With this type of protection it has been possible to produce cables which have stable optical performances in the temperature range -50°C to +60°C, or are capable of absorbing elongation of up to 0.5% without stressing the fibre. The same considerations can be applied for the grooved optical core in which the fibres are loosely deposited with excess length inside a cylindrical extrudate having helical grooves. Also in this case the maximum compression or elongation that the cable structure can support without giving any stress to the fibres or increase their attenuation are determined by the initial fibre position and the geometrical parameters of the grooved core (core diameter, groove pitch, groove depth) (Fig.10). By suitably optimizing these parameters cables having the same performances of loose tube type have been manufactured. This solution is particularly attractive for its reduced dimensions and the potential simplicity of the manufacturing machinery; moreover the initial fibre excess length inside the grooves can be controlled with much higher precision than for loosely coated fibres. However compared with loose type solution, grooved core cables can present some peculiar drawbacks e.g. difficulties for end preparation. They seem mainly suitable for those applications for which cable size and stringent tolerances on fibre excess length are requested.

1.2) Hydrogen influence on optical fibre transmission characteristics

Due to its small molecular dimension, hydrogen diffuses quite rapidly through all known materials and in particularly in glass,

where the diffusion coefficient was estimated around $1,5 10^{-11}$ cm^2/sec. at 20°C.
Therefore, when a fibre is exposed to an hydrogen atmosphere, molecular hydrogen diffuses into the fibre until its concentration inside the fibre is in equilibrium with the outside partial pressure.
The effect of the presence of hydrogen inside the glass structure on fibre transmission characteristics are basically three (Fig.11).

a) Loss increase (absorption peak) due to diffused hydrogen molecules: this effect is completely reversible and has limited influence at the operating wavelengths (0.85 um, 1.3 um, 1.55 um).

b) Loss increase (absorption peaks) due to OH groups formed by chemical reaction of hydrogen with the various glass components namely Sylicon, Germanium, Phosphor. This loss increase is irreversible and is strongly accelerated by the presence of phosphor as a dopant.
The effect of this phenomenon is significant at 1.3 um and particularly at 1.55 um, while it is negligible at 0.85 um.

c) Loss increase (U.V. absorption peak) due to structural defects (colour centres) formed by hydrogen interaction with the glass structure. The tail of the U.V. peak extend its influence at all the operating wavelengths but its magnitude is a slowly decreasing function of wavelength. Moreover the loss increases are strongly influenced by the temperature.
The possible source of hydrogen in optical cables are mainly:

- out-diffusion from cable components
- metal corrosion reactions in presence of water
- electrolytic phenomena.

In order to ensure the full reliability of the optical cables a certain number of countermeasures have been taken:

- use of fibres with reduced hydrogen sensitivity. The reduction of phosphor content strongly affects the fibre sensitivity to hydrogen

- suitable cable design. A careful choice of cable structure makes it possible to drastically reduce hydrogen concentration inside optical cables

- use of hydrogen absorber. In order to reach full safety even in the most critical situation and to allow more flexibility in cable design, different types of hydrogen chemical absorbers can be provided as for instance by Soc.Cavi Pirelli(patent pending). These materials have the properties of permanently fix the hydrogen atoms to their molecular structure and they can be suitably processed in order to be embedded in cables during the manufacturing process for example as sealing compound.

2) OPTICAL CABLE PRODUCTION

Different types of optical cable structures have been manufactured with satisfactory results for the TLC apparatus.In the following, reference is done to examples of typical constructions mainly based on the experience done in the Pirelli Group. The difference among the various cable structures are mainly related to the outer protection that is strongly dependent on the external applied mechanical and thermal stresses that the cable has to substain during its service life.

2.1) Optical fibre cables for underground installation

The most significant conditions recognized to have an influence on the cable design, according to the laying technique (duct or directly buried) are summarized hereunder:

- necessity of ensuring optical transmission performances of the carrier in terms of attenuation and bandwidth, within a practical temperature range and for all the service life of the cable
- Presence of traditional copper conductor circuits (pairs or quads)
- Presence of metallic or non-metallic central strength member
- Presence of water barrier
- Condition of ducts or subducts
- Pulling length
- Presence of outer mechanical protection.

a) Duct installation
Types of optical cables that have the peculiarity of being at the same time robust and flexible, were developed.

Cable with tight buffered fibres. Usually this kind of cables is fully dielectric.Cable make-up can be either concentric or unit.
In order to eliminate the risk of longitudinal water penetration as a consequence of damages to the external protection, cables are fully filled.
Proper outer protection have been designed, such as sheaths of low modulus synthetic material (e.g. polyurethane), in order to eliminate the risk of mechanical compression stresses.
To ensure an adequate resistance to high mechanical stresses a protective layer of textile yarns, like aramidic fibres (Kevlar®) acting as peripherical strength member have been adopted.

-Cable with loose buffered fibres.Each single tube can include one or more fibres.Cables can be either metallic or dielectric.

Tubes are stranded together around a steel of fibreglass rod to form an optical unit.
In the case of unfilled cable a moisture barrier of aluminium polyethylene laminated tape (polylam) bonded to the outer polyethylene sheath can be applied.

This kind of cables can be fully filled: all spaces inside and outside the tubes can be filled with a special filling compound. The outer protection is similar to that one of tight buffered fibres. For both types of constructions (tight or loose) in order to provide a protection against rodent attack a light metallic armour can be applied.
In Figs.12÷15 are shown some examples of constructional details of tight or loose buffered cables suitable for duct installation.

b) Direct buried installation Cables suitable for this installation have usually the optical unit similar to that one of cables for duct installation but normally include an additional armouring layer to minimize the risk of damage from backfill, land movements, digging, rodents and other land work.
A very robust cable was developed where the metallic armour is made of a continuous welded corrugated steel tape.

In Fig.16 is shown an example of cable construction.

2.2) Optical fibre cables for aerial installation

Società Cavi Pirelli has developed optical aerial cables that can be installed in extreme environmental conditions.
The cable designs have to take into account the maximum stresses both dynamic and permanent due to overloads generated by ice and wind and environmental conditions such as wide and gradual daily temperature variations or sudden temperature changes due to alternations of sun and clouds.

Several types of cable have been designed with capacity usually not greater than 6 fibres and most of them are already in an industrial or experimental phase, namely cables to be hung to independent rope and self-supporting cables. Reference is made to cable types suitable for telecommunication overhead lines installed on poles, when the span lengths do not generally exceed 50/60 m.
Aerial cables installed by hanging them to independent ropes are to be considered in the safest conditions in terms of mechanical resistance versus environmental stresses induced by wind and ice. Moreover, under normal working load, no mechanical strain affect the optical cables as the rope is already installed and pretensioned when the cable is hung to it.
On the contrary the main problem in designing self-supporting cables is to reduce at a safe level the fibres permanent strain.

Therefore loose tube construction, both with stranded tubes or grooved elements, is generally used as the optical core.
Self-supporting optical cables contain a strength member which may be either external or peripherical to the cable core.
The former type is no doubt the most popular among conventional cables and allows to employ well-known and easily available fittings as they only come into contact with an external strength member.
The solution with external strength member involves the use of highly resistant steels, which are characterized by a linear elastic characteristic in the range of admissible strains and without any residual and significant permanent strain after application of cyclic loads.
The self-supporting cable with strength member concentric to the cable core shows instead the advantage of a quite smaller overall size and therefore smaller wind and/or ice overloads.
Figs. 17 and 18 show some examples of self-supporting aerial cables.

2.3) Optical submarine cables

a) Telecommunication Cables.
Due to its high transmission capacity and small dimensions optical fibres are particularly suitable for application in undersea transmission systems for which repeater spacing and cable size are the most critical factors. However taking into account the stringent requirements of undersea systems the cable manufacturers have to face a challenging task in the development of this particular optical cable.
The main concern with this design of cables is to provide a very high reliability that ensures the stability and integrity of the fibre transmission path for a system design life of at least 25 years.
The cable must meet several important design requirements for satisfactory system operation. They can be summarised as follows:

- to provide a pressure, moisture and hydrogen free environment for the fibres;
- to ensure minimum strain during all manufacturing and service conditions in particular during laying and recovering from deep seabed (4 km) or attack by anchors and trawlers of fishing vessels in shallow water;
- to allow a continuous production of long cable length (30÷90 km) by including factory splices of optical fibres;
- to provide a low insulated power feed conductor for the repeaters.

As example, it is described the submarine cable developed by Soc. Cavi Pirelli, for laying down to 4000 m, whose structure for deep sea is shown in Fig. 19 and that of shallow water in Fig. 20.

At the centre of the cable is an optical core made by 6 fibres tightly protected stranded around a metallic strength member and embedded in a high viscosity water blacking material. The fibres are single mode with high proof test level (1%). As an alternative structure for the optical core, a grooved plastic element can be used and in this case a significant extra length is given to the fibres inside the grooves in order to allow cable elongation without fibre stress.
The optical core is protected from external compression forces by an alluminium tube manufactured by assembling three segments whose section is fan shaped. An external double layer anti-torsional armour made of flat steel wires gives to the cable structure the required mechanical axial strength.
An outer alluminium or copper tube is provided as hermetic barrier and for power feeding.
The cable is finished with an extruded polyethylene sheath. An armour of steel wire is provided for shallow water applications. Its strength element is torsionally balanced so that negligible twist is generated when the cable is in tension and no cable elongation will result due to untwisting. This cable is therefore able to substain the laying and recovering and repairing strains without impairing fibre mechanical life.
On the other hand the combination of the external tube and the steel wires provide a highly pressure resistant structure to protect the fibres from external hydrostatic stresses.
As regards hydrogen, all the materials used in this cables have been checked for the hydrogen content and show reduced gas or hydrogen generation. Moreover, a special activated element has been introduced in the optical core filling compound in order to absorb the residual emitted hydrogen. Therefore the effect of hydrogen will be negligible for the system life.

b) Optical cables inserted in power cables.

The complexity of signalling and telecommunication systems needed for fixed or floating plants in the sea, generally in proximity of the coasts, has given rise to new requirements for the performance of telecommunication cables adequate to this task. These cables must in fact transmit a relatively high number of communications and signals up to distances of the order of some tens Kilometres, must operate very close to submarine power cables and consequently in an environment with several electromagnetic interferences and must be very strong from a mechanical point of view, due to the risk of damage which is very frequent in sea areas with shallow water and considerable shipping traffic.
The possibility of inserting telecommunication cables inside power cables is a target at which system users aimed for these reasons.

- A single cable can be installed having the double task of power and telecommunication transmission with a consequent economic advantage.

- A capillarity distribution of the telecommunication services is ensured to the different points of the power distribution system.

- The power cable, considering its dimensions and outer protection type, can represent a preferential way from the mechanical protection point of view, even for the telecommunication circuits.

As example, the composite (power+optical) cable developed by Soc.Cavi Pirelli is described, where the optical unit, that is located in the interstices of power cable, is generally constituted of a number of fibres not higher than 12, with such a geometrical configuration as to require the lower space. Fibre types can be either single or multimode having a diameter of 125 microns as standardized by CCITT and IEC.
These fibres are loosely protected by a plastic tube and are stranded on a central strength member and the so formed optical core is sealed and sheathed with synthetic material and protected with a continuous metallic layer (e.g. lead sheath or copper welded tube).
All the spaces in the optical unit, both inside and outside the tubes, are fully filled with special filling compound.
The optical core is covered with copper tapes that have the purpose of protecting the optical cable against teredos; this protection is generally necessary in shallow water, especially in warm sea.

Several technical problems had to be solved during design and manufacture of these cable types:

- prolonged operation in water under pressures which may reach 10 atm. In case of absence of continuous metallic protection on the optical cable, which acts as hermetic barrier resisting at these pressures, the fibre protection shall be such as to allow a troubleless operation.
  Considering the results obtained from hydrostatic pressure tests carried out for long periods on fibres suitably protected by means of synthetic layers with low water absorption and on finished cables, it can be stated that the fibre transmission characteristics are not subject to remarkable decay under the action of pressures up to 10÷15 atm.

- Choice of materials having a good resistance against environmental degradation at high temperatures, as for instance in the interstices between the power cores under normal operation conditions. Special synthetic materials such as acrylates, silicone fillers, fluoropolymers, fluorurated polyammides can be selected in order to reach the characteristics necessary to this purpose.

- Continuous sealing of the optical core. The sealing shall be realized in order to guarantee a complete water tightness also in the case of an accidental severance of the cable and also during operation.

- Factory length and manufacturing joints. Often composite cables have a required shipping length much longer that the maximum factory length, generally used in the terrestrial plants.
  The manufacturing technology must be such as to allow that the manufacturing lengths be of 5-10 km in order to minimise the joint number and to optimise the manufacturing process. The single manufacturing lengths have to be jointed during cable construction using suitable methods in order to avoid discontinuity points which will decrease the fibre transmission capability.
  The attenuation of each joint has to be limited to approx. 0.2 dB for the multi-mode fibres and to 0.3 dB for the single-mode fibres.

Fig.21 shows an example of a composite cable with an optical core placed in the interstices of power cable.

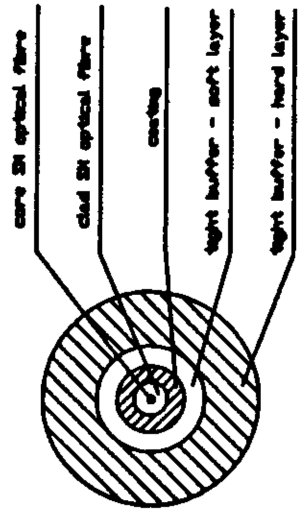
2.4) Optical ground wire (OPGW)

Optical fibres are very attractive for aplication inside a ground wire, due to their small dimensions, their high transmission capacity and their insensivity to electromagnetical induction.
The requirements for an optical ground wire, generally identified as OPGW, concern primarily mechanical and conductive characteristics.
Cable design must then provide the following topics:
- high mechanical stifness, to minimize cable sag for long spans in all environmental conditions and therefore to avoid interference with power conductors;
- high electrical conductivity, to withstand short circuit currents with a reasonable temperature increase;
- waterproofness, to avoid moisture to reach fibres.

OPGW cables were developed suitably for spans with average length up to 400 ÷ 600 m and to withstand short circuit currents e.g. up to 20 kA for half a second. In the following a typical construction is described:

The optical core is dielectric, fully filled and contains a number of fibres ranging from 4 to a max. of 24. Over this core, protected by a thermal barrier, there is an aluminium tube and an outer stabilized armouring. This last consists of one or two layers of galvanized steel or aluminium alloy or aluminium clad steel wires (Figg. 21 and 22).
Fibres are generally single mode with a suitable proof test level and attenuation less then 0.4 or 0.5 dB/km at 1300 nm.
As hydrogen hazard concerns, all the considerations made on submarine telecommunication cables (particularly the use of the hydrogen activated compound) are here valid.

SM fibre with tight protection



optical fibre with loose protection

1 primary coated optical fibre
2 loose tube protection

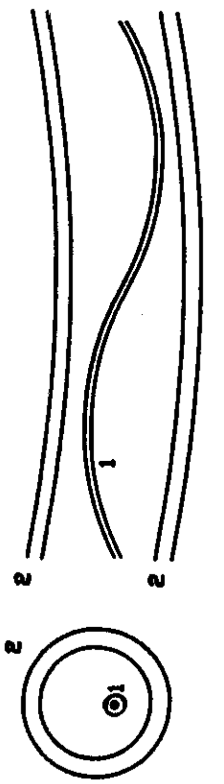
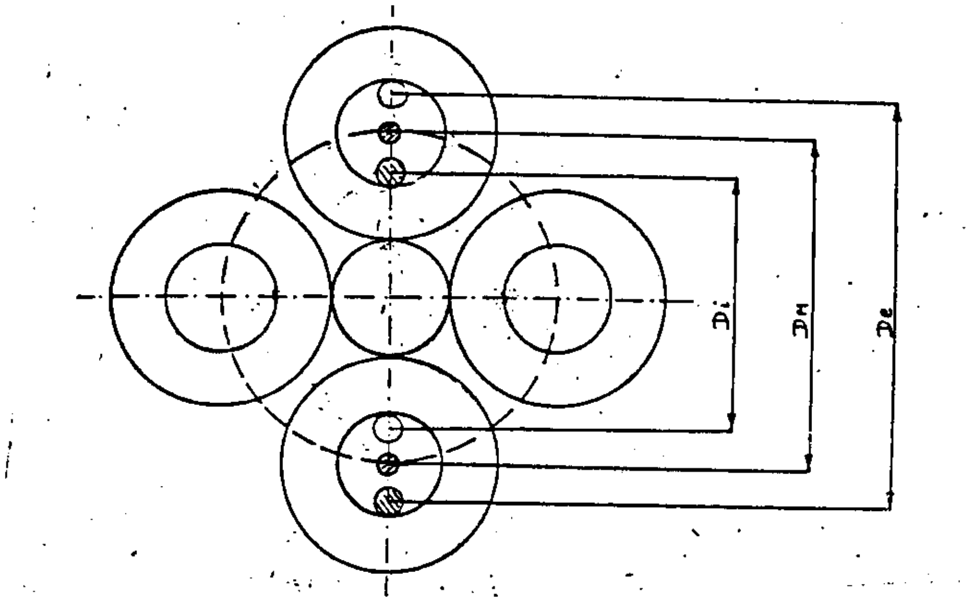


fig. 2



● = Fiber initial position
O = Fiber at maximum cable compression
◐ = Fiber at maximum cable elongation

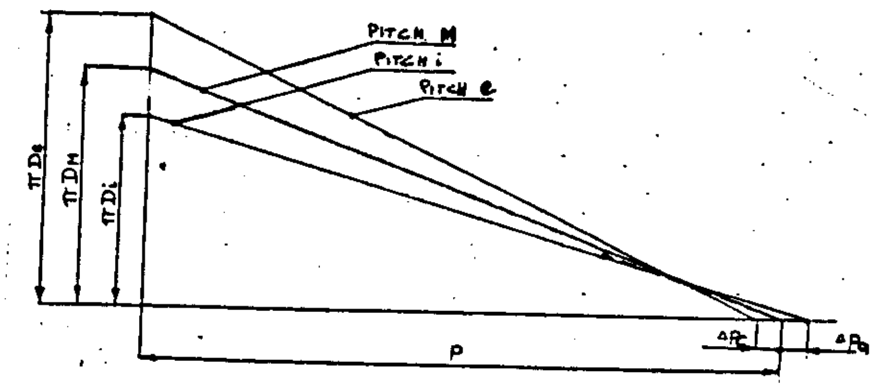


fig. 3 - Loose protected fibres. Different paths for the fibre inside an helically stranded tube. Schematic representation.

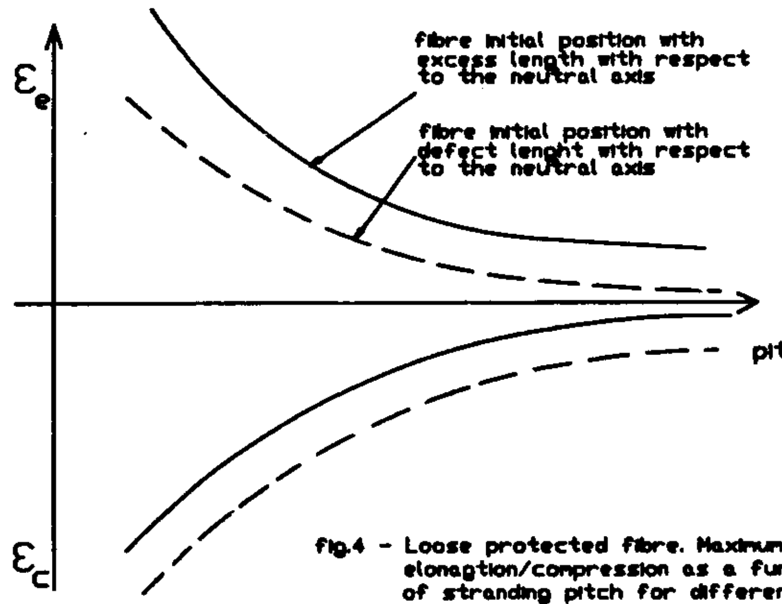


fig.4 - Loose protected fibre. Maximum permissible elonagtion/compression as a function of stranding pitch for different fibre initial position. Qualitative illustration.

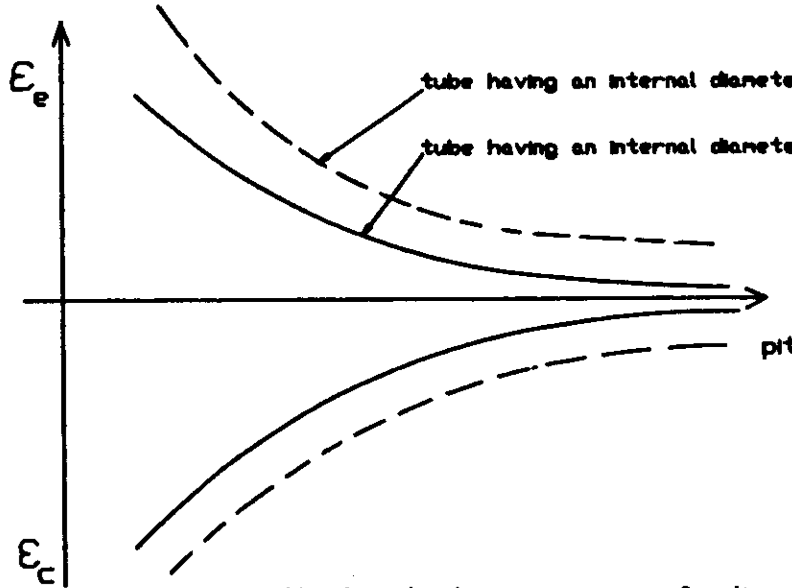
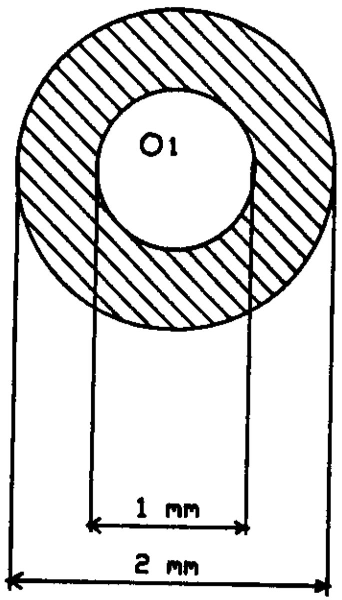


fig. 5 maximum permissible elongation/compression as a function of stranding pitch for different tube inside diameter.

cross-section of loose tubed fibre



1= 125 µm primary coated fibre

fig. 6

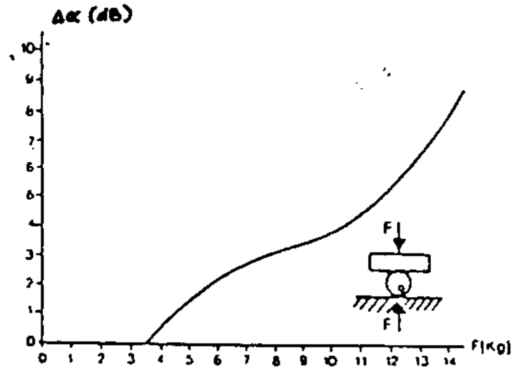


Fig.7 Loose tubed fibre (external/internal diameter 2/1 mm) increase in attenuation versus lateral compression force (fibre compressed between a plate and a cylindrical body with R = 1 mm).

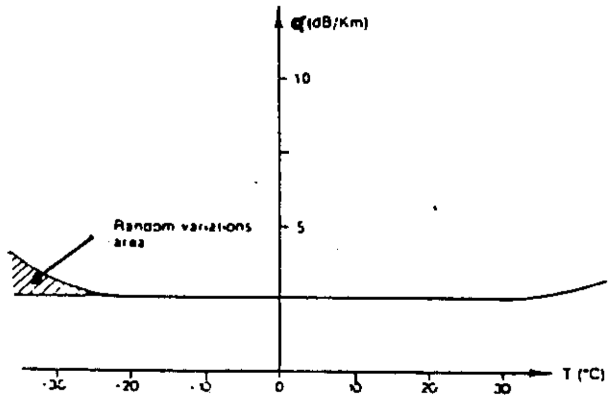


Fig.8 Cable incorporating loose tubed fibre with an excess length of 0.1 percent at 20°C.
Typical attenuation versus temperature.

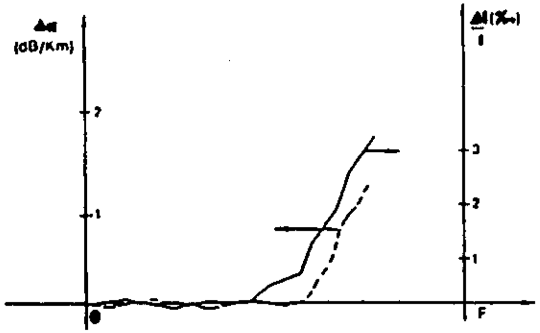


Fig.9 Cable incorporating loose tubed fibre in a concentric formation
Example of variations in attenuation and elongation, encountered experimentally, in terms of the axial load.

GROOVED CYLINDRICAL CORE DIFFERENT FIBRE POSITION FOR MAX.CABLE COMPRESSION AND ELONGATION

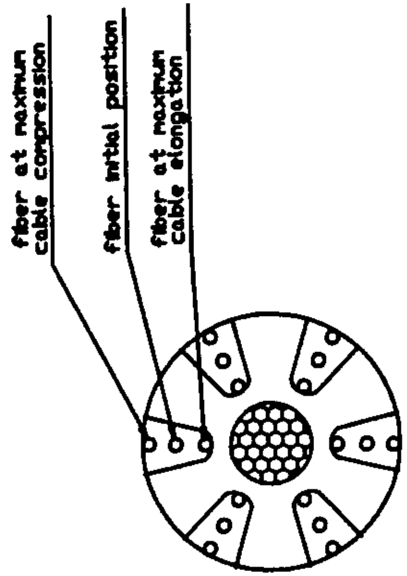
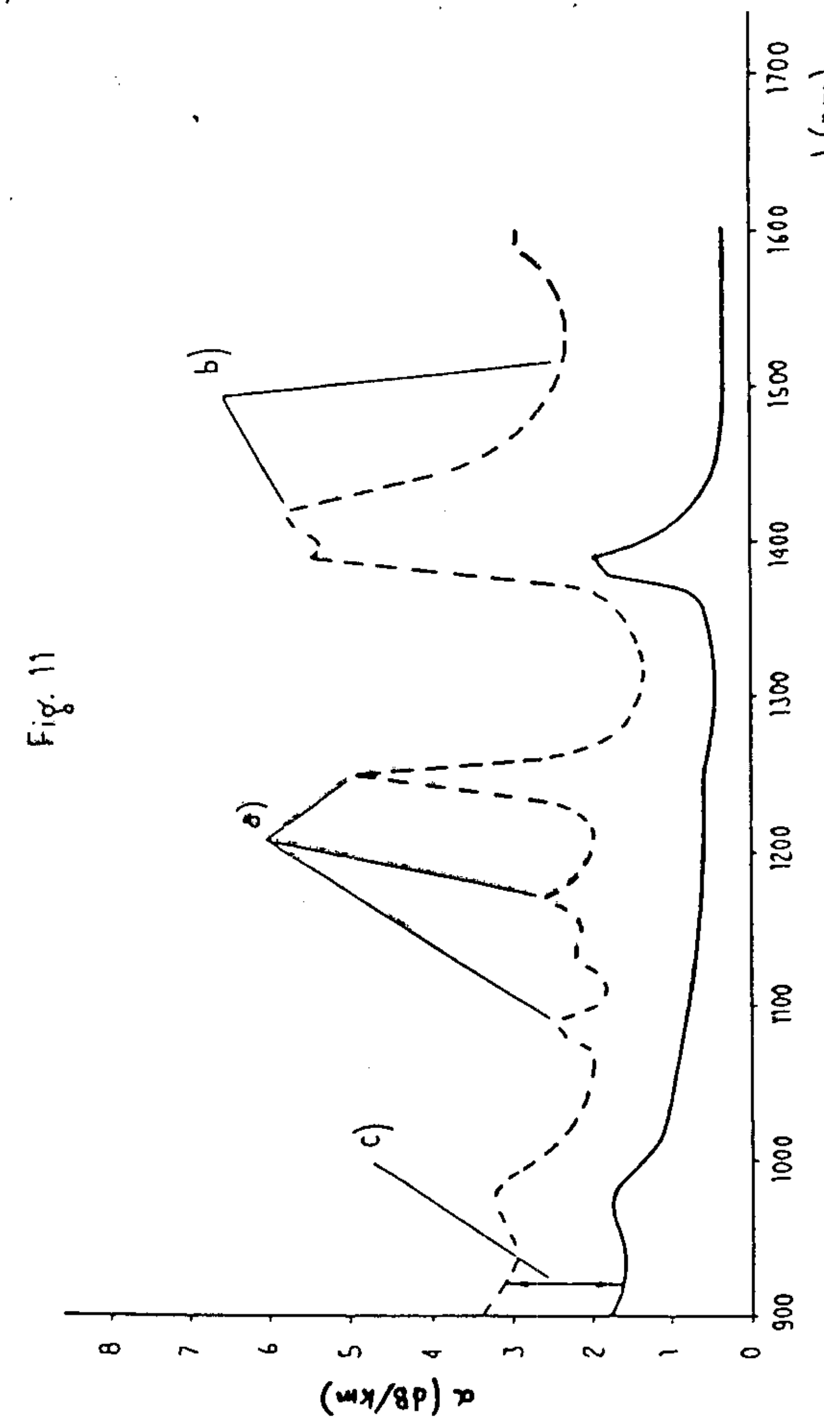


fig.10

Fig. 11

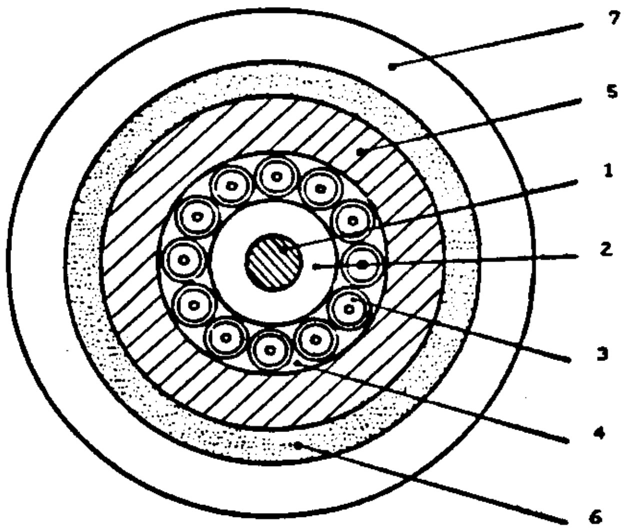


Hydrogen effect on optical fibers transmission loss : monomode fiber spectral attenuation before (——) and after (- - -) H_2 diffusion (30 days, 100°C, 1 atm)

Fig. 12

12 "TIGHT PROTECTED" FIBRE CABLE

(DUCT INSTALLATION)



1) Central dielectric member
2) Plastic layer
3) Tight protected optical fibre
4) Filling compound
5-7) Plastic sheath
6) Double layer of kevlar yarns

TWELVE FIBRE OPTIC CABLE

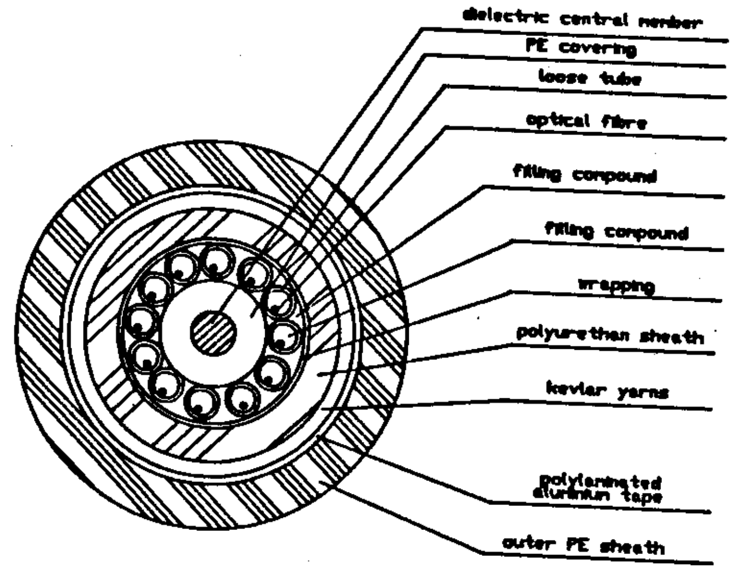
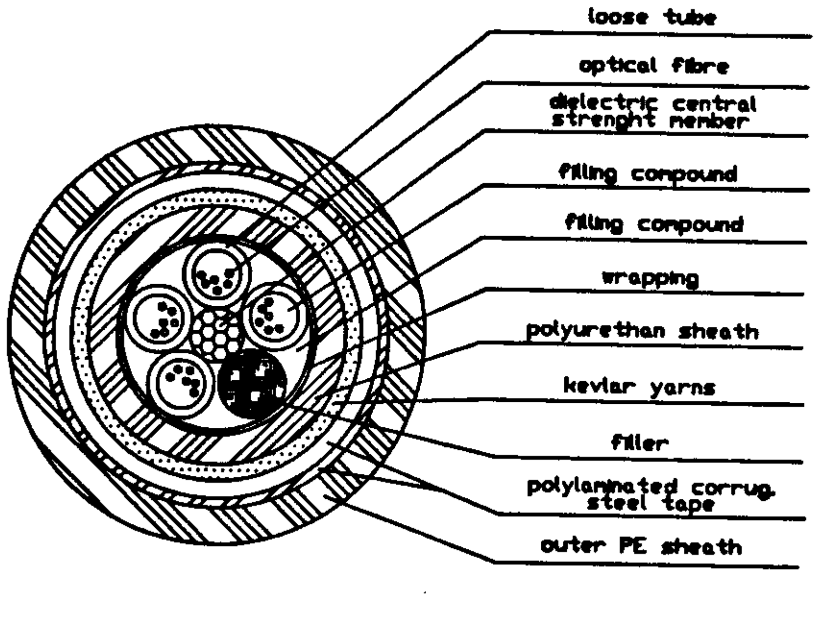


fig.13

fig.14

TWENTYFOUR FIBRE OPTIC CABLE FOR DUCT INSTALLATION



TWELVE FIBRE OPTIC CABLE (groove structure)
DUCT INSTALLATION

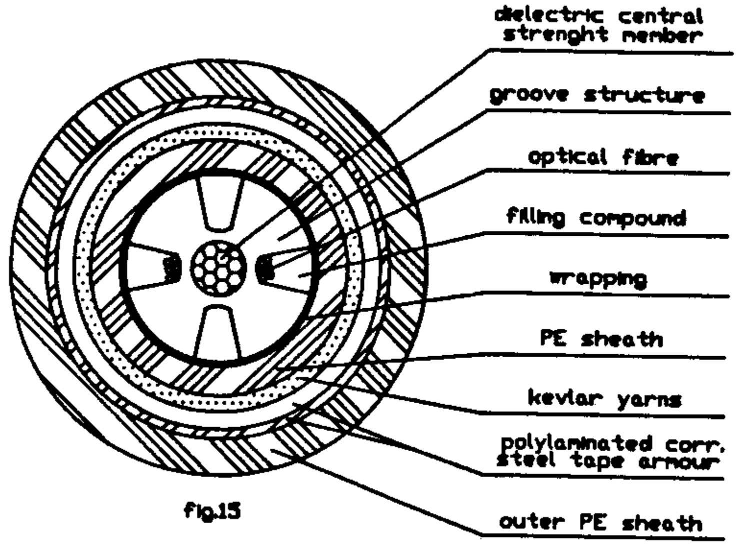
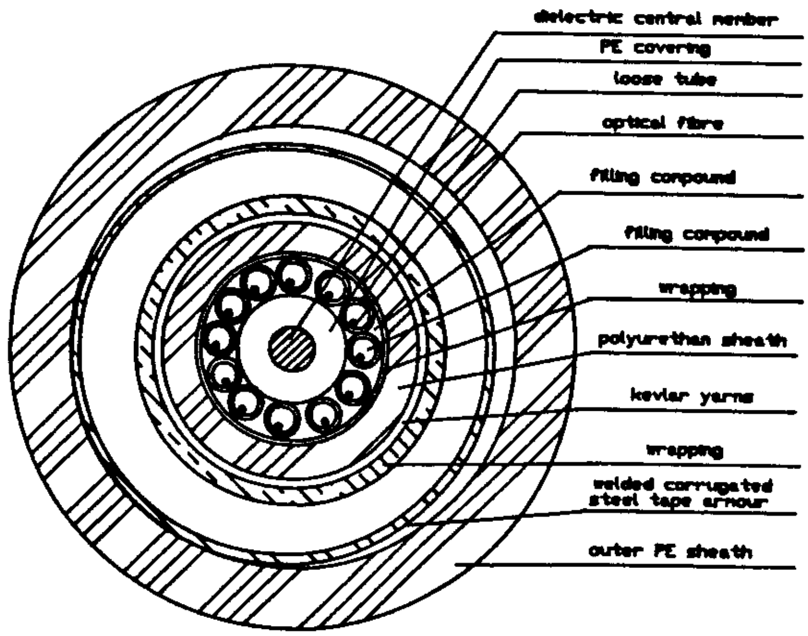


fig.15

fig.16

TWELVE FIBRE OPTIC CABLE FOR DIRECT BURIED INSTALLATION



SIX FIBRE OPTIC CABLE SELFSUPPORTING AERIAL

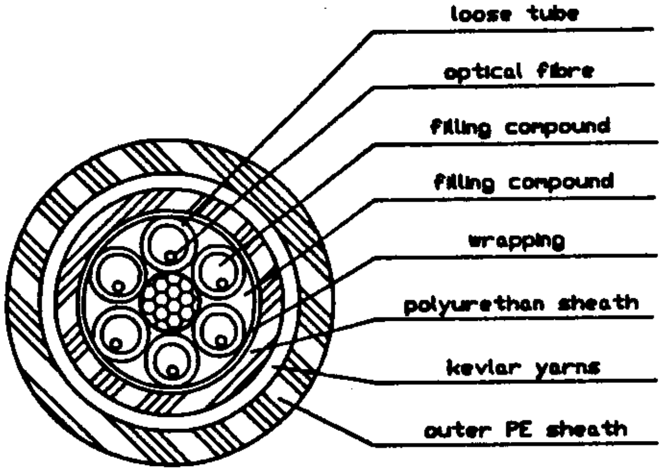


fig.17

SIX FIBRE OPTIC CABLE SELFSUPPORTING AERIAL (groove structure)

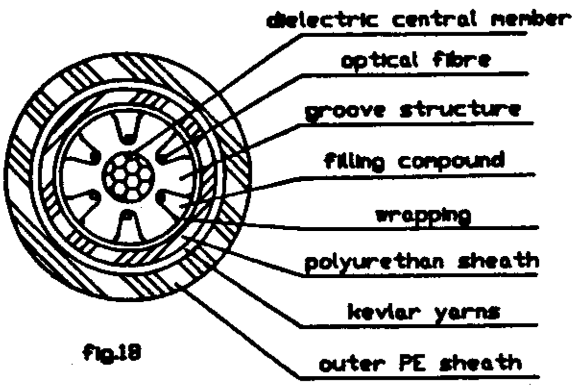
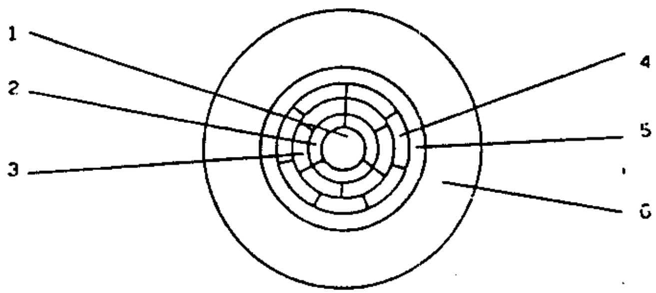


fig.18

Fig. 19

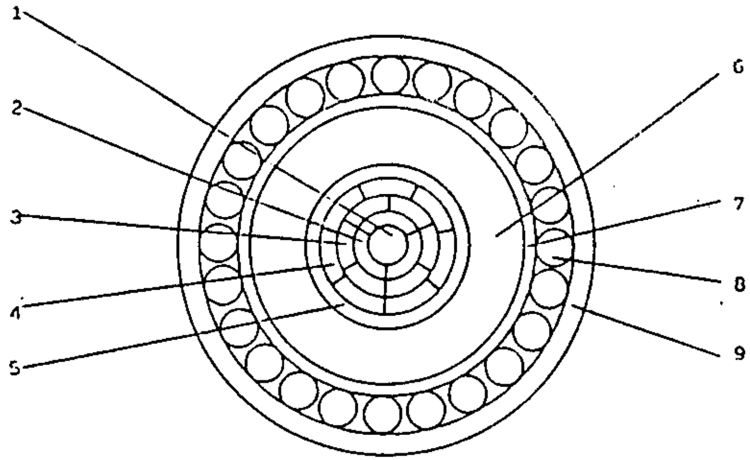
Section of submarine cable for deep water



1. Fibre optic core
2. 1st layer } of metallic shaped segments
3. 2nd layer } (e.g. hard aluminium, high resistance steel)
4. 3rd layer }
5. Copper (or aluminium) welded tube
6. Polyethylene sheath

Fig. 20

Section of submarine cable for shallow water



1. Fibre optic core
2. 1st layer } of metallic shaped segments
3. 2nd layer } (e.g. hard aluminium, high resistance steel)
4. 3rd layer }
5. Copper (or aluminium) welded tube
6. Polyethylene sheath
7. Bedding of synthetic threads
8. Armouring of galvanized steel wires
9. Outer serving of synthetic threads

SCHEMATIC DRAWING OF COMPOSITE CABLE

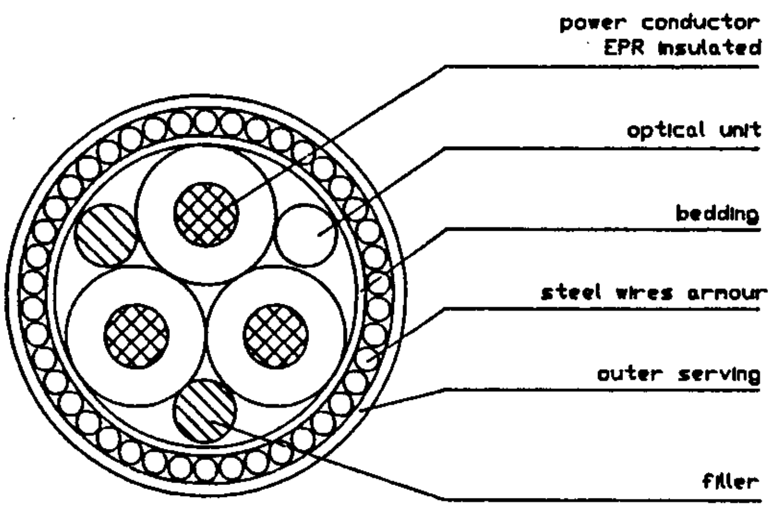


Fig. 21 a

SCHEMATIC DRAWING OF OPTICAL UNIT

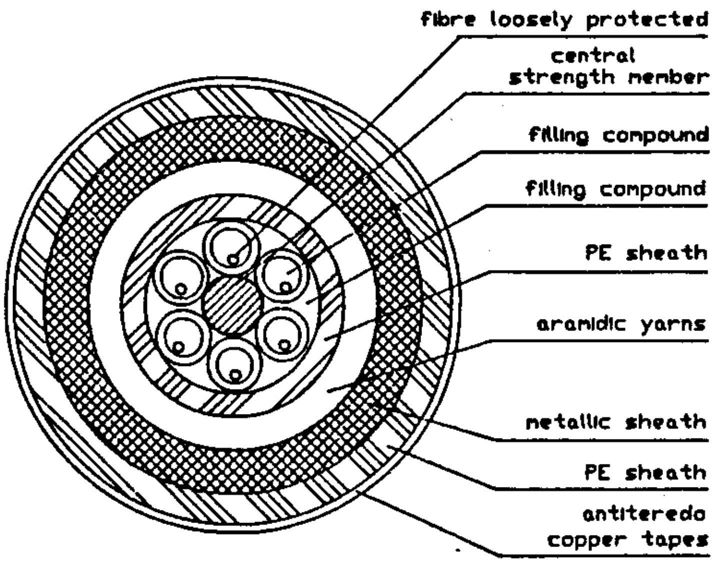
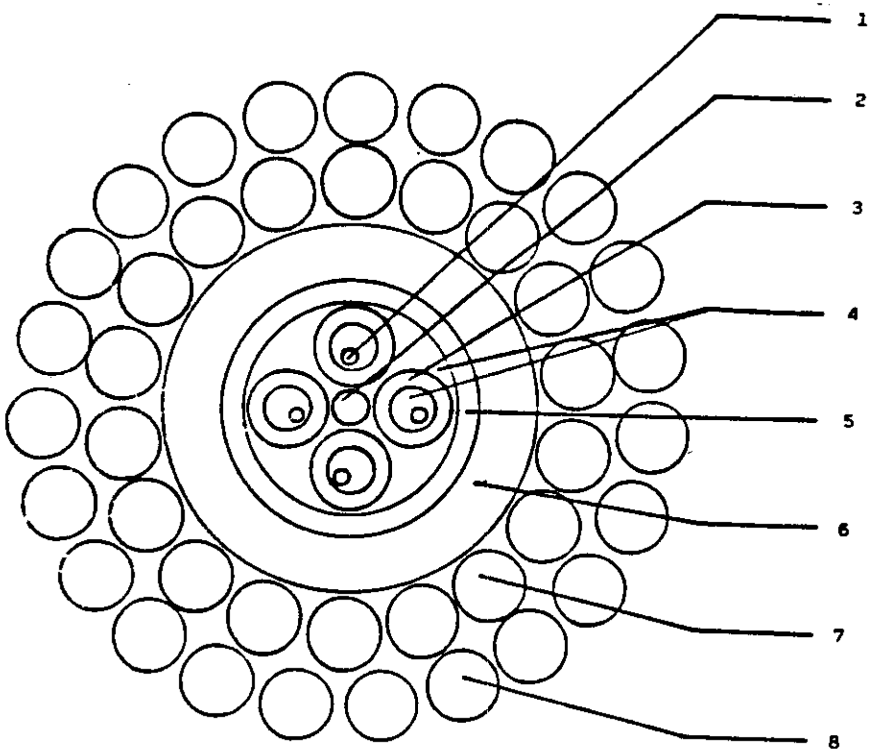


Fig. 21 b

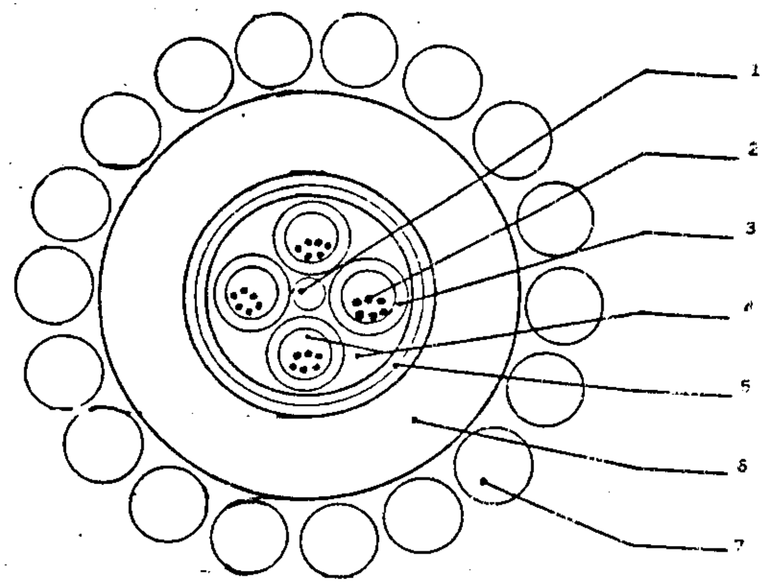
FIG. 22



1. Optical fibre
2. Non metallic central element
3. Loose plastic tube
4. Filling compound
5. Protective tapes as thermal barrier
6. Aluminium sheath
7. 1st layer of galvanized steel wires
8. 2nd layer of aluminium alloy wires

- Optical ground wire (OPGW) with double wire layer armouring, containing 4 fibres.

FIG. 23



1. Fiberglass central strength member
2. Optical fibres (twenty-four)
3. Four plastic tubes
4. Filling compound
5. Protective bending
6. Aluminium sheath
7. Aluminium clad steel wires

- Optical ground wire (OPGW) with single wire layer armouring, containing 24 fibres.