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Brief Analysis of Problems in Construction of Climbing Direct Burial Optical Cables

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1. Background

Along with the development of optical fibre communication, the optical fibre network keeps extending, leading to more and more complex laying environment. When laying optical fibre in mountainous or hilly areas, the use of climbing direct burial cables is unavoidable. Typically, these areas have steep terrain, many trees, and more stones than earth, the field of view is therefore smaller; and very good command and coordination are requisite during construction; otherwise, failures like being in back buckle of optical cable, stumbling of optical cable on stumps or obstacles, or pinning of optical fibre by big stones may easily occur, resulting in unguaranteed construction quality.

Nowadays, most of climbing direct burial optical cables used domestically consists of common direct burial cable plus single-layer steel wire armor structure. Such optical cables have excellent tensile and compression resistance, and have certain endurance to stone hitting, excessive tensile force, and alike. However, if the optical cable is in back buckle or seriously twisted, problems such as breakage of optical fibre in optical cable or attenuation stage may occur.

The status of optical cable in back buckle is analyzed herein. The reason for hook & eye closure of climbing direct burial optical cable is addressed through careful observations and operations on the construction site. Relevant analysis has been validated by tests; and solutions to the problem have been proposed.

2. Structure and Performance of Climbing Direct burial Optical Cable

According to existing design specifications, climbing direct burial optical cable is formed by common direct burial optical cable with external single-layer (Figure 1) or double-layer steel wire armor (Figure 2).

In standards, the specified mechanical performance index of 1 ton climbing direct burial optical cable is that: long-term tensile force of optical cable shall not be less than 4000N, short-term tensile force shall not be less than 10000N; long-term flattening pressure of optical cable shall not be less than 3000N/100mm, and short-term flattening pressure shall not be less than 5000N/100mm. However, there is no specific requirement for twisting and bending or alike.

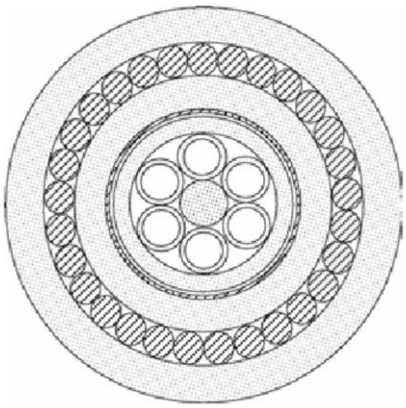

Figure 1 Single-layer Steel Wire Armor Climbing Direct Burial Optical Cable

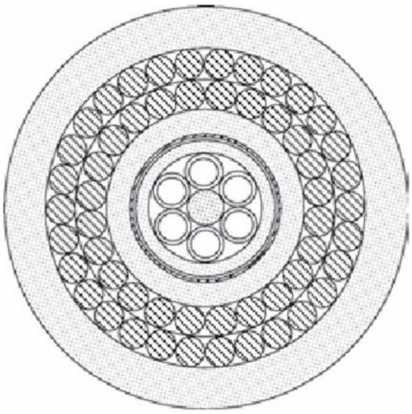

Figure 2 Double-layer Steel Wire Armor Climbing Direct Burial Optical Cable

Usually, the single-layer steel wire can meet the requirements above, the manufacturers always use single-layer steel wire to save cost and reduce the diameter and weight of optical cable. As shown in Figure 1, if the core diameter of direct burial cable core is 14mm, and the steel wire diameter is 1.5mm, then 30 steel wires can be stranded. If the steel wire strength is not less than 40kg/mm^2, and the elongation of steel wire is equal to the free elongation of optical cable (the elongation when the optical fibre is unstressed) 0.5%, the tensile force is not less than 300Mpa, the steel wire strand angle is 76°, then:

The optical cable tensile force

=30 steel wire tensile force + central strength member tensile force

$=30\times300\times3.14\times0.75^2\times\sin76°+3000$

=12000N

Based on the calculation above, it can be seen that the design meets the standard requirements.

Tests prove that such structure also meets the flattening strength and the impact resistance specified in the standard. If the cable is laid according to the technical requirements, such optical cable can guarantee that the tensile force and bending radius during construction will not exceed the allowable range. The laid optical cable will be free of any problem and completely meet the design requirements.

3. Phenomenon and Analysis of Back Buckle of Climbing Direct Burial Optical Cable

Because of harsh conditions on construction site and miscellaneous source of construction personnel, essentials for laying such optical cable are not grasped enough, so the phenomenon of back buckle occurs frequently in construction of climbing direct burial optical cable. This is because the length of a single tray of optical cable is generally 2~3km, the construction personnel have to make the "∞" shape treatment at the intermediate tray due to personnel and terrain limitations. If the "∞" knot is not untied in the direction opposite to making the "∞" shape knot, the twisting force will be brought to the end of the "∞" knot where a small ring will be produced; moreover, steel wire armored optical cable has great dead load, and such small ring caused by stress can be hardly released automatically, and buckling may be formed if the cable is pulled forcibly, namely the back buckle.

When buckling is formed on stranding optical cable, the central strength member will deform and protrude outward, and the external steel wire pitch reduces at the back buckle; it squeezes inward and flattens the loose tube; therefore, attenuation step or breakage occurs as the optical fibre inside the tube is stressed. In severe case, the twisting forces of multiple points may concentrate at one point, and the deformed central strength member may even penetrate the multi-layer sheath inside the cable and the external stranded steel wire, stretch out of the outer cable sheath, and cause complete damage to optical cable structure.

Through several times of field laying of climbing direct burial optical cable, we found that the optical fibre breakage or the attenuation step always took place around the "∞" shape knot after cable laying.

To validate the phenomenon above, we have made a test on the steel wire armored climbing optical cable; the test results are as shown in Table 1:

Table 1 Test of Steel Wire Armored Climbing Optical Cable

Number of cores of tested optical cable	Length of tested optical cable (m)	Number of test staff	Test method	Test result
36	400	30	Make 35 "∞" shape knots on the cable at every 10m, turn over the "∞" shape knots and pull forward, release the "∞" shape knots in the direction opposite to making the "∞"shape knots.	No twisting force is produced at the end of "∞" shape knot, and there is no optical fibre attenuation step.
36	400	30	Make 35 "∞" shape knots on the optical cable at every 10m, turn over the "∞"shape knots and directly pull forward.	Twisting force is produced at the end of "∞" shape knot, resulting in buckling; and optical fibre attenuation step occurs.

Meanwhile, we also made a test in which the steel wire armored optical cable is made into small rings of different diameters and then straightened forcibly, so as to observe that whether the loose tube inside cable is flattened when the bending radius of steel wire armored optical cable is less than 20 times of the optical cable outer diameter (i.e., the bending radius allowed in optical cable construction); the test results are as shown in Table 2.

Table 2 Test of Steel Wire Armored Optical Cable Straightened Forcibly After Looping

Optical cable diameter (mm)	Small ring radius (mm)	Cable diameter magnification	Test method	Whether the sheath is flattened
21.0	630	30	Dissect the sample for observation, after forcibly straightening the small ring	No
21.0	420	20	Dissect the sample for observation, after forcibly straightening the small ring	No
21.0	210	10	Dissect the sample for observation, after forcibly straightening the small ring	No
21.0	100	5	Dissect the sample for observation, after forcibly straightening the small ring	Yes

4. Suggestions for Construction of Climbing Direct Burial Optical Cable

(1) Before optical cable laying, construction and relevant personnel shall receive appropriate training on construction notes, for examples, cable laying method. Essentials and safety; and it must be guaranteed that the construction personnel will follow the command;

(2) As the climbing direct burial optical cable is heavy and the terrain of laying site is complex, the construction will be difficult and more workers will be required. It is suggested to provide enough personnel for construction of climbing direct burial optical cable (suggested staff number 110~140 persons);

(3) In optical cable laying, engineering technicians shall be provided with necessary communication equipment, such as intercom and loudspeaker. Technicians shall be assigned to cable tray "∞" shape knot, obstacle crossing, topographic turning and optical cable front lead,

in order to control the cable laying speed and avoid the occurrence of "surge" or ""caused by forcible pulling when optical cable is stored up in the middle.

(4) When optical cable runs through PVC tube, the cable laying personnel shall be instructed to thread the optical cable into the PVC tube directly, in order to avoid cable twisting. After laying a certain distance, the optical cable shall be prevented from being stored up in small rings around the PVC tube, which may cause serious cable twisting if kept pulling the optical cable;

(5) When making the "∞"shape knot, suitable terrain shall be selected, and the "∞" shape knot shall be made as big as possible. To avoid problems while releasing the "∞" shape knots, as less "∞" shape knots shall be made as possible when conditions allow;

(6) The "∞" shape knots shall be released with correct operation; the "∞" shape knots shall be released in the direct opposite to making the "∞"shape knots. If the "∞" shape knot is turned over improperly, resulting in that the small ring caused by stress cannot be released when the "∞" shape knot releasing is about to finish, it is not allowed to straighten the small ring; instead, reservation treatment shall be made at the small ring;

(7) Prior to backfilling, engineering technicians shall straighten out the optical cable in natural and straight status, in order to avoid backfilling when optical fibre is not straightened out (e.g., vertical and curved status).

5. Repair Method for Climbing Direct Burial Optical Cable After Occurrence of Attenuation Step

(1) Measure the position of step by using OTDR, precisely measure the length of optical fibre at the stage point (preferably use small pulse width, e.g., 20ns), then use the measured optical fibre length F_1 - F_1 × n(optical cable stranding rate, e.g., 4 cores ~36 cores, n = l.2%) to figure out the optical cable length at the fault point, and then find out the optical fibre chop mark length according to the starting and ending meter marks of the test point;

(2) After found the fault point by sudden turning of optical cable meter marks, remove 300~400mm of the optical cable outer sheath, and then remove the steel wire of the armor (do not damage the inner sheath), then use the OTDR for monitoring; when found the attenuation of the optical fibre stage point reduces, it means that the fault point can be repaired by the following method;

(3) The cable straightness at the opened point shall be guaranteed. The melting points of optical cable sheath and the loose tube are usually greater than 180℃, so gasoline burner can be used for heating, such that the heat can be transferred into the cable core to expand the tube filling inside the loose tube. The blast burner must be 20~30cm away from the fault point for uniform heating, and the heating time shall not be less than 3~5min; meanwhile, the OTDR shall be used for monitoring; if the optical fibre stage at the fault point disappears and the optical fibre attenuation restores to the normal value, it means that the flattened loose tube has been rounded by expansion;

(4) After the optical cable is fully cooled, heat shrinkable sleeve can be added to the repaired point; the optical cable can be put at the trench bottom, backfilled by 30cm soil; then all optical fibre shall be retested;

(5) Certain reservation shall be made at the repaired point according to the geographical location, in order to prevent the optical cable against stress, and to use for future repair in case.

To validate the reliability and practicability of the method, we have made several tests on optical cable in back buckle without fibre breakage; and the dissection of optical fibre samples proved that the loose tube formerly flattened in the optical cable has been basically restored to the extent that will not affect the optical fibre.

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