Ocean Engineering 89 (2014) 99–112

Contents lists available at ScienceDirect

Ocean Engineering

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

# On the importance of slamming during installation of structures with large suction anchors

T. Næss [a,*], J. Havn [a], F. Solaas [b]

[a] Subsea 7, Department of Hydrodynamics and Offshore Technology, P.O. Box 205, 4065 Stavanger, Norway
[b] MARINTEK (Norwegian Marine Technology Research Institute AS) Department of Offshore Hydrodyanamics, Norway

ARTICLE INFO

*Article history:*
Received 18 October 2013
Accepted 7 July 2014

*Keywords:*
Slamming
Suction anchor
Splash zone
SIMO
Analysis

ABSTRACT

The dynamic loads experienced when deploying structures with large suction anchors from an offshore construction vessel has been studied. Both model tests and CFD-analyses have been used to calibrate a numerical model of a typical Integrated Template Structure (ITS). The numerical model has then been used in time domain analyses in order to study the dynamic loads in the main lift wire when the ITS is lowered through the splash zone.

An overall conclusion from this study is that from a lifting point of view neither the structural integrity of the ITS nor the crane will be jeopardized when crossing the splash zone in a typical deployment operation on the Norwegian Continental Shelf (NCS).

The CFD analyses reveal the importance of entrapped air and water when the top of the suction anchor is crossing the splash zone. For the Gjøa ITS suction anchors used in the study, the openings on top of the suction anchors are quite large (perforation of 6%) which limits the amount of entrapped air during the water entry phase and also the amount of entrapped water in the water exit phase.



## 1. Introduction

For a subsea structure installed using a monohull construction vessel, the crossing of the splash zone is traditionally looked upon as the critical phase of the operation when it comes to the dynamic forces in the lifting wire. It is commonly assumed that the combined effect from crane tip motion and wave kinematics will induce the overall largest vertical hydrodynamic forces on the structure to be installed when the structure is close to the surface. The larger the hydrodynamic properties of the structure are relative to the mass, the more critical the phase when the splash zone is crossed is believed to be.

The added mass term for a suction anchor is large compared to the structural mass since it usually includes the mass of the entrapped water. As known from standard literature (Faltinsen, 1990), the added mass term will induce forces that are in phase with the relative acceleration between the suction anchors and the water particles. Due to the large added mass term relatively to the structural mass, these added mass forces often becomes large and can be critical with respect to the dynamic forces in the lift wire.

However, for a suction anchor there is another force term that traditionally is considered as even more critical, namely the so-called "slamming force". When the top of the suction anchor penetrates the surface, the added mass will increase from practically zero, to the fully developed added mass over a short vertical distance as illustrated in Fig. 1.

This sudden increase in the added mass term will induce a force that is commonly phrased as the "slamming force" in literature (DNV, 2013; Faltinsen, 1990) and can be expressed as:

$$F_s = \frac{d}{dt}(A_{33}V) \tag{1}$$

where $F_s$ is the slamming force, $A_{33}$ is the added mass in vertical direction and $V$ is the relative velocity between the surface and the object.

As mentioned, the entrapped water is usually included in the added mass term for a fully submerged suction anchor. This is also the case for the work presented in this study.

One may however question whether the complete entrapped water should be included when the slamming force is calculated. If one argues that the slamming force is governed by the flow picture at the top of the suction anchor, one may also argue that the slamming force is not that dependent upon the height of the suction anchor, i.e., the slamming load for a suction anchor with height 7 m should be approximately the same as the slamming force for a suction anchor with 14 m height given that the top of the suction anchors are identical. Hence, care should be used when if a slamming force model representative for a given suction anchor is to be applied on a suction anchor with different height.

* Corresponding author. Tel.: +47 97784397

http://dx.doi.org/10.1016/j.oceaneng.2014.07.011
0029-8018/

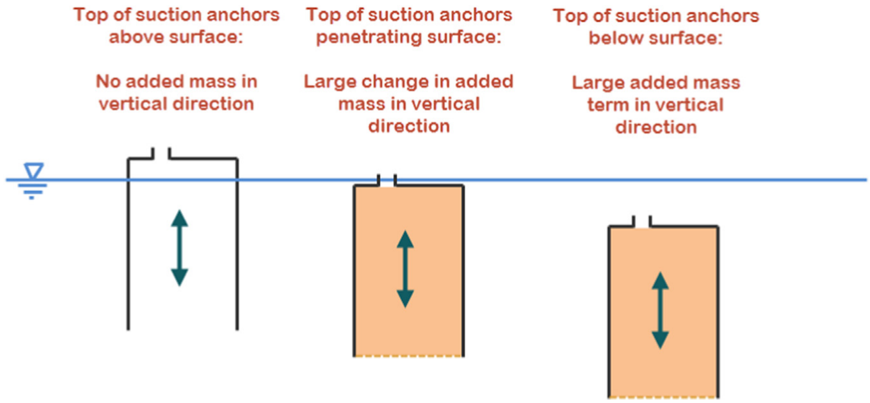


**Fig. 1.** Suction anchor – entrapped water.

One should notice that the slamming force is only a part of the total "water entry" force. As discussed in both DNV-RP-H103 and Faltinsen (1990), the total load picture for an object penetrating the surface will be influenced by both the buoyancy force and viscous effects.

In addition, one should mention that a suction anchor in the splash zone also will be exposed to a "water exit" force. And as discussed in Faltinsen (1990), the water exit force will in general not have the same characteristics as the water entry force. The enclosed water and drainage of the enclosed water will for instance often be an important parameter for the "water exit" force.

The slamming force is hard to quantify. The added mass term in itself is quite straight forward to quantify for a suction anchor since it is dominated by the entrapped mass, but in order to gain a reliable estimate on the slamming load, the change in added mass as a function of the distance to the surface must be defined. This is illustrated in Fig. 1. And it is this distance, where the added mass terms increases from zero to fully developed added mass that will define the slamming force together with the added mass term.

At present very little data is published on how to distribute the added mass term with depth in order to achieve a representative level on the slamming force. Some guidelines on how to quantify the slamming load is given by DNV in DNV-RP-H103, but these guidelines are mainly linked to simplified analyses and are by nature conservative compared to results from time domain analyses.

In connection to the Gjøa project in 2009, the Gjøa Integrated Template System (ITS) was to be installed by the monohull construction vessel Skandi Acergy. The ITS and the Skandi Acergy deck is shown in Fig. 2, and as seen by the figure, the ITS is essentially four suction anchors tied together by a simple frame. Hence, the hydrodynamic load picture is dominated by the four suction anchors.

Prior to the offshore operation, the project realized that there was a need to quantify the hydrodynamic properties for the ITS in order to ensure that the structural capacity of the crane was not jeopardized during the operation. Consequently, forced oscillation tests of the Gjøa ITS was carried out by MARINTEK in Trondheim. The main objective with the model tests was to use the results to calibrate a numerical model of the suction anchors, so that an engineering software as SIMO (MARINTEK, 2013) could be used to estimate the expected hydrodynamic loads experienced during a deployment of the ITS in an irregular sea state. As shown in Jacobsen et al. (2011) and Jacobsen and Næss (2012) the results from the SIMO analyses predicts limited hydrodynamic forces in the splash zone and seems to agree well with crane log recorded during the operation but that the slamming load is conservatively estimated for higher sea states.

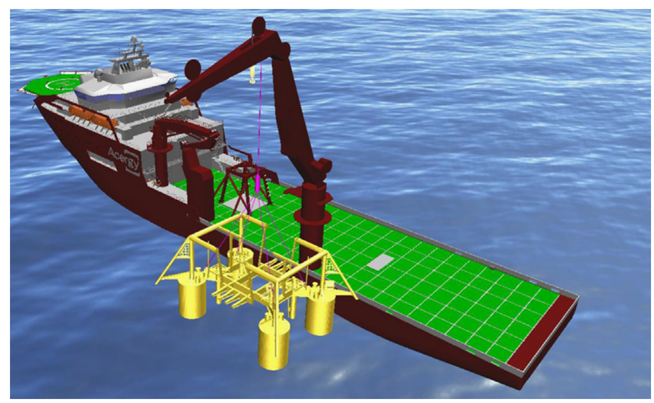

**Fig. 2.** Gjøa ITS deployed using Skandi Acergy – visualization from SIMO analyses.

Recently, an effort has been made to analyze the water entry and water exit forces of the top of the Gjøa ITS suction anchors using Computational Fluid Dynamics (CFD). Based on results from these analyses a better understanding of the load picture for the water entry and water exit of the top of the suction anchors has been gained and an improved numerical SIMO model with less conservatism (Jacobsen et al., 2011; Jacobsen and Næss, 2012), has been established. In the following sections the results from the model tests are presented together with the results from the CFD analyses, an improved SIMO model are defined and finally the practical implications for the offshore operations are discussed in view of results from time domain analyses in SIMO.

## 2. Forced oscillation tests – results and main findings

The forced oscillation tests were performed by MARINTEK (Solaas, 2008) and some of the results are presented and discussed in Jacobsen et al. (2011) and Jacobsen and Næss (2012). The tests were carried out for different submergences of the ITS, but in this context only the results obtained from the tests where the top of the suction anchors is oscillated in the water surface is of interest.

The set-up of the tests that is of relevance in this context is illustrated in Fig. 3 and the main properties for the ITS is summarized in Table 1. Notice that the dimensions stated in the table means that the perforation ration for the top of the suction anchor is about 6%.