Marine Structures 42 (2015) 115–136

Contents lists available at ScienceDirect

Marine Structures

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

Corrosion fatigue load frequency sensitivity analysis

O. Adedipe*, F. Brennan, A. Kolios

Cranfield University, Bedfordshire MK43 0AL, United Kingdom

ARTICLE INFO

Article history:
Received 9 May 2014
Received in revised form 17 March 2015
Accepted 17 March 2015
Available online 21 April 2015

Keywords:
Monopile
Offshore wind turbines
Seawater
Fatigue
Crack

ABSTRACT

This paper presents experimental assessment of crack growth rates of S355J2+N steel in a corrosion fatigue environment similar to what is experienced on offshore wind farm monopile structures under various cyclic load frequencies in order to assess the effect of cyclic frequency of the applied loading within a frequency range pertinent to the structure. Fatigue crack propagation behaviour in this test programme is evaluated through fatigue tests on six compact tension test specimens in air and in laboratory simulated seawater under free corrosion condition. Fatigue crack lengths were monitored by back face strain (BFS), DCPD and ACPD. A regression model was derived through the BFS method to express strain values as a function of crack length to width ratio. The effectiveness of BFS method is particularly demonstrated in the simulated marine environment. Within the range of test frequencies, crack growth rates in simulated seawater when compared to the equivalent air test revealed environmental reduction factors of 2 and 4 at lower and higher values of stress intensity factors respectively. Significant difference in the results of the seawater test frequencies is discussed.

1. Introduction

Corrosion and fatigue have been a dominant degradation mechanism for steel structures, with the combination of the two, known as corrosion fatigue having amplified effects in structures in the harsh

* Corresponding author.
E-mail address: o.adedipe@cranfield.ac.uk (O. Adedipe).

http://dx.doi.org/10.1016/j.marstruc.2015.03.005
0951-8339/

marine environments. Fatigue loads in typical offshore wind turbine support structures are mainly caused by wave, wind and operational loads from the rotor during operation. Therefore, offshore wind turbine monopile structures in deep waters have to be designed against corrosion fatigue in order to ensure their fitness for purpose. Corrosion is a time dependent mechanism and therefore corrosion fatigue tests need to be conducted at cyclic load frequencies representative of those experienced in service. However, understanding of dominant cyclic frequency is important when designing offshore wind turbines against corrosion fatigue. Lower cyclic frequencies are known to be more damaging under corrosion fatigue conditions for a number of reasons but mainly due to the longer time exposed to electrochemical corrosion elements per cycle. Also, cyclic frequency has a significant effect on the corrosion fatigue crack growth rates and therefore, a comprehensive understanding of the response of offshore wind farm monopile structures to dominant frequency is very important in order to produce realistic outcomes in laboratory test programmes similar to what is experienced in service.

The majority of research and published documents have focussed on the fatigue performance of tubular welded joints and plates fabricated from conventional fixed offshore platform steels such as BS 4360 50D [1–9]. In addition, most corrosion fatigue tests conducted on offshore structural steels such as BS 4360 50D, BS 7191 355D were carried out at the most damaging wave operating frequency of 0.1–0.2Hz with cathodic protections [6–12]. Most of the experimental programmes [1–9] were undertaken two decades ago on the corrosion fatigue behaviour of fixed offshore platforms for oil and gas industry, where the natural frequencies are designed to be well above the wave excitation frequency. However, some of the works reported in literature have emphasised on the use of small scale test specimens for experimental investigation. This is due to their simplicity, relatively low cost, ability to simulate various numbers of variables and to determine useful fatigue data which can be extrapolated to real structures.

Scott et al. and Thorpe et al. [1,2] reported the corrosion fatigue crack growth behaviour of BS 4360 grade 50D steel in air and synthetic seawater using compact tension test specimen at a loading frequency of 0.1 Hz. Etube et al. [10] adopted a loading frequency of 0.2 Hz in a number of large scale corrosion fatigue tests to compare the fatigue behaviour of BS 4360 grade 50D and SE 702 steel. Constant amplitude fatigue test on welded joints fabricated from BS 4360 50D was investigated in air and in synthetic sea water at a loading frequency of 0.16 Hz [11], but it was observed that results based on conventional S–N approach were published as no fatigue crack growth data was reported. Vaessen and de Back [12] also conducted similar experiments as Booth [11] but they adopted a loading frequency of 0.2 Hz. Corrosion fatigue studies of welded joints fabricated from BS 4360 50D had also been extensively reported in the 1978 European Offshore Steels research seminar [6–12]. Majority of the published results have generally revealed that, at loading frequency of 0.1–0.2 Hz, seawater was detrimental to the fatigue performance of the joints and had also enhanced fatigue crack growth rates.

More recently, Griffiths and Turnbull [13] investigated the effect of exposure or soaking time to compare the corrosion fatigue crack growth of compact tension specimens that were extracted from AISI 4340 and BS4360 50D steels respectively. The tests on both materials were conducted at loading ratio of 0.167 Hz. Havn and Osvoll [14] also presented the effect of cathodic protection on crack growth rate of BS 4360 50D bar specimens at a loading frequency of 0.2 Hz in substitute ocean water prepared according to ASTM D1142-80.

Despite the number of research studies that have been conducted on offshore structural steels, there is still lack of proper understanding on the effect of corrosion fatigue on offshore wind turbine support structures. This paper documents the experimental assessment of crack growth rates of S355J2+N steel in a corrosive environment under various cyclic load frequencies in order to ascertain the effect of cyclic frequency of the applied loading within a frequency range pertinent to the reference structures. Comparison between the crack growth rates of S355J2+N steel and high strength steels data obtained under similar conditions are also established.

2. Overview of cyclic frequency for offshore wind turbine monopiles

Offshore wind turbines monopile structures are slender structures with more complex dynamic behaviour than the offshore platforms used in the oil and gas industry due to the added effect of operational loads from the rotor compared to what is obtainable in oil and gas platforms. It is also