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Damage assessment of a tunnel-type structure to protect submarine power cables during anchor collisions

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ABSTRACT

The dynamic characteristics of a tunnel structure used to protect underwater power cables, the so-called A-duct, were determined for anchor collisions to provide a procedure for damage assessment and recommendations. The required physical quantities of five target anchors, including the drag coefficient, were obtained using an element-based finite-volume method and ANSYS-CFX software. The terminal velocities of the anchors were then calculated to maximize the colliding kinetic energy. For collision analysis, four parameters (anchor type, ground condition, collision velocity, and collision point) were considered, and the A-duct was modeled based on the Riedel–Hiermaier–Thoma concrete model using ANSYS-Autodyn software. Our analysis results indicated severe damage ($D = 1$) for most of the gauge points; the damaged area and level increased with the anchor weight. The results showed that the damage was concentrated in the collision area for stock anchors; however, for stockless anchors, damage was also evident in adjacent areas (*i.e.*, damage propagation) due to the anchor head shape as well as the transfer mechanism provided by its reinforcing nets. Accordingly, the 2-ton stock anchor caused more damage at the gauge points near the collision location than the 2-ton stockless anchor. Second, regardless of the ground conditions and rotation angle of the anchor heads with respect to the vertical axis, the damage levels were almost identical. Fixed boundary conditions and non-rotational angle were sufficient for the model used. Third, the damaged areas became smaller when the anchor collision locations deviated from the reference gauge

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point (P1), *i.e.*, the center of the A-duct. Finally, a comparison of the field-test results to equivalent numerical collision simulations indicated that the size of the predicted and experimentally observed damaged areas were in agreement within 7%.

1. Introduction

The use of submarine power cables has increased due to the recent development of offshore wind farms, in addition to their conventional use to connect islands to the mainland. Accordingly, several protection methods have been developed to ensure the safety of installed submarine power cables under environmental and accidental loads [25].

Among the loading conditions, anchor collision is one of the most critical accidental loads encountered. The International Cable Protection Committee [8] stated that anchor activities were responsible for 48% of the total failures of submarine cables. Jie and Yao-Tian [10] and Yoon and Na [26] reported power-cable failures for various ship anchorages. More recently, conventional protective structures have been replaced by more robust materials and structures to deal with anchor collision and other damage events [20,22].

Newly developed protective structures for cables must be tested thoroughly to ensure their safety and stability. Yoon and Na [25] reported anchor drop tests of flexible concrete mattresses for safety assessment; however, their tests used relatively conservative drop heights because they did not accurately calculate the drag coefficients of the target 2-ton stock and stockless anchors. To fix this problem, Woo and Na [21] carried out a flow analysis of the target anchors, in which the drag coefficients, terminal velocities, and corresponding water depths were calculated for 2-ton stock and stockless anchors. Their results were used for collision simulations of rock berms, which are protective structures created by stacking rocks, to facilitate the development of safety criteria and assessment tools [23].

Tunnel-type structures have been installed in shallow waters to protect submarine power cables from ship anchorages and fishery activities in these areas. However, the tunnel-type structures are particularly susceptible to anchor collision. To date, research into the structural behavior and associated damage assessment against anchor collision has been limited. The existing field tests are mostly case studies carried out under conservative assumptions [25], or numerical simulations that do not include damage evaluation [22]. Thus, a parametric study of the tunnel structures during anchor collisions is necessary.

In this study, a numerical procedure was developed to evaluate the dynamic behavior of an A-duct tunnel structure during anchor collisions to provide damage assessments and design recommendations. First, the required physical quantities (drag coefficients) of the target anchors were obtained through computational fluid dynamics via ANSYS-CFX software [1]. Five anchor types were considered for the flow analysis. The drag coefficients were obtained and the terminal velocity of the anchors was calculated to maximize the colliding kinetic energy. The A-duct tunnel-type structure was then modeled using the Riedel–Hiermaier–Thoma (RHT) concrete model [13] and ANSYS-Autodyn software [2]. Four parameters were considered for the model: anchor type, ground condition, collision velocity, and collision point. Finally, the analysis results were verified by existing field-test results. Recommendations were made based on the damage assessment.

2. Materials and methods

2.1. Terminal velocities of anchors

Stock anchors are still used on many small crafts and fishery vessels due to their superior holding power. However, because stock anchors are extremely cumbersome and difficult to stow, they have been abandoned by large merchant and navy ships. Submarine power cables are usually installed in