International Journal of Marine Energy 10 (2015) 17–38

Contents lists available at ScienceDirect

International Journal of Marine Energy

journal homepage: www.elsevier.com/locate/ijome

Fatigue reliability and calibration of fatigue design factors of wave energy converters

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ARTICLE INFO

Article history:
Received 12 August 2014
Revised 8 January 2015
Accepted 8 January 2015
Available online 14 January 2015

Keywords:
Calibration
Fatigue design factor
Reliability
Stochastic model
Wave energy converter

ABSTRACT

Target reliability levels, which are chosen dependent on the consequences in case of structural collapse, are used in this paper to calibrate partial safety factors for structural details of wave energy converters (WECs). The consequences in case of structural failure are similar for WECs and offshore wind turbines (no fatalities, low environmental pollution). Therefore, it can be assumed that the target reliability levels for WEC applications can be overtaken from offshore wind turbine studies. The partial safety factors cannot be directly overtaken from offshore wind turbines because the load characteristics are different. WECs mainly focus on wave loads where for offshore wind turbine the wind loads are most dominating. Fatigue failure is an important failure mode for offshore structures. The scope of this paper is to present appropriate Fatigue Design Factors (*FDF*), which are also called Design Fatigue Factors (*DFF*), for steel substructures of WECs. A reliability-based approach is used and a probabilistic model including design and limit state equation is established. For modelling fatigue, the SN-curve approach as well as fracture mechanics are used. Furthermore, the influence of inspections is considered in order to extend and maintain a certain target safety level. This paper uses the Wavestar prototype located at Hanstholm (DK) as case study in order to calibrate *FDFs* for welded and bolted details in steel structures of an offshore bottom-fixed WEC with hydraulic floaters.

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http://dx.doi.org/10.1016/j.ijome.2015.01.004
2214-1669/

1. Introduction

Wave energy converters (WECs) may become an important contributor of electricity from renewable energy sources in the future. Nowadays WECs exist on prototype level and are supposed to be further developed and improved.

Fatigue failures of offshore structures is a common failure mode. Fatigue failure often occurs in consequence of corrosion at welded structures or bolts. Background information about corrosion procedures in welds can be found in [1]. Due to the fact that failure consequences of a WEC lead to lower consequences (no risk of human life, low environmental pollution) compared with oil and gas platforms, WECs can be designed considering a lower safety level than oil and gas platforms. The consequences of failure of a WEC component can be assumed to be similar to failure consequences of a broken offshore wind turbine component. For offshore wind turbines, the dominating load is wind induced whereas for offshore platforms fatigue is mainly caused by wave loading [2]. Due to different safety levels as well as different dominating load characteristics and different control strategies compared with existing offshore structures, fatigue impact on WEC substructures need to be assessed and safety factors need to be calibrated.

The scope of this paper is to define appropriate partial safety factors (fatigue design factors) for steel substructures of WECs. In traditional deterministic designs, the amount of needed structural material is determined, among others, by the value of safety factors, which reflect the uncertainties related to design parameters and the required reliability level. Improved designs with consistent reliability levels can be obtained by probabilistic design methods. A reliability-based probabilistic approach, as used e.g. for offshore wind turbines [3], is used here where uncertainties related to loads, strengths and calculation methods are accounted for. A stochastic model for fatigue design has been established. Design and limit-state equations are developed based on a SN-curve approach. Palmgren–Miner rule with linear damage accumulation is used as recommended in most relevant standards, see e.g. [4] and [5]. Also a fracture mechanics approach is used for including different inspection strategies in order to maintain a given safety target level. Inspections can be used to extend the life-time as well as decrease the needed safety level due to better control of fatigue control growth [6]. Different inspection methods are compared as well as different inspection strategies based on an equidistant inspection plan or a risk-based inspection plan, where inspections are performed when the annual probability of failure exceeds the maximum acceptable annual probability of failure, are discussed.

An example is shown in the paper focusing on the Wavestar device which is located at Hanstholm (DK). This kind of device is an offshore bottom-fixed device which consists of floaters impelling a hydraulic system. The loads are determined using real measured wave states and an in-house hydrodynamic program (see [7] for more information) to estimate the loads.

In Section 2 general background information about probabilistic reliability assessments is given and Section 3 discusses acceptable reliability levels for fatigue failure of WECs. How fatigue can be modelled including no inspections (SN-curve approach) is shown in Sections 4.1 and 4.2 shows an approach when including inspections (Fracture mechanics). In Section 5, the Wavestar example is shown and resulting *FDF* values are shown. The conclusion from this article is given in Section 6.

2. Probabilistic reliability assessment

In practice, material characteristics of a structural detail (e.g. their yield stress), loads and environmental conditions contain uncertainties, which are not directly taken into account in a deterministic approach. Deterministic approaches only consider mean values of a certain parameter. Probabilistic reliability methods enable to model parameters as stochastic variables and take their uncertainties into account. There exist epistemic uncertainties which are related to limited data or limited knowledge about the behaviour of the system. Epistemic uncertainties can be reduced e.g. by increasing the knowledge and collecting more relevant data. Aleatory uncertainties are irreducible and account for physical uncertainties such as the fatigue strength. Epistemic and aleatory uncertainties need to be included in probabilistic reliability assessments.