FIRE HAZARD OF 6-500 kV CABLE LINES IN POLYMER PIPES

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In the latest edition of the magazine "ELECTRICITY. Transmission and distribution" several articles were published at once, where the results of testing pipes for cables are given. I would like to comment on these works, as well as on the article "On the issue of the spread of burning of electrical wiring laid in the ground in plastic pipes" by a group of authors from the institute VNIIPO (hereinafter — the article of VNIIPO).

Keywords: cable line, cross-linked polyethylene, polymer pipe, cable laying in pipe, horizontal directional drilling method, heat stability, fire-resistance

Introduction

Laying modern cable lines (CL) 6-500 kV in pipes is convenient for design and installation organizations, but with an unsuccessful choice of pipes, it can turn into problems for operating services. So, Figure 1 shows an example where, due to the inattentive attitude to the quality of pipes and the lack of technical supervision during construction, the pipes were "squeezed" with cables laid in them, which led to the inability to repair the CL and reuse the pipes to accommodate new cables in them.

In the situation of Figure 1, where the pipe laying was carried out at the bottom of the trench, at least it was possible to excavate the track and take photos that allowed to establish what happened. In the same place where the pipes are tightened into the ground by the method of horizontal directional drilling (HDD), it is not possible to fix the deformation of the pipe that occurred during the operation of the CL, because the line is laid at a great depth of up to 5÷20 m.

What is wrong with the deformation of the pipe in the HDD sections? In case of damage to the cable on the HDD section, it cannot be repaired (due to its deep location), and then to restore the normal operation of the CL, replacement of the cable with a new one is required, assuming that the cable with fault will first be removed from the pipe, and then a new, serviceable one will be tightened in its place. So, it will be impossible to remove the cable from the deformed pipe (it will remain in the ground forever), and restoring the normal operation of the CL damaged section will mean its new construction, which is unlikely to be fast, because it is necessary:

– find funding;
– to organize a tender for design work, during which it is necessary to determine the location for a new section of the CL, since the old section of the CL remaining in the ground can no longer be used, and it blocked the most suitable corridor for the HDD route, agreed initially;
– to execute the project and pass expertise;
– organize a tender for construction and installation works;
– perform these works;
– take the updated CL into operation.

Fig.1. Consequences of negligent attitude to laying cables in pipes.

It is important to understand that it will most likely not be possible to identify and punish those responsible for the loss of the HDD route, since the court must have some photo or video materials to make a decision, and they simply will not be due to the significant depth of the object. The restoration of the normal operation of the CL will take up to several month or even years.

For the first time, a warning about the danger of CL construction in unsuitable pipes was made in the article "Requirements for pipes for laying power cable lines" (Dmitriev M.V., Cable-news magazine, No. 6, 2014). In total, in recent years, the author has devoted about ten articles to this topic, which attracted various specialists to the discussion of pipe problems. One way or another, but cable operators thought about the fact that in its current form, the mass construction of 6-500 kV CL in pipes, especially by the HDD method, is a kind of time bomb (if we do not pay close attention to the quality of pipes and do not agree on what important properties cable pipes should have).

In recent years, unfortunately, factories have appeared that allegedly offer "pipes for cables". So, in the article [1] of specialists from Lenenergo, it is noted that a significant part of such products are simple water pipes made of polyethylene grades PE 63, PE 80, PE 100, PE-RT, but painted in bright colors (red, blue, green, etc.) to illusive indicate their special appointments. Unfortunately, in reality, such pipes do not meet the needs of cable networks, and their existence on the market is explained by the following circumstances:

– most of the test reports and certificates were issued by laboratories and centers that have never belonged to either the electric power industry or the pipe industry (they are engaged, for example, in food, furniture, etc.); or, if they had the necessary accreditation, they have already been withdrawn;

- cable operators do not have simple methods to understand that the pipes brought to the facility, despite the bright colors and specific names, are ordinary polyethylene water pipes, and that it is better not to use them.

Considering the above, we can advise you not to hesitate to verify the authenticity of protocols and certificates. Usually, a lot becomes clear if you try to find on the Internet at least minimal information about the testing laboratory or certification authority specified in the pipe documents. There are also cases when deception is more difficult to establish – if certification is carried out on "specially prepared" samples, and similar products are brought to the facilities, but of a different (bad) quality and properties. Firms that come across on presentation of forged protocols and certificates should be excluded from the register of suppliers of products.

It is also important to note that a detailed study of the technical specifications for "cable" pipes will be useful, since many of these technical specifications become clear even without studying the authenticity and essence of the protocols and certificates provided. Often such technical specifications do not contain sections where specific requirements for pipes would be given, studying which it would become clear that the pipes relate specifically to cable networks, and not to water supply, gas, sewerage, drainage, etc. Often, such technical specifications do not even contain methods for testing pipes for their compliance with such important requirements for cable operators as long-term heat stability, annular stiffness number SN, tensile strength of welds, etc.

Requirements for pipes for 6-500 kV CL

Special polymer pipes for laying 6-500 kV CL, as shown, for example, in [2], must have at least the following properties:

- heat stability at a temperature of at least 90°C (the pipe ability to maintain all its characteristics for 40-50 years under the conditions of the 90°C temperature of cables insulated with cross-linked polyethylene XLPE);
- resistance to fire (for the inner layer which it in direct contact with the cable);
- sufficient ring stiffness SN (kN/m^2);
- the possibility of connecting pipes to each other by butt welding;
- flexibility sufficient for laying by the HDD method;
- sealing of the ends for excluding pipes silting;
- the presence of end funnels, which reduces the risk of deformation of the CL by the edges of the pipes.

The heat stabiblity of pipes made on the basis of polyethylene grades PE 63, 80, 100 is maintained for a long time only at a temperature of 40°C (see cold water pipes standard GOST 18599-2001), and for this reason these pipes are not suitable for laying XLPE cables with an operating core temperature of 90°C.

Annular stiffness SN of pipes made on the basis of PE-RT polyethylene at a temperature of 90°C turns out to be even worse than conventional PE polyethylene (PE 63, 80, 100). The fact is that PE-RT was created only as a material for hot water pipes, where it was necessary to achieve stability of the pipe wall under the influence of internal pressure of high-temperature water but not external pressure of the ground and transport.

Despite the listed well-known facts about polyethylene pipes of grades PE 63, 80, 100, PE-RT, the situation is such that many pipe plants manage to mislead power engineers and supply their products for the needs of laying responsible and expensive 6-500 kV CL, not to mention CL up to 1 kV.

The situation is aggravated by the fact that in our country there are no methods for testing pipes, for example, for heat stabiblity, and therefore various laboratories approach testing in a different way. Thus, studies [3] of polyethylene pipes for heat stability were carried out in the laboratory for only a few hours, whereas the concept of "heat stability at 90°C" means that a pipe at 90°C should retain its properties not for several hours, but at least 40-50 years. This was also noticed in Lenenergo service company [1], and experts in the VNIIPO article, in turn, noted the need for additional experiments involving various scientific centers of the country.

In addition to heat stabiblity, another important characteristic of pipes is their resistance to fire and burning – the article of VNIIPO is devoted to the study of this issue. Unfortunately, the object of research in the VNIIPO article is ordinary polyethylene pipes, and not special polymer pipes for 6-500 kV CL. Of course, VNIIPO has the right to carry out studies of polyethylene pipes for customers on a commercial basis according to any test program, but it is important to note that these studies are only remotely related to the topic of laying high-voltage 6-500 kV CL, and can be taken into account only for CL up to 1 kV, since only in networks up to 1 kV regulatory documents it is allowed to use polyethylene in the manufacture of pipes.

Pipes according to IEC 61386-2014, designed for CL up to 1 kV

The permission to use polyethylene in pipes for CL up to 1 kV is due to the fact that:

- the responsibility of CL up to 1 kV is significantly less than that of CL 6-500 kV;
- the cost of a CL up to 1 kV is significantly less than that of a 6-500 kV CL;
- the operating temperature of the CL up to 1 kV is less than that of the CL 6-500 kV;
- for CL up to 1 kV, you will not find expensive and complex HDD hundreds of meters long.

The regulatory document authorizing the use of polyethylene pipes when laying CL up to 1 kV is IEC 61386-2014 "Pipe systems for laying cables". The IEC standard contains several related parts (1, 2, 3, ... 24), forming a single document. In the first part (61386.1) "General requirements" in the section "Scope of application" it is clearly written that IEC 61386-2014 applies only to low-voltage networks with a voltage of up to 1 kV AC and up to 1.5 kV DC.

The fact that IEC 61386-2014 is not related to the 6-500 kV CL was also noted in the article [1] "Lenenergo". Also, unfortunately, it is not correct to refer to the 6-500 kV CL and the tests from the VNIIPO article, which were carried out only on CL up to 1 kV laid in conventional polyethylene pipes (corrugated and smooth).

It is gratifying that testing centers like VNIIPO have been preserved and are operating in our country. I hope that in the foreseeable future, they will be able to organize tests for the spread of burning not at all of polyethylene pipes for low-voltage cables of classes up to 1 kV, meeting IEC 61386-2014, but large-scale tests of special polymer pipes for 6-500 kV CL, having the above characteristics, such as long-term (40-50 years) heat stabiblity at 90°C, resistance to the fire and burning, tightness of the ends, etc. I believe that the initiator and customer of such tests could be any of big grid companies, because they have to operate hundreds and thousands of 6-500 kV CL laid in pipes.

It should be noted that it would be advisable to conduct tests of special polymer cable pipes in the presence of power engineers, because this would allow us to take into account the specifics of the work of 6-500 kV CL as correctly as possible, as well as correctly interpret the results of experiments.

Having completed the discussion about low-voltage (up to 1 kV) and high-voltage CL 6-500 kV, we draw attention to a serious problem that VNIIPO faced when conducting tests for the spread of burning – this is the lack of test methods.

Scheme of the fire test

GOST R 53313-2009 "Molded electrical products. Fire safety requirements" describes the following procedure for checking the CL in pipes for the spread of burning: "The test sample should be a segment or segments of electro assembly products with a total length (3500 ± 50) mm, with wires or cables laid inside them and fixed on a metal ladder."

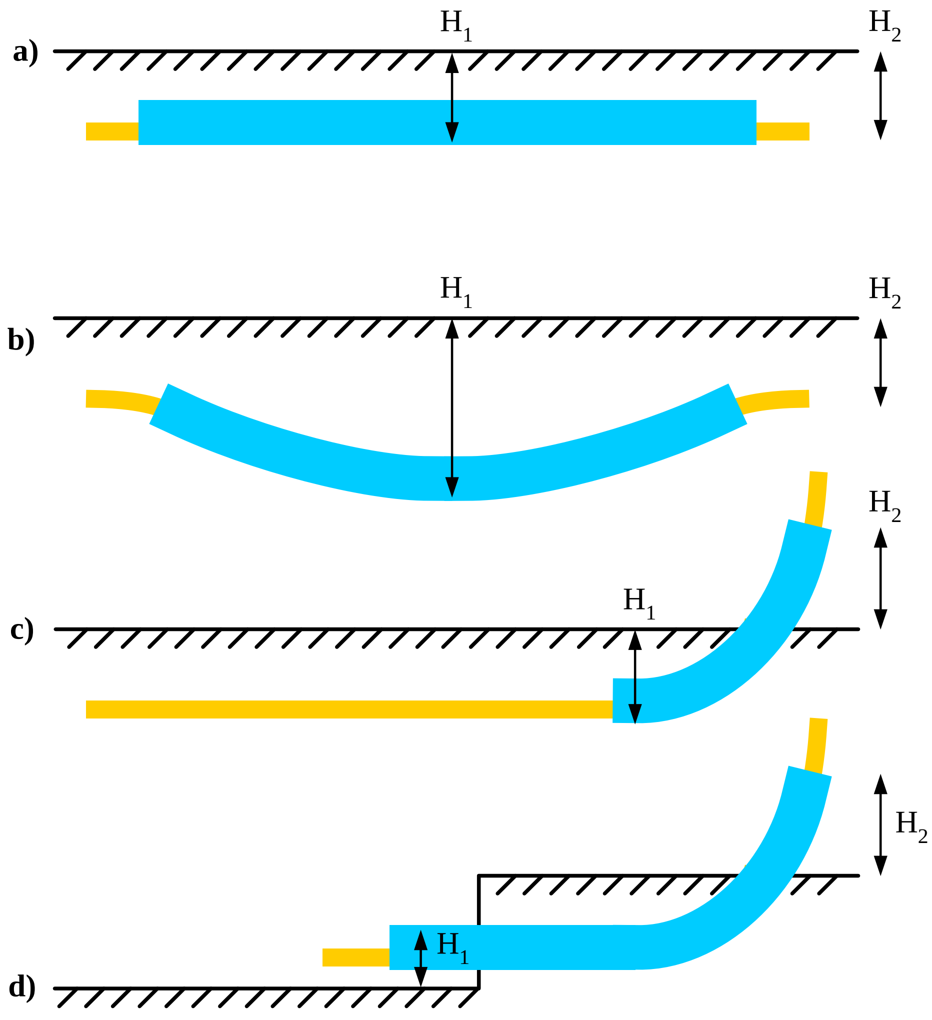

Fig.2. Cable in a pipe in the ground:
(a) laying to the bottom of the trench, (b) laying by the HDD method,
(c) exit from the ground to the cable termination, (d) VNIIPO experiment.

As can be seen, the methodology specified in GOST R describes only those CLs that are located in pipes in the air. This method of cable placement is typical when performing low-voltage electrical wiring (for CL up to 1 kV), but practically does not occur for high-voltage 6-500 kV CL, which, if laid in pipes, then in the ground: at the bottom of the trench (Figure 2a) or by the HDD method (Figure 2b).

The only case when 6-500 kV cables are still laid in pipes in the air is the cable coming out of the ground to the cable terminations (Figure 2c), and increased flexibility is required here, and it is necessary to use not smooth-walled pipes (as in Figures 2a and 2b), but corrugated pipes.

The absence in GOST R 53313-2009 of a correct experimental scheme for the case of laying a CL underground led to the need for its development, and specialists in the VNIIPO article gave their own version – it is shown in Figure 2d. It can be seen that the scheme resembles the case of a CL coming out in a pipe from the ground to the air (like in Figure 2c), but is far from the variants of Figures 2a and 2b.

Taking the total length of pipes in which CL 6-500 kV of our country are laid for 100% (all variants of Figures 2a, 2b and 2c combined), it can be argued that the length of pipe coming out from underground to air (Figure 2d) will be hardly 1%. Consequently, the experiments carried out by VNIIPO according to the scheme of Figure 2d, to some extent could cover only 1% of those conditions in which 6-500 kV CL of our country actually work. The remaining 99% of the 6-500 kV CL are still unexplored.

Sealing of pipe ends

The differences between the VNIIPO experiments and the real cases of laying CL 6-500 kV are additionally reflected in Table 1. In the VNIIPO experiments, both ends of the pipe were placed in the air, and at significantly different heights, which created the effect of a flowing wind tunnel inflating the flame of an already very flammable (group G4) ordinary low-voltage polyethylene pipe, which is only 10-15% filled with cables with combustible outer sheathes (experiment #1). But even with the experiment set up in this way, where, it would seem, everything is done for burning, the authors conclude: "When testing samples with sealed pipe ends, the samples passed the test." Interestingly, the experiments were carried out for a tripled volume of kerosene in comparison with the one that is usually used.

Table 1. Comparison of placing methods for pipe with a cable in the ground.

Laying method	Scheme	H_1, m	H_2, m
To the bottom of the trench	Fig.2,a	-1.5	-1.5
By the HDD method	Fig.2,b	-(5÷20)	-1.5
Exit from the ground to the cable termination	Fig.2,c	-1.5	+3.0
VNIIPO experiment	Fig.2,d	+0.2	+3.0

If in the experiments of VNIIPO they came to the conclusion that the sealing of the ends seriously affects the pipes burning, then it is impossible not to pay attention to the following – in practice, in 99% of cases, both ends of pipes of 6-500 kV CL are underground (Figures 2a and 2b) and are sealed in one way or another. There are the following options for sealing:

– special seals (Figure 3);
– mounting foam (Figure 4, prohibited for use due to fragility);
– soil (prohibited due to silting of the pipe and problems with cable removal).

Even if there are no special seals or prohibited foam, in any case, wet soil remains at the ends of the pipe.

So, the overwhelming number of real 6-500 kV CL, shown in Figures 3 and 4, have little in common with the experiments of VNIIPO, which assume the output of CL to the air (Figure 5) and its almost unlimited flow to the ends of the pipes. However, nevertheless, the research of VNIIPO is important because they have demonstrated the fundamental role of such factors as sealing the ends of pipes and the degree of filling of pipes with cables laid in them.

Fig.3. Special polymer pipe for cables. It is equipped with an internal nonflammable (NF) layer and sealed with seals. The solution is designed for 6-500 kV CL.

Fig.4. Unpainted pipe made of ordinary polyethylene. It does not have an internal nonflammable (NF) layer and seals (foam instead). The solution is designed for CL up to 1 kV.

Fig.5. Blue-painted corrugated pipe made of ordinary polyethylene. It does not have an internal nonflammable (NF) layer and seals. The solution is designed for CL up to 1 kV.

The usual role of sealing the ends of pipes with CL is to protect the pipes from cable silting [1, 2], but now another purpose should be added here – this is to restrict air access to the pipe in order to minimize the consequences of fire and burning.

As for the degree of filling of pipes with cables, the factors of choosing this parameter are contradictory. On the one hand, to limit fire and burning good solutions are those where the pipes densely filled with cables, leaving the air a minimum of space. On the other hand, such a dense filling of the pipe is not suitable either for the conditions of cable pulling (especially if we are talking about a long pipe section) or for cooling conditions, since, as was shown in [4], only large-diameter pipes are able to provide high load current carrying capacity of the cable due to effective cooling of the cable:

– by the action of convection of a large volume of air in the pipe;
– increasing the contact area of the pipe system with the ground.

Taking into account the problems of sealing pipes and filling them with cables, the reasons for the appearance of special polymer cable pipes with an internal nonflammable (NF) layer (Figure 3) become clear, the presence of which has recently begun to attract the attention of the biggest Russian grid service company ROSSETI and its branches.

Special polymer NF pipe for 6-500 kV CL

To make a polymer pipe for a 6-500 kV CL completely nonflammable is not only expensive, but also to some extent meaningless. The fact is that the fire from pipe's outer side is excluded, because there, as rightly noted in the article VNIIPO, usually the pipe is adjacent to the soil. Therefore, it should not be surprising that the "nonflammable" polymer pipes developed for 6-500 kV CL have only a thin inner layer as an NF layer.

The appearance of special polymer pipes with an internal NF layer made it possible to remove restrictions on the choice of pipe diameter and accept it increased (for the convenience of cable pulling and to increase the permissible load current), without worrying about the large volume of air in the pipe, unfavorable in matters of fire. Strictly speaking, there are several more arguments in favor of using polymer pipes with an internal NF layer.

Firstly, in all experiments, one way or another described in GOST R 53313-2009 or in the VNIIPO article, it is considered acceptable when the samples were damaged in a section up to 2.5 m long. Power engineers in cable networks of 6-500 kV are hardly tripled by such a statement of the question. The fact is that the emergency cable, even if only 0.1 m is damaged, still cannot be repaired, and it must be removed from the pipe for replacement. But if not only the cable is damaged in the same area, but also the pipe, then it may lose the annular stiffness SN and deform so much that it will not allow you to remove the cable and replace it with a new one. The section of the CL will require expensive and long-term new construction.

Secondly, the presence of an internal NF layer in the pipe minimizes damage to the pipe by the arc of the short-circuit current, if it occurred in the CL on the pipe section. Strictly speaking, here the NF layer no longer performs a fire-fighting role, but rather the role of protecting the pipe body from the high temperature of the incandescent wires of the CL and the arc of the short-circuit current.

Thirdly, there are a number of cases when the CL in the pipes still has contact with a large volume of air. This can include:

– cable exits from the ground to the cable termination (Figure 2b or Figure 6);
– wells for cable blocks (Figure 7, it is discussed in detail in article [5]);
– entry of cables into cable rooms, basements.

The question may arise: if you use pipes with an internal NF layer, then the CL, probably, should also be used with an external NF layer? The answer to the question is the research in the article of VNIIPO, where it is shown that the burning of cables and pipes depends more on the sealing of the ends of the pipe and the volume of air in it, rather than on the material of the cable sheath. Also, the absence of the need to put cables with an NF outer sheath into NF pipes is also explained by the fact that from the "pipe-cable" pair, it is the pipe that should be more durable and reliable, since it should provide the possibility of cable re-laying for decades without replacing the pipe with a new one.

Fig.6. Exit to the terminations of 330 kV CL, made by a special heat-resistant corrugated pipe equipped with seals, UV-resistant, having an internal NF layer.

Fig.7. The well at the turning point of the CL 10 kV block route.

Pipe diameter and filling ratio

It has been shown that sealing the ends of polymer pipes with a 6-500 kV cables allows you to choose the diameter of the pipe without focusing on burning issues. Strictly speaking, cable operators have always done this – the internal diameter $D_{in} = D - 2e$ was assumed to be at least 1.5 times larger than the diameter of the cable d, and this rule was explained by the need to ensure unhindered cable pulling in long-length pipes, taking into account the rigidity of the cable and the bends of the route (Figure 8).

The ratios of the cable outer cross-section S_C and the entire inner section of the pipe S_P can be selected using a simple formula:

$$\frac{S_C}{S_P} = \left(\frac{d}{D_{in}}\right)^2$$

where $S_C = \pi\frac{d^2}{4}$ – outer cross-section of cable with outer diameter d;

$S_P = \pi\frac{{D_{in}}^2}{4}$ – inner cross-section of pipe with inner diameter D_{in}.

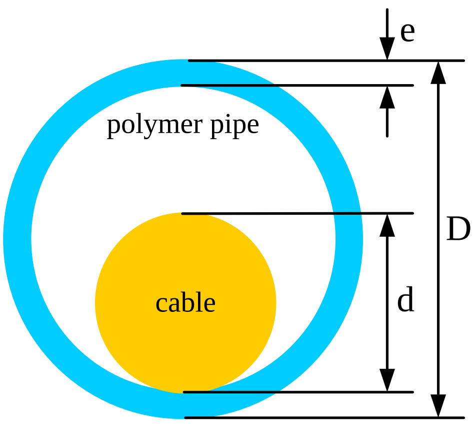

Fig.8. Geometric dimensions of the cable and pipe.

The calculation results are presented in Table 2, from which it can be seen that for the maximum permissible diameter ratio $D_{in}/d = 1.5$, familiar to power engineers under the conditions of unhindered tightening of the CL into the pipe, cable products occupy 44% of the pipe volume. In practice, the pipe diameter is chosen with some margin, and the ratio $D_{in}/d = 1.7$ is more common – it exactly corresponds to the filling of 35%, which, according to VNIIPO, is critical in terms of issues of the spread of burning through pipes that do not have end seals, and less than which value is no longer recommended.

It can be assumed that if the pipe is equipped with seals, and also endowed with an internal NF layer, then there will be no restrictions on filling the pipe. In this case, various options for filling the pipe with cables will be acceptable — for example, only by 10-15%, which corresponds to $D_{in}/d = 2.5 \div 3.0$. By the way, experiment #1 from the VNIIPO article was conducted just when filling the pipe by only 10-15% (he established the fundamental role of sealing the ends).

An increase in the diameter of pipes from the usual $D_{in}/d = 1.5 \div 1.7$ to $D_{in}/d = 2.5 \div 3.0$ will give improved cooling conditions for the CL due to the appearance of convection (mixing) of air in the pipe and a large area of pipes contact with the ground [4].

Table 2. Filling the pipe with cable products.

D_{in}/d, p.u.	S_C/S_P, p.u.	Pipe filling
1,5	0,44	44%
1,7	0,35	35%
2,0	0,25	25%
2,5	0,16	16%
3,0	0,11	11%

Conclusions

1. When laying 6-500 kV CL in pipes, special attention should be paid to the material of the pipe wall, the presence of sealing of the ends of the pipe and the inner NF layer.
2. Pipes for laying high-voltage CL are special polymer pipes, in the manufacture of which polyethylene of the water grades PE 63, PE 80, PE 100, PE-RT should not be used. The use of these grades of polyethylene is possible, but only when laying low-voltage CL up to 1 kV.
3. Requirements for pipes for low-voltage CL are given in IEC 61386-2014, the scope of which applies exclusively to networks up to 1 kV, as indicated in the English and French versions of the document. These requirements have little in common with what is needed for high-voltage 6-500 kV CL.
4. Sealing the ends of pipes with a 6-500 kV CL is important not only to prevent soil, foreign objects, animals from entering them, but also to limit the air flow that affects the burning of cables in pipes (due to CL overload or short circuit). Pipe sealing should be performed with special seals, but not with mounting foam.

5. In the case of high-quality sealing of the ends of the pipe, in particular:
   - eliminates the need to stack NF-sheathed cables in pipes;
   - restrictions on the degree of filling of the pipe volume with cables are relaxed.
6. The use of the inner NF layer in special polymer pipes is recommended:
   - on HDD routes, where it is always important for the pipe to preserve its integrity, shape and basic properties;
   - in the block of cables;
   - at the exit points to the cable terminations (usually these are corrugated pipes with end seals, with an inner NF layer, UV-resistant);
   - in cases where cables fill less than 35% of the space inside the pipe (when the ratio of the inner diameter of the pipe and the diameter of the cable $D_{in}/d > 1.7$).

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