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Field test research on failure of photoelectric composite submarine cable under impaction by dropped anchors

Xu Jia[1)], *Qiang Gao [2)], Liping Wang [3)],
Menglan Duan [4)] and Tao Zhang [5)]

[1)] *COONC Research Institute, Beijing, China*
[2)] *Department of Mechanics and Engineering Science, Fudan University, Shanghai, China*
[3), 4)] *Offshore Oil and Gas Research Center, China University of Petroleum-Beijing, Beijing102249, China*
[5)] *Qingdao Hanhe Cable Co.,Ltd*
[2)] *gaoq12@fudan.edu.cn*

ABSTRACT

As the name suggests, photoelectric composite cable is formed by integrating optical fibers into submarine power cable. And it's more and more widely distributed for oil & gas and offshore wind power development. However, submarine cable faults have been increasing by years. Anchor damages account for a big cause of submarine cable faults. So it's significant to evaluate the impact resistance of photoelectric composite cable and the cable damage degree under impact. In our field tests, a typical three-core photoelectric composite cable is laid on seabed and impacted by free falling anchors. It's found that the cable will produce global flexural deflection and local indentation. The optical unit is more vulnerable than power units under impact. The armoring layer wire easily yields at impact point.

1. INTRODUCTION

Submarine power cables are laid on or in the seafloor, used for power and signal transmission. More specifically, submarine power cables can be divided into three categories, i.e. submarine electric power cables, optical fiber cables and photoelectric composite cables. In offshore oil field and wind power farm, photoelectric composite cables are much more used than other two kinds of submarine cables. Unfortunately, the possibility of cable fault also increases. Human factors contribute the most, of which anchor damage accounts for the majority (Kordahi et al. 2007). However, the experimental study on photo-electric composite cables subject to impact by dropped anchors is rarely seen.

[4)] Professor
[2)] Graduate Student

In addition, present international mechanical test specifications, such as CIGRE Electra 171 (1997), for electric power cables and photoelectric composite cables have not yet prescribed the impact resistance for photo-electric composite cables. DNV-RP-J301 (2014) lists the mechanical properties that the purchaser should specify when necessary, including the mechanical impact resistance, but mechanical impact test procedures not given.

So it's significant and necessary to evaluate the impact resistance of photoelectric composite cable and the cable damage degree under impact.

In this paper, field test process of dropped anchor impact on a three-core photoelectric composite submarine cable is designed. The anchor is released at different heights in the air, and impacts different points on the cable. The deformation of steel wire armoring layer is measured. Then the cable is disassembled to observe and measure the power component and optical fiber unit. Then, the mechanical failure mode of cable under anchor impact can be evaluated qualitatively or quantitatively. It's clear to examine the impact resistance of cables under different impact energy. In the tests, impact energy is equal to gravitational potential energy.

2. TESTING PROGRAM

The field test site, the seabed of Fenghe bay in Qingdao, China, is an intertidal zone. When tide rises, it's submerged, and when tide ebbs, the seabed emerges. The seabed is mainly fine sand. Before impacting on the cable, the geotechnical parameters of seafloor are measured with a flat dilatometer test (DMT), including internal friction angel (φ). DMT now is a very popular method for in-situ measurement of soil properties, with advantages of efficiency and economy. The operating principles of DMT are elaborated in detail in the reference (Marchetti et al. 2001). Along the cable path, the internal friction angels of sand at five different points with the same horizontal interval of 1.4 m are measured, as shown in Fig. 1. The average internal friction angel of the test region is 40°.

Fig. 1 Soil properties test with DMT

2.1 Equipment and Procedures

The test setup is designed to study the deformation of photoelectric composite cable impacted by dropped anchors. As shown in Fig. 2, the main test setup consists of a truck carne, an electric release device, anchors, impact test specimen of a typical composite 3-core AC power cable with an optical fiber cable integrated. Other auxiliary tools are measuring tape, U-clamps, cable cutting saw and vernier caliper, etc. The electric release device is transformed from linear actuator, connected to reversible switch through wire. It's very easy and convenient to operate and release the anchor in the air during impact tests. Anchors used for impacting tests are admiralty anchors, often equipped on fishing vessels. They are standard products, meeting the Chinese specification GB/T545-1996 (State Bureau of Technical Supervision 1996). The impact field test is as shown is Fig. 3.

Admiralty anchors of two kinds of mass are chosen, i.e. 100 kg and 500kg. An anchor is lifted to different heights by truck crane through the electric release device. The bottom of anchor will impact the longitudinal axis of the photo- electric composite cable. After impact, the deformation of the armoring layer will be measured with vernier caliper. Then disassemble the cable and measure the deformation of internal cable entities, i.e. optical unit and power units.

The profile of photoelectric composite cable used for tests is as shown in Fig. 4. It has an optical unit and three power elements. The outermost layer is wire armoring, the most import protection structure from external aggression. Fig. 4 (a) is the cable specimen. Fig. 4 (b) is the rough schematic diagram of cable cross-section with subtle difference.

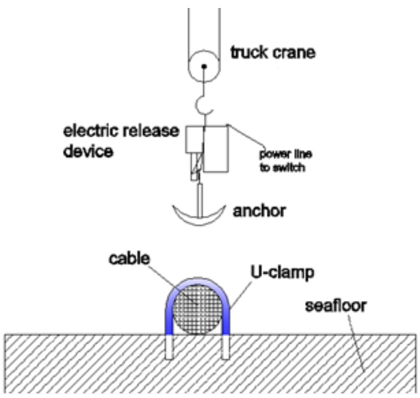


Fig. 2 Schematic diagram of test system

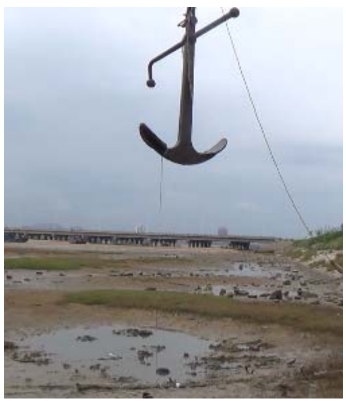


Fig. 3 Impact test on site

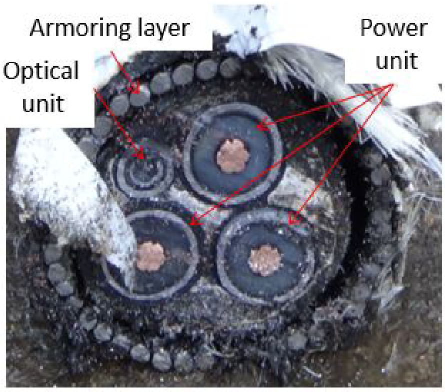


Fig. 4 (a) Cross section of cable specimen

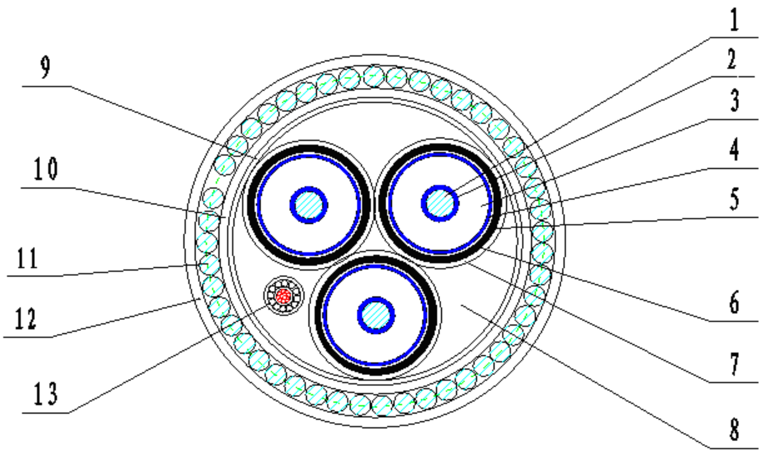


Fig. 4 (b) Schematic diagram of cable cross-section

Table 1 Main technical parameters of the cable

Item	Component	Nominal thickness (mm)	Nominal Diameter (mm)
1	Waterblocking copper conductor	7/3.06	8.3
2	Conductor shield	0.8	9.9
3	XLPE insulation	5.5	20.9
4	Insulation shield	0.8	22.5
5	Semi-conductive waterblocking layer	2×0.6×40	24.9
6	Alloy lead sheath	1.5	27.9
7	Anti-corrosion layer and PE sheath	2.0	31.9
8	PP filler (cabling diameter)		68.9
9	Cable tape	1×0.4×70	69.7
10	Bitumen-impregated PP bedding	1.0	71.7
11	Steel wire armoring	φ 4.0	79.7
12	Bitumen-impregated PP covering	3.0	85.7
13	Stainless steel tube optical unit	1×10 optical fiber cores	

The main technical parameters are listed in Table 1. The nominal diameter of the whole cable is 85.7mm, the outer diameter of optical unit 16.48mm.

2.2 Test results and analysis

The type of the cable is HYJQF41-12/20kV-3*50+10B1, which means copper conductor XLPE insulated separately lead sheathed thick steel-wire armored fiber covering submarine optical fiber /electric power composite cable.

As shown in Fig. 5, after being impacted, the cable armoring layer produces indentation. The whole cable produces a deflection. In one word, global and local deformations of the cable occur under impact. The heavier is the anchor, the more obvious is the deflection of the cable. Fig. 6 shows the schematic diagram of global and local deformation.

The test conditions and results are listed in Table 2. The deflection of power element δ is measured. The measurement and calculation methods are listed as follows.

The permanent dent depth H_t of armoring layer is defined to represent the external cable damage, as shown in Eq. (1).

$$H_t = D_{cable} - D_{impact} \quad (1)$$

Here, D_{cable} is the outer diameter of cable; D_{impact} is the thickness of section after impact.

The oval deformation rate $e_{optical}$ of optical unit is defined to describe the shape change of cross-section for internal cable entities, as shown in Eq. (2).

$$e_{optical} = \frac{D_{optical} - D_{\mathrm{minthick}}}{D_{\mathrm{minthick}}} \cdot 100\% \quad (2)$$

Here, $D_{optical}$ and D_{minthick} is the outer and minimum diameter of optical unit respectively

(a) Anchor (100kg) falling 3m

(b) Anchor (500kg) falling 3m

Fig. 5 Armoring layer damage under impact

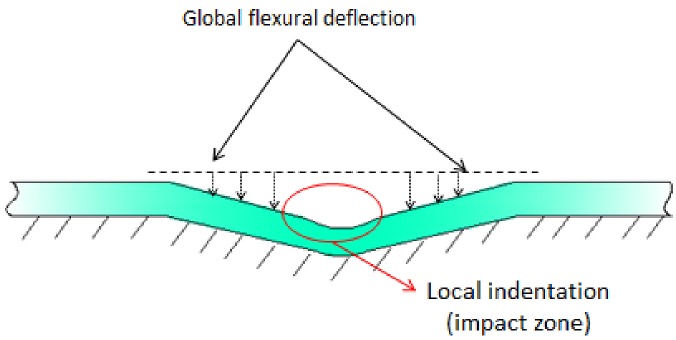
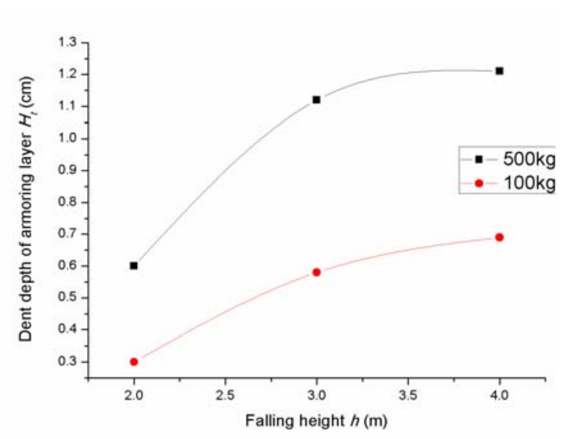


Fig. 6 Global and local deformation

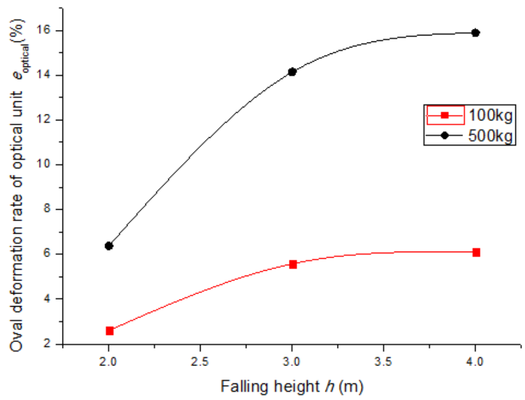
The oval deformation of cable power elements is visible but very slight. Cable power elements mainly produce bending deformation with slight shape change of cross-section. However, the optical unit has a hollow steel tube with optical fibers inside. It's much easier to be squeezed to change its profile under impact. The degradation of electric performance of the cable, i.e. power and signal transmission should be further examined.

Table 2 Test conditions and results

Anchor weight m(kg)	**Falling height h (m)**	δ **(mm)**	H_t **(cm)**	$e_{optical}$ **(%)**	**Power unit section**
100	2	19.48	0.3	2.61	Oval deformation is visible but very slight
	3	30.50	0.58	5.58	
	4	41.00	0.69	6.1	
500	2	39.00	0.6	6.38	
	3	43.00	1.12	14.14	
	4	50.15	1.21	15.88	



(a) Dent depth of armoring layer H_t



(b) Oval deformation rate of optical unit $e_{optical}$ (%)

Fig. 5 Relationship of cable deformation with anchor weight and falling height

As shown in Fig. 5, the dent depth of armoring layer and oval deformation rate of optical unit increase with anchor weight and falling height. The relationship of cable deformation with anchor weight and falling height is nonlinear.

3. CONCLUSIONS

（1） Photoelectric composite cable impacted by dropped anchors produces global and local deformations. The global deformation is flexural deflection of the whole cable body. The local deformation is the indentation of armoring layer and profile change of internal entities.
（2） Optical unit is more easily to be damaged than power elements.
（3） The relationship of cable deformation with anchor weight and falling height is nonlinear. The more impact energy, the larger deformation.

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REFERENCES

CIGRE Electra 171 (1997), “Recommendations for Mechanical Tests on Submarine cables”.
DNV-RP-J301 (2014), “Subsea Power Cables In Shallow Water Renewable Energy Applications”, 144-145.
Kordahi, M.E., Shapiro, S., Lucas, G. (2007), “Trends in Submarine cable system faults”, Submarine Optical Conference, 37.
Marchetti S., Monaco P., Totani G., Calabrese M. (2001), “The Flat Dilatometer Test (DMT) in Soil Investigations - A Report by the ISSMGE Committee TC16”, International Conference On In-situ Measurement of Soil Properties, 2001 May; Bali (Indonesia).
State Bureau of Technical Supervision (1996), GB/T 546 - 1996 - Admiralty anchor. Beijing (China): Chinese Standards Press.