Hydrodynamic challenges related to safety of offshore structures

Arne Nestegård
Det Norske Veritas, N-1322 Høvik, NORWAY
e-mail: arne.nestegard@dnv.com

A main concern related to safety of offshore structures is the hydrodynamic loading of the structure during its expected lifetime. The safety of a fixed or floating structure is contingent on the robust design of the structure. Design of an offshore structure is usually based on a methodology in which a target component safety level is obtained by defining specific limit states and ensuring that the environmental loads do not exceed these limits. The most typical limit states are the Ultimate Limit State corresponding to the ultimate resistance of the structure for carrying loads and the Fatigue Limit State related to the possibility of failure due to the effect of cyclic loading. For each of the limit states representative loads are defined. For the ultimate limit state, the characteristic load corresponds to a load with an annual probability of exceedance equal to or less than 10^{-2}. For the fatigue limit state, the characteristic load is the expected load history on the structure during its lifetime [1].

For offshore structures the main environmental loads are loads induced by waves, wind and current. Other loads can be due to earthquake, tidal effects or snow and ice. An ultimate limit state with 10^{-2} annual probability of exceedance is defined as a certain combination of the different environmental loads. A typical combination is wind with annual probability of exceedance of 10^{-2}, waves 10^{-2} and current 10^{-1}. Load effects relevant for ultimate limit states are ususally highly nonlinear and accurate methods and numerical tools may be lacking. Also there is an inherent inaccuracy in the environmental conditions applied. This introduces an uncertainty in the load level to be applied in design. This is then compensated by multiplying the load effect by a safety factor which may be typically 1.3. It is an aim for the industry to be able to reduced safety factors for use in design.

An example of an ultimate load effect is the global wave impact on the deck structure of a fixed offshore platform. Fixed platforms are designed with a positive airgap so that the highest waves can never reach the deck level. This assumes that one is able to predict the highest waves that can be expected to occur with a certain probability at the platform site during its lifetime. During the last years the scientific community and the offshore industry have become aware of new giant waves, or freak waves, that can not be deduced from classical methods in wave statistics. Since the design and building of some platforms, an extensive amount of new wave data collected during their operational life has lead to higher estimates of extreme crests. In addition platforms may have been subject to subsidence of the seabed, so that waves with an annual probability larger than 10^{-2} will actually hit the deck. The solution of such wave impact problems is challenging for several reasons. First of all, the fluid volume hitting the deck are at the top of a single crest of a highly nonlinear random sea. The detailed kinematics $\mathbf{v}(\boldsymbol{r},t)$ of such waves is not known. Secondly, the hydrodynamic problem of three-dimensional impact of a general structure and a nonlinear wave can only be accurately modelled by CFD methodologies. Finally, the geometry of a general deck structure is complex with lots of local details, requiring a qualified modelling philosophy. In the simplest case, the platform deck is supported by a jacket structure consisting of slender elements that do not disturb the incoming wave. For such cases simplified numerical methods based on explicit force expressions for water entry problems have been applied. Recently new numerical simulation tools based on the Volume-of-Fluid method have been developed for analysis of wave in deck impact [2]. A nonlinear incoming wave is specified at the boundary of the computational domain and interacts with the platform deck. An important observation is the downward suction force following the upward impact force. Such numerical tools are presently being used to assess lifetime extension of existing platforms. The same numerical method can be used to analyse the water on deck on floating production ships in large waves. In this problem, the inflow wave to be specified is modified by the presence of the ship.

Another ultimate load effect is higher order loads causing high frequency resonant response of large volume structures like tension leg platforms and gravity based structures. A well established method and computer tools do not yet exist to predict the resonant "ringing" response caused by such nonlinear wave loads.

An example of an important fatigue load effect where satisfactory prediction methods and tools are lacking is the combined vortex induced vibrations and wake induced oscillations of risers in close proximity. This presents new challenges with respect to possible collisions between the risers. The force field generated by the upstream riser may generate complex, large amplitude displacements of the downstream riser. These wake induced instabilities may be governing for whether a pair of adjacent risers will collide or not [3]. Wake induced instabilities may be classified into two main categories. When a vertical riser is situated in the wake of an upstream one, several static equilibrium configurations are in general possible. The number of possible static equilibrium positions will generally depend on the incoming current profile as well as riser configurations (spacing, top-tension). The downstream riser may move between several possible stable equilibrium positions due to disturbances in the inflow; e.g. due to vortex shedding, turbulence or buffeting forces. The resulting motion pattern may hence be quite complex. No stable static downstream configuration exists when the current velocity exceeds the critical current velocity. The downstream riser will start to wander in the wake of the upstream riser when the critical current velocity is exceeded. These self-started dynamic oscillations caused by the position dependent variation in mean drag and lift force are commonly termed *wake induced oscillations*. A similar challenge is the galloping motion of subsea umbilical and pipelines when subjected to high current velocities.

References

[1] Offshore Standard DNV-OS-C101 "Design of Offshore Steel Structures, General (LRFD Method). October 2000.

[2] Helmholt-Kleefsman, T. & Veldman, A. (2004) Comflow User Manual – Safe Flow project.

[3] Recommended Practice DNV-RP-F203 "Riser Interference". January 2005 (Draft)