Reliability Engineering and System Safety 155 (2016) 212–223

Contents lists available at ScienceDirect

Reliability Engineering and System Safety

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

Reliability updating based on monitoring of structural response parameters

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ARTICLE INFO

Article history:
Received 20 October 2015
Received in revised form
7 July 2016
Accepted 8 July 2016
Available online 16 July 2016

Keywords:
Monitoring
Structural response
Fatigue
Riser wellhead
Ship hull
Ice load

ABSTRACT

Short- and long-term aspects of measuring structural response parameters are addressed. Two specific examples of such measurements are considered for the purpose of illustration and in order to focus the discussion. These examples are taken from the petroleum industry (monitoring of riser response) and from the shipping industry (monitoring of ice-induced strains in a ship hull). Similarities and differences between the two cases are elaborated with respect to which are the most relevant mechanical limit states. Furthermore, main concerns related to reliability levels within a short-term versus long-term time horizon are highlighted. Quantifying the economic benefits of applying monitoring systems is also addressed.

1. Introduction

What is the benefit of monitoring structural response parameters? This question is generally addressed within the framework of so-called structural health monitoring which has received increasing attention and accordingly also attracted significant research efforts during the last decades.

The main objective of the present paper is to address the short- and long-term benefits of measurements/monitoring of structural response. Two specific examples are considered in order to focus the discussion: The first example deals with monitoring of the angular components at the lower flex joint of a marine drilling riser, while the second example is concerned with measurement of strains that are induced by ice loading on a ship hull.

There are usually multiple objectives associated with measurement of structural response processes and parameters. One such objective is frequently to monitor "the conditions" (or performance indicators) on-line such that counteractive measures can be activated when a critical threshold is reached. A second objective can be to perform extrapolation of key parameter values into the future in order to estimate when a critical condition will be reached. A third objective is related to the long-term learning process,i.e. to gain improved under-standing of structural behavior as well as updating of the calculation models that are applied. Hence, an overarching objective is to provide a tool that may serve to supply basic information for the purpose of decision support in a wide sense. This applies both to the short-term and long-term time horizons.

In relation to updating of the applied calculation models, possible observed deviations between the measured and computed response implies that the calculation model needs to be revised. Such a revision can in some cases consist of more than a pure updating of particular parameters in the sense that the whole analysis framework needs to be upgraded.

An important issue in relation to how the measurements are processed is also which type of limit state that is critical. For the case that the fatigue limit state is anticipated to be the dominant one, the accumulated effects caused by a sequence of short-term stationary conditions is estimated. Prediction of the time until the critical threshold is reached will be the "performance measure". On the other hand, if the extreme response within a short-term condition (with a duration of a few hours) could possibly exceed the critical level, prediction of response levels within a much shorter time horizon will be in demand.

These issues are highlighted in the following. The presented results which are obtained from measurements and calculated response are mainly based on the following sources: Stange [1], Stange and Leira [2], Suyuthi [4] and Suyuthi et al. [5–7].

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http://dx.doi.org/10.1016/j.ress.2016.07.006
0951-8320/

2. Monitoring of riser angles for assessment of wellhead fatigue

2.1. General

The first example is related to the issue of wellhead fatigue during offshore drilling. This potential failure mode has been increasingly focused upon during the last decade. There are multiple reasons for this increasing concern, such as: (i) The specific values which were assumed for the design parameters during initial design may no longer apply. (ii) The size and weight of the Blow-out Preventers (BOPs) that are being applied have steadily been increasing. (iii) Larger surface vessels which operate in more and more hash weather are put into operations. (iv) For each well, there are more BOP days than assumed during initial design. Accordingly, it does not come as a surprise that well-head fatigue and the associated potential failure modes are coming strongly into focus.

Extreme response on the other hand is (at least in principle) taken care of: For angles exceeding a certain level, automatic emergency disconnect of the riser from the BOP is assumed to occur. Such a disconnect can be initiated e.g. by a drift-off or a drive-off of the surface vessel which frequently is associated with failure of the positioning system (e.g. errors related to the GPS-measurements). This implies that extreme loading which will endanger the integrity of the well-head can be disregarded (if the automatic disconnect system is activated).

Monitoring of the riser angles will also provide guidance in relation to when a manual disconnect action will need to be initiated in the case that the automatic emergency disconnect should fail. The time scale associated with such an operation is quite short, i.e. of the order of minutes.

Assuming that extreme loading is properly taken care of, the fatigue limit state comes into focus for all the mechanical components of the system. The riser itself can be inspected at regular intervals after retrieval when the drilling operation is completed. This implies that the condition of the permanently installed seabed components are of most concern as these cannot easily be inspected. In particular, estimation of the accumulated fatigue damage at the well-head is of key importance.

2.2. The measurement system

A schematic layout of the marine drilling riser is shown in Fig. 1. The riser is attached to an Aker H-3 rig at a water depth of 325 m in the North Sea. The interface between the local and global analysis models are at the transition between the top of the wellhead and the lower face of the BOP.

The components of the instrumentation system are shown in Fig. 2. The two orthogonal components of the riser angles at the Lower Flex Joint (LFJ) are measured by means of Inertial Measurement Units (IMU). Based on the measured angles, the loads which are acting on the wellhead can be estimated by introducing a local stress analysis model (i.e. by application of a Finite Element representation).

This is shown schematically in Fig. 3 where the tension, bending moment and shear force (for the case of a 2D load-effect representation. These force components are first transformed to force and bending moment components at the interface between the BOP and the wellhead. A local model of the well-head can subsequently be applied. Clearly, a more comprehensive model which comprises both the wellhead and the BOP can also be applied if this is required e.g. based on relative flexibility concerns.

An example of a measurement sequence for the two riser angle components is shown in Fig. 4(a). A level plot of the histogram which represents the relative time the angular process spends in each square block is shown in Fig. 4(b). It is found that a bivariate Gaussian model provides an adequate analytical model for the histogram.

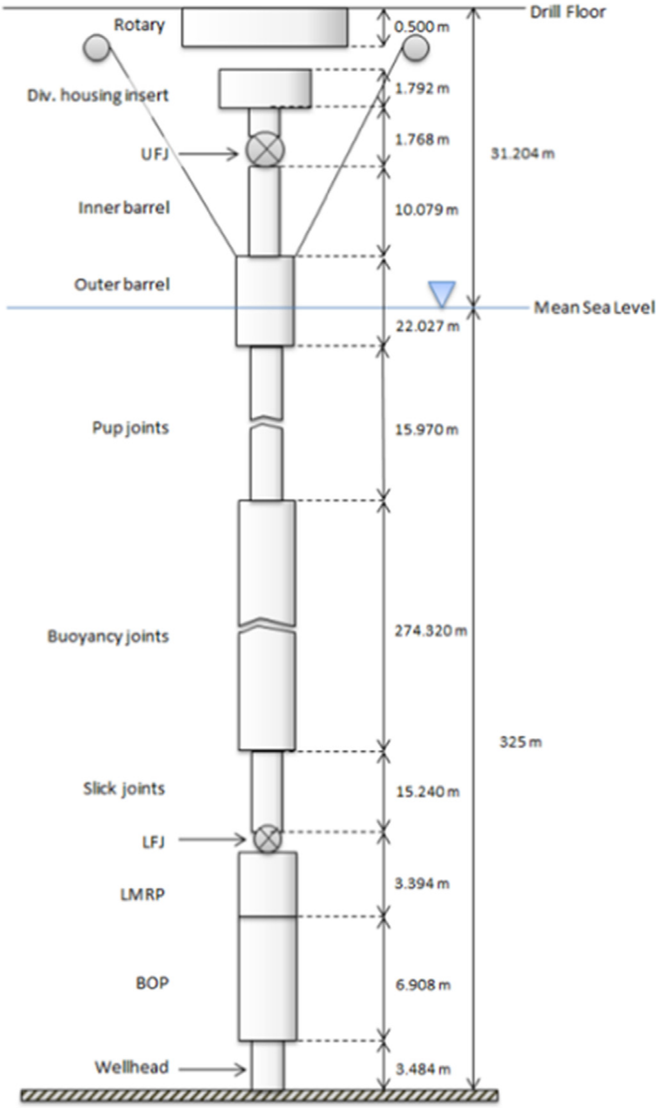

Fig. 1. Basis for numerical riser model, Stange (2012).

In Fig. 5, a number of projection planes for the angular process are indicated by straight lines. This will serve for the purpose of estimating the fatigue damage contributions from different directions. The cycle histogram can be established for each of these directions and subsequently the corresponding contribution to the well-head fatigue damage can be established.

2.3. Comparison between full-scale measurements and numerical Simulations

By computing the resulting total angle for each of the blocks in Fig. 4(b), a “one-dimensional” cycle distribution can be established for the angle range. The result is shown in Fig. 6.

The frequency distribution of the response process components is also of significant interest. The response spectral densities for the total angle are shown in Fig. 7(a), (b) and (c) for three consecutive hours. It is seen that for the first two hours the frequency distribution is quite similar with two main peaks within two distinctive frequency intervals. However, for the third hour there is a pronounced shift with the main peak being located at very low