Marine Structures 49 (2016) 97–115

Contents lists available at ScienceDirect

Marine Structures

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

An efficient time domain fatigue analysis and its comparison to spectral fatigue assessment for an offshore jacket structure

Said Fawad Mohammadi [a,*], Nelson Szilard Galgoul [a], Uwe Starossek [b], Paulo Mauricio Videiro [c]

[a] Universidade Federal Fluminense, Niterói, Rio de Janeiro, Brazil
[b] Hamburg University of Technology, Hamburg, Germany
[c] Petrobras S.A., Rio de Janeiro, Brazil

ARTICLE INFO

Article history:
Received 9 December 2015
Received in revised form 11 April 2016
Accepted 13 May 2016

Keywords:
Time domain fatigue
Spectral fatigue
Offshore jacket
Life extension

ABSTRACT

Industry codes require inspections of critical joints within certain intervals to ensure the structural integrity of fixed offshore structures and suggest the use of spectral fatigue analyses to identify them. Spectral methods are considered less reliable but more efficient than approaches in the time domain, which are generally considered highly accurate but computationally unfeasible. This paper evaluates both the time and the frequency domain approaches using a large platform as an example. The results obtained from a, computationally demanding, full-scale time domain fatigue assessment are used as the standard to quantify the errors resulting from the assumptions and simplifications made in the spectral fatigue analysis. These results indicate, also, that the simplifications involved in spectral fatigue lead not only to the well-known inaccuracy but also to consistently lower fatigue lives. This excessive conservatism leads to unnecessary and costly inspections. This paper contributes to the literature in two important ways. First, it shows the main causes of the inaccuracies of the spectral method and quantifies them. Second, it proposes a novel approach for the time domain fatigue analysis which drastically reduces the computational burden, while maintaining a high degree of accuracy. Performing fatigue analyses in time rather than frequency domain increases the accuracy and the reliability of the results and extends the fatigue life of the joints of the structure since several conservative assumptions are eliminated.

1. Introduction

The common reason for large-scale tubular structures to fail after a long period of service life is fatigue [1]. Industry codes such as API [2], DNVGL [3] and ISO [4] require an evaluation of the resistance against fatigue failure to ensure structural integrity. Based on the indications of the fatigue analyses, periodic inspection plans are set up [5], which are very costly whether performed by divers or Remote Operated Vehicles (ROV's). The comparison of inspection results, with predictions obtained from the spectral fatigue method (*SF*) shows that these predictions are very conservative. Since *SF*-based predictions

* Corresponding author.
E-mail addresses: s.mohammadi@tuhh.de (S.F. Mohammadi), nsg@nsg.eng.br (N.S. Galgoul), starossek@tuhh.de (U. Starossek), pmauricio@petrobras.com.br (P.M. Videiro).

http://dx.doi.org/10.1016/j.marstruc.2016.05.003
0951-8339/

are used to schedule inspection plans the conservatism of *SF* has proven to be very expensive. Conversely more accurate and reliable methods to determine locations of high risk of fatigue failure, such as solutions in the time domain, offer substantial cost saving potential.

The time domain fatigue analysis (*TDF*) is considered more accurate than *SF* [6]. Nevertheless, the codes still recommend spectral methods although they are known to be less accurate for purely practical reasons: Spectral methods are computationally much less demanding. In practical terms the codes only recommend *TDF* when the structural model or its loads have highly nonlinear properties. Computational constraints have made *TDF* unfeasible until now [6], because the corresponding computation time can easily last several days. Previous work has attempted to reduce the computational burden of *TDF* [7] by averaging scatter diagrams, which introduces unquantified errors into the analysis and should therefore be avoided. Time domain analyses for an extreme response have so far found application in systems such as Tension Leg Platforms and Spars [8], where dynamic response plays a larger role, and should be adopted for fixed structures as well if dynamic amplification becomes significant [9]. Due to the computational restrictions these analyses are usually used to simulate only one single seastate for a short period of time while a full analysis would require the consideration of hundreds of seastates.

The fatigue resistance of an example structure is analyzed by both methods, *TDF* and *SF* using the software packages USFOS [10] and SACS [11] to quantify how far the results of both methods differ. A full scale *TDF* simulates the entire history of the platform, which, from a computational point of view, is a very demanding analysis and not suitable for design projects. The results of the full scale *TDF* are used as a benchmark for the results obtained by *SF* and enable also an evaluation of the simplified *TDF* method, proposed herein, which is intended to drastically reduce simulation time, while maintaining accuracy.

2. Specifications of the case study

The platform used for the case study has a total height of approximately 170 m from the main deck to the mudline and a water depth of about 150 m. The jacket dimensions at the water plane elevation are about 60 m by 40 m. The piles are modeled as equivalent beam elements, whose stiffness is derived from a full nonlinear pile-soil interaction analysis. The weight of the entire platform is about 53,000 t. The jacket and the steel structure of the topsides weigh approximately 26,000 t, while the remaining 27,000 t result from the modules and additional equipment placed on the structure.

Corrosion effects or material degradation over time are not taken into account. This paper focusses on tubular connections below the splash zone or below a water depth of 20 m, where corrosion has less impact. A viscous damping coefficient of 1.5% is used based on the recommendations of API [2] and ISO [4]. The drag and inertia coefficients applied are those recommended by API [2], which also recommends an increase of 6% due to appurtenances ($C_d = 0.85$, $C_m = 2.12$). The material is represented by a linear elastic material model as recommended by ISO [4] for fatigue assessments. The highest natural period of the sample platform is larger than 3 s, which is why dynamic effects are included [2]. In the offshore environment the most common failures for tubular structures occur in the heat affected zone of the welds [1], which is where fatigue is being investigated. This paper uses stress concentration factors (*SCF*) based on the Efthymiou equations [12], which are recommended by most codes. Both analyses, *SF* and *TDF*, determine the fatigue damage for eight hot spots per tubular connection. As indicated in Fig. 1, there are a total of four hot spots on the chord (1–4) and four hot spots (5–8) on the brace side. In the case of the sample platform 93 joints are monitored, which contain 600 connections with eight hot spots each, thus resulting in a total of 4800 hot spots.

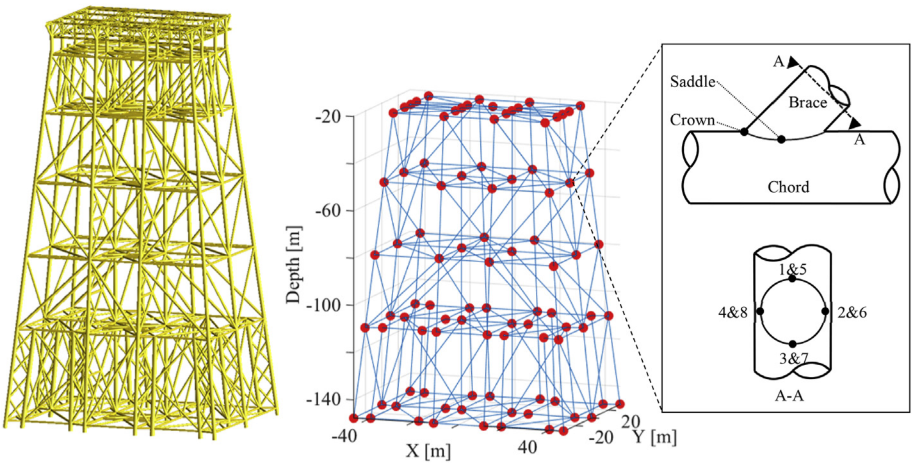

Fig. 1. Monitored connections of the jacket and definition of hot spot positions.