



Damage assessment for submarine photoelectric composite cable under anchor impact

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ABSTRACT

The impact of dropped anchor on submarine photoelectric composite cables may possibly cause electrical faults, i.e. electricity and optical signal transmission failure. In order to study the impact capacity and structural impact failure mechanism, a test setup is designed originally to examine the structural and functional integrity. A detailed finite element model (FEM) is created, considering material nonlinearity and component interaction. A parametric analysis has been performed to predict the deformation of components and impact forces, under different impact velocities and collision directions. Relationships between the armor layer indentation rate and that of internal power and optical units are achieved. The impact deformation of internal entities can be evaluated intuitively by armor layer indentation. The proposed experimental and numerical methods are well correlated, suitable to assess the impact capacity of subsea power cables and assist the protection design of subsea power cables in engineering.

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1. Introduction

Submarine power cables can be divided into three categories regarding to their functions, viz. power cables for electric transmission, optical fiber cables for signal transmission and photoelectric composite cables with the above two functions integrated. Nowadays, photoelectric cables gain an extensive popularity in oil & gas field and offshore wind farms for power supply and signal transmission [1]. Submarine cables are relatively fragile, lying on a seabed that is shared with other users, such as the fishing industry and ship anchoring. Vessel anchors are hostile intervention on submarine cables. Especially, those submarine cables close to vessel anchorages or shipping channels are at high risk of anchor damage [2,3]. Anchor impact is one of the most critical accidental loads encountered among loading conditions [4]. Attwood [5] mentioned that the most frequent cause of cable failure was external damage by anchors and heavy fishing tools. An example of two Skagerrak cables fault caused by external mechanical impact from anchors and beam trawlers was given. According to the statistics by Worzyk [6], anchor caused 18% of the total faults of submarine telecom

cables in the Atlantic Ocean, as presented in Fig. 1. In addition, Yoon and Na [7] reported that contribution of anchoring activities to cable faults increased to 48%, and became the largest cause of submarine cable faults in recent years. Once the cable is impacted to some extent, the electric transmission and/or signal transmission will be cut off, seriously affecting the crowd's production and life.

Drop of anchor will happen where ships manoeuvre, in harbour basins, ship lanes, or fishing grounds. When designing a new cable route or designing protection measures for installed cable, it's necessary to assess the risk of cable fault caused by anchor collision. Several researchers have conducted risk assessment. Allan and Comrie [8] used a risk matrix to assess damage frequency and consequence. The risk assessment consisted of frequency of occurrence of hazard events and evaluation of the consequence of the event. Nakamura et al. [9] carried out reliability analysis of submarine cables in Japan and built a mathematical model to calculate the probable cable failure rate due to ship anchoring. Guo [10] used probabilistic risk assessment method to study the possible failure rate of submarine cables by anchor damage. For instance, the annual failure frequency of a submarine cable installed in Qiongzhou Strait by dropped anchor was 0.000726. It was relevant to the number of vessels passing the routing area and the probability of loss of control of anchor handling. Although it was quite low risk, the possibility of being struck by a falling anchor could not be ruled out.

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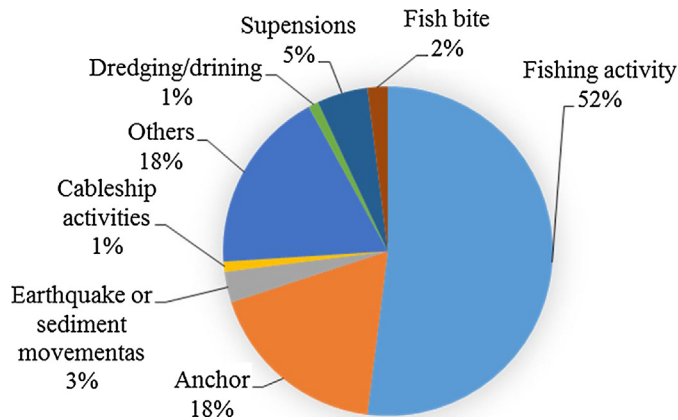
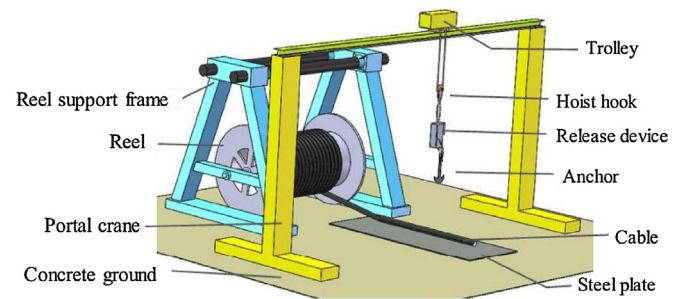


Fig. 1. Cause of damages to telecom cables in the Atlantic.

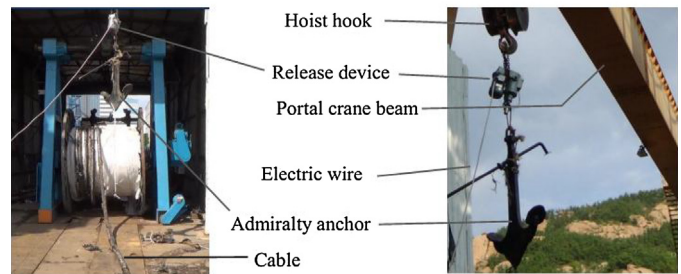
In addition, some specifications emphasize the risk of anchor collision. DNV RP J301 [11] points out that the accidental limit state, e.g. objects dropped onto cables and anchor impact should be considered in the design of subsea power cables. In the protection method of rock installation, the impact of falling rock onto the cable should be confirmed to not compromise the cable integrity. The International Telecommunications Union (ITU) [12] specifies the test methods and conditions to examine the impact resistance of optical fibre submarine cable systems. API SPEC 17E [13] indicates that the armor layer is used to sustain tensile loads in the umbilical and also has the additional function of providing impact protection. It shall be documented that structural integrity is not endangered due to impact loads. Extreme impact load shall be evaluated. Impact forces due to rock dumping shall be analysed. Impact load and energy relationship with consequence shall be determined. Two important common specifications for submarine cables of the International Council on Large Electric Systems (CIGRE), ELECTRA 171 [14] and ELECTA 189 [15], recommend the methods of mechanical tests, like coiling test, tensile test, tensile bending test et al. but without clues about mechanical impact.

However, the aforementioned international specifications do not give out the test or simulation methods to determine the impact resistance of submarine photoelectric composite cables against anchor collision. A detailed understanding of impact failure mechanism of such cables is quite useful in order to achieve the required performance. But only few researchers have investigated the impact capacity of submarine photoelectric composite cables. Jia et al. [16] performed impact tests of composite cables on the seacoast. It was found that the cable would produce global flexural deflection and local indentation. The optical unit was more vulnerable to be crushed than power units during impact.

Static lateral crushing of umbilicals, flexible pipes and cables provide some reference for impact analysis of cable. Guttner et al. [17] presented and compared two different numerical models for prediction of stress and strain fields in the steel tube umbilical components under crushing. The elastic-plastic behavior was adopted for the steel tubes. Alsos et al. [18] performed impact analyses for an 8-inch (bore diameter) flexible production riser. The cross section deformation, impact forces and indentation were achieved. Tayama et al. [19] conducted static lateral compression tests to confirm the ability of 6.6 kV XLPE submarine cable with optical fiber sensors for detecting anchor damage and defacement of wire armor. The relationship between compression load and transmission loss in optical fiber sensor and cable deformation rate was achieved. Nishimoto et al. [20] investigated the ability and sensitivity of 66 kV XLPE submarine cable with a damage-detecting optical fiber sensor. The submarine cable was placed on a steel test bench and compressed gradually by a metal weight having a 60° angle with edge radius



(a) Schematic diagram of test setup



(b) Real photos of test setup

Fig. 2. Impact test setup.

of 10 mm. The relationship between the deformation rate and the increase loss in optical fiber was also attained. The cross section of deformed cable at 30% deformation rate was given.

Although field tests can be expected to yield accurate data, in general, field impact tests are expensive and quite inconvenient, limited by test locations, weather conditions, instrument and human support. And it is difficult to accurately describe using a theoretical formula. Therefore, factory or laboratory test methods and numerical procedures need to be developed.

In this present work, experimental and numerical methods are proposed for damage assessment of submarine photoelectric composite cables during anchor impact. Firstly, a factory test arrangement is established to examine the impact properties of composite cable, including structural integrity and electrical performance. Secondly, a nonlinear finite element model (FEM) is proposed and then verified by test results. The complex interaction within composite cable, such as contact and friction between cable strands is taken into consideration. Finally, a parametric analysis is performed, considering different collision velocities and impact directions. Damage assessments are conducted from the perspective of structural and functional integrity. The impact responses of cable are discussed in detail, including sectional deformation and impact force. The proposed experimental and numerical methods show a good potential for ascertaining the impact capacity for submarine cables and for cable protection design, such as determining the proper impact energy of rock placement. The methods can also provide some references for determination of allowable impact limits for subsea power cables or umbilicals.

2. Experimental investigation

2.1. Test setup and procedure

The test setup is designed to study the structural deformation and resulting performance degradation of photoelectric composite cable impacted by dropped anchors. As shown in Fig. 2, the test setup mainly consists of a portal crane, electric release device, admiralty anchor, test specimen cable. Other auxiliary tools are

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