Detecting Critical Scour Developments at Monopile Foundations Under Operating Conditions

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Introduction

Scour depth measurements are applied to prove that the maximum allowed scour depth is not violated during normal operation or severe storm conditions. However, at fatigue driven monopile foundations, this practice can lead to high maintenance costs of the equipment and eventually over-maintenance activities. Instead, the exploitation of the structural reserves stemming from design assumption versus real site conditions is suggested. Damage accumulation is highly influenced by the time behaviour of the transient scour behaviour and real soil properties. This paper elaborates on novel low cost monitoring methods to detect when a scour development is truly critical when taking site conditions into account. The feasibility of a warning system that raises an alarm when the structural integrity is put at risk is studied.

Approach

Scour depth measurements are regarded as expensive and conservative indicator for critical conditions with respect to structural integrity of fatigue driven monopiles. Three measurement data requirements have been identified to qualify for an alarm system: 1) criticality – the measurement should have a direct link to a structural failure, 2) measurability – it should be based on a cost effective measurement technique and 3) uniqueness – the root cause of an alarm raised should be scour development only. A multitude of environmental conditions superimpose in the natural frequency measurements. To assess the suitability of this indicator, a sensitivity study of the first natural frequency to different environmental influences is conducted at an up-to-date monopile design. Scour development, marine growth, corrosion and water levels variations are considered relevant changes affecting the natural frequency.

The impact of scour development by means of violating design thresholds is evaluated. Therefore Ultimate Limit State (ULS), Fatigue Limit State (FLS), Natural Frequency Analysis (NFA) and Serviceability Limit State (SLS) are checked in concept study detail according to current guidelines. The impact of different inputs to the design fatigue life calculation is evaluated by re-runs of FLS simulations with varying settings.

The detailed natural frequency and load calculations are conducted using Ramboll Offshore Structure Analysis Programs (ROSAP), a state-of-the-art tool package to design and optimize offshore structures according to current standards and certification requirements.

Main body of abstract

Three main criteria for an indicator of an alarm system are defined to select a reasonable scour monitoring: **criticality**, **measurability** and **uniqueness**.

Criticality refers to the fact that the indicator for scour development shall be linked to potential structural failure modes such as exceeding the yield stress or material fractures. The arising damage must be identified before a failure occurs and the specification of a threshold must be possible.

Measurability requests an existing measurement technique for the indicator. The measurement equipment and the measurement procedure should be simple, robust and reliable. Installing above the water level increases the accessibility during the repair.

Uniqueness of the indicator to describe scour is crucial to focus the monitoring on this effect. If other effects may result in a change of the indicator, the sensitivity has to be determined to ensure that scour is the dominating cause.

The common used scour depth S in meter is not directly linked with any failure or serviceability limit. A common criterion according to design guidelines [1] is $S < 1.3\ D$, with the pile bottom diameter D, but this is only an assumed scour depth for design. There are several approaches to measure the scour depth directly via optical methods or float-out devices. A reliable and low cost long term operation of these techniques is questioned, however. No other effect besides scouring or seabed movements is known to affect the scour depth.

The first natural frequency of the support structure in Hz will change due to scouring. This indicator is related to a failure resulting of resonance. There is no general threshold, but the natural frequency should not coincide with excitations. Germanischer Lloyd recommends in its guideline [2] that the ratio of a rotor-induced excitation to one of the natural frequencies of the tower shall not be between 0.95 and 1.05. Natural frequencies can be gained by measuring accelerations and subsequent modal analysis [3]. The flexibility parameter is affected by any stiffness or mass change of the system, e.g. more mass due to marine growth, less mass and stiffness due to corrosion, more or less oscillating surrounding water mass due to changing water levels. Further stiffness changes may occur due to soil degradation, in a grouted connection or by cracks.

The sensitivity study confirms scour as dominating cause for natural frequency changes, however. The natural frequency reduction by extremes of corrosion (-0.37%), water level changes (-0.18 or +0.14%) or marine growth (-0.03%) are distinctly smaller than for scour up to 1.3D (-5.04%). The minor effects added together reduce the natural frequency in the dimension of only a eighth of the scour impact.

The correlation of scour and the natural frequency can be used to define a stepwise linear function for identifying scour. Coinciding scour, corrosion and water level variations are investigated to estimate the error of this approach. Lifetime corrosion allowances (0.3 mm/a extern, intern 1 mm) and 50 year extreme water levels are combined with different scour states in a factorial investigation. The resulting look-up error is visualized in Figure 1 with the scour depth given per unit (pu). The classification can deviate by 0.25 D at small scour depths, but the error is lower for larger depths. The errors are mostly conservative with identified scour depths greater than the actual ones.

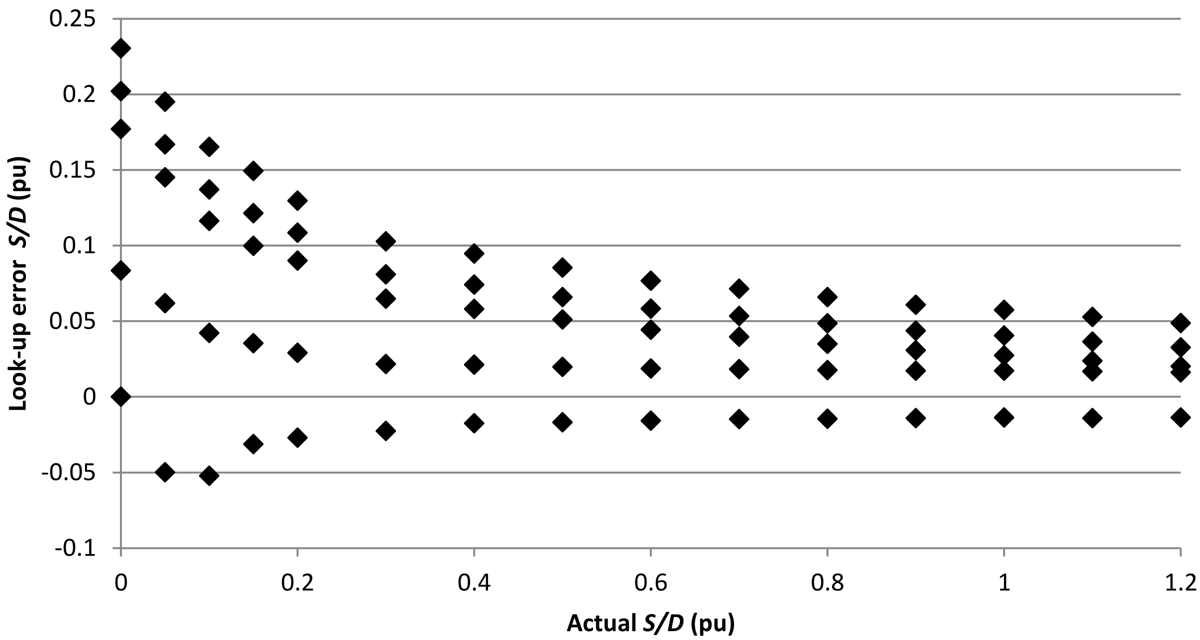

Figure 1: Look-up error considering unknown corrosion and water level states

The criticality of the natural frequency depends on the design of the support structure. Re-run design calculations with increasing scour depths indicate the bearable scour limit in ULS, FLS, NFA and SLS. The natural frequency change is not the most critical consequence for the investigated designs. The support structures are fatigue driven and any scour results in an inacceptable fatigue lifetime shortening.

All in all, the measurability and uniqueness of the natural frequency are seen as appropriate, but there is a lack of criticality.

If fatigue is the first hit threshold, a monitoring of the dynamic loading is promising. Several assumptions in the design fatigue calculation may even lead to a compensation of scour damages. S*ystematic* assumptions are considered to have no practical alternatives. One of the most severe one is the linear damage concept. *Design* assumptions depend on specific material characteristics or design choices for the calculation as e.g. the specific S-N curve or an assumed structural damping. Assumptions concerning *loads* and *environment* are based on site information, as e.g. wind and wave characteristics or water levels, scour and similar.

To assess the impact on the fatigue life a selection of assumptions are varied in a FLS sensitivity study. Therefore parameters are changed in as small as possible steps, limited by the availability of data. In absence of reliability information of site-specific data, possible parameter variations are guessed. Figure 2 shows the resulting fatigue damage of the selected changes. A reduced water level is investigated by an implementation of a less conservative global water level rise interpretation. A marginal water level reduction of 0.3 m could already compensate a slight scour with a depth of S=0.15D. Equivalent wind loads are provided by the turbine manufacturer for a park configuration, which is used in the reference, or for IEC class B turbulence intensity. The damage per year due to wind loads at approx. 0.025 higher turbulence intensity is nearly as high as the one with an extreme scour depth (S=0.5D). The wind loads are defined for a site-specific average mean speed, a variation of this assumed mean speed by 0.5 m/s results in a damage change larger than the amount of slight scour. An increase of structural damping from 1.4 to 1.5 % results in a damage reduction in a similar dimension.

The actual consequences of design assumptions are highly design and site specific. The possibility of a compensation of effects in the fatigue damage is illustrated, however.

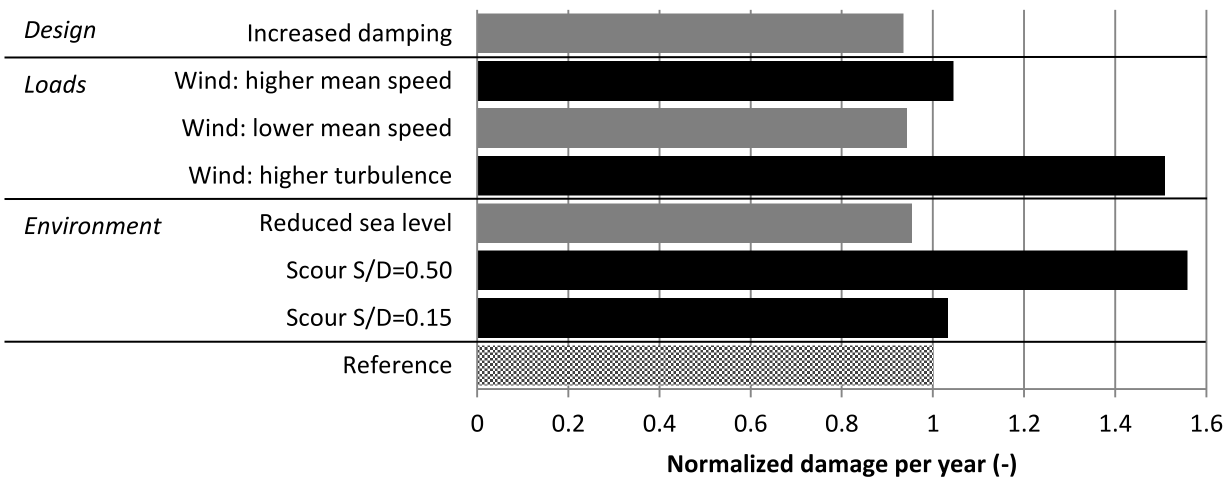

Figure 2: Fatigue damage for selected settings

Getting back to the three criteria to evaluate a scour indicator, it can be stated that:

1. Fatigue monitoring is linked with the dynamic failure caused by scour. For the investigated designs the fatigue lifetime is the first violated threshold of scouring.
2. Dynamic load measurement and estimation have been investigated in research projects recently [4]. Accordingly, an adequate measurability with acceptable costs is assumed.
3. Uniqueness for detecting critical scour is not given by fatigue monitoring.

Conclusion

A combination of fatigue monitoring and natural frequency supervision is suggested for the detection of scour in the framework of an early warning system. The advantages of both methods, the sufficient uniqueness for scour of the natural frequency and the good criticality of fatigue monitoring, will merge.

Learning objectives

The paper focusses on the selection of a suitable measurement approach to detect critical scour development in the scope of an early warning system. The suggested monitoring approach contributes to the optimization of current maintenance practices.

References

[1] DNV GL AS, "Design of Offshore Wind Turbine Structures. Offshore Standard DNV-OS-J101," DNV GL AS, Høvik (Norway), 2014.

[2] GL, "Guideline for the Certification of Offshore Wind Turbines IV-2," GL Renewables Certification, Hamburg (Germany), 2012.

[3] M. El-Kafafy, C. Devriendt, W. Weijtjens, G. De Sitter and P. Guillaume, "Evaluating Different Automated Operational Modal Analysis Techniques for the Continuous Monitoring of Offshore Wind Turbines," *Dynamics of Civil Structures,* vol. 4, pp. 313 - 329, 2014.

[4] U. Smolka and P. W. Cheng, "On the Design of Measurement Campaigns for Fatigue Life Monitoring of Offshore Wind Turbines," *Proceedings of the Twenty-third International Offshore and Polar Engineering,* 2013.