Notes for the Students by *Marilena Greco:*

In the following, a list with examples of topics is given, but others could be identified especially in the context of marine greener-energy applications and of bio-inspired solutions to support efficiency and effectiveness for marine vehicles and platforms.

1. Potential and viscous, nonlinear wave drift loads relevant for moored platforms, in general, and for Floating Offshore Wind Turbines, in particular.
2. On the importance of non-linear hydrodynamic effects and handling of inconsistencies between different modules in the analysis of a floating offshore wind platform – *Proposed by DNV*.
3. Nonlinear wave energy converter hydrodynamics – *Proposed by CorPower Ocean*.
4. Potential re-use of in-place concrete sub-structures for generating renewable energy from ocean waves – *Proposed by Mr. Bjørn Sjetnan, with a patent on this*.
5. Failure mechanism for oil boom devices for spilled oil.

This information will be also available on http://folk.ntnu.no/marilena/; moreover, other topics could be considered based on your individual interests.

In case of any doubt/need of information about any of the proposed topics, please just contact me. Sincerely yours, marilena.

1. **Potential and viscous, nonlinear wave drift loads relevant for moored platforms, in general, and for Floating Offshore Wind Turbines, in particular.**

Background: During the 1990s, some research showed that viscous effects contributed to a substantial increase in wave drift loads in high sea states for slender structures. Later, documented occurrence of mooring line failures in sea states that were less severe than the design states motivated in-depth research to cover the knowledge gap. Wave drift loads have traditionally been found from linear or second-order hydrodynamic analyses based on perturbation theory; however, during recent years it has been questioned whether these methods in some situations underestimate the wave drift loads. Indeed, it is shown that the wave loads can differ when waves are steep and/or when the first order motions of the floating body are large. A Statoil project in 2014 and then the "EXWAVE JIP" project for semisubmersibles and other column-based floating platforms in 2016, proposed an empirical sea-state dependent formula, modifying the mean wave drift forces from potential-flow theory to account for viscous contributions. The existing research on wave drift loads in high sea states primarily focus on drilling-type semisubmersibles (such as the on to the left in Figure 1). More novel type of marine structures, such as floating offshore wind turbines (e.g., the design to the right in Figure 1), have significantly different characteristics both in terms of geometry and inertia properties. A knowledge gap therefore needs to be filled through research to better understand the importance of viscous contributions to the wave drift loads on these structures, which will be important to ensure that the floating wind industry evolves with robust designs. For large volume structures, such as the structure in the middle of Figure 1, potential-flow type nonlinear wave loads beyond second order may be important, which is relevant for the design of ship-shaped units such as FPSOs as was addressed in the second phase of the “EXWAVE JIP”.

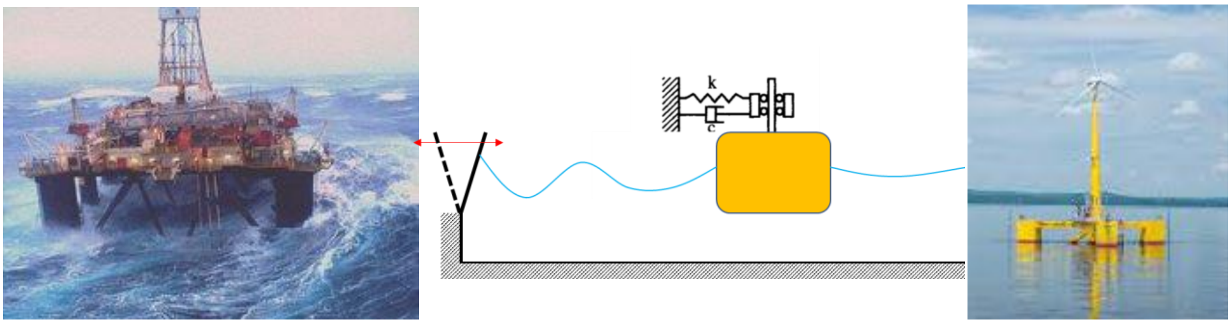


Figure: Left: Platform in harsh weather. Center: Sketch of 2D model tests. Right: VolturnUS-S FOWT.

Two topics are proposed, as detailed in the following.

A) <u>Experimental study relevant for drift loads of moored offshore structures in waves</u>

Nojiri and Murayama (1975) published an experimental study on the wave drift forces on a two-dimensional (2D) ship section in regular waves. Experimental results from this study have been used as a reference to benchmark numerical results by numerous authors during the last three decades. However, since the original publication is old, and written in Japanese, the details of the experiments are not well known. This includes parameters that are important to determine the experimental accuracy and possible error sources. It is therefore proposed to repeat these experiments, as well as make use of the most recent knowledge related to wave drift loads to extend the study. A tentative outline of the research would be:

Main Objectives: Starting during the project-thesis work and continuing during master-thesis work, the candidate should repeat the experiments performed by Nojiri and Murayama (1975), see sketch in the center of the Figure 1. The outcome of the study may contribute with fundamental knowledge that is important to bridge identified knowledge gaps for wave drift loads and slowly varying motions of floating structures with respect to nonlinear wave-body interaction effects.

More specifically the student must:

1. Design the experiments so to have a suitable and well controlled experimental setup and model and perform the analysis in regular waves with the body as freely floating.

2. Compare motions, wave reflection and transmission coefficients and wave drift forces with the original experiments. Make a systematic error analysis. Perform an experimental sensitivity study on the effect of wave steepness and body motions on the wave drift loads.

3. If time allows, two other cross-section geometries could be analyzed, e.g., with non-wall sided geometry at the mean free surface (including presence of flare), so to assess relevance of these features on the examined wave loads.

B) Potential and viscous, nonlinear drift loads for Floating Offshore Wind Turbines in waves

A previous master thesis examined numerically the mean wave drift loads on a selected semi-submersible floating offshore wind turbine (FOWT) concept, the "VolturnUS-S" (see right of the Figure), assumed fixed and interacting with regular waves. A laminar-flow solver within OpenFOAM was selected and comparisons of the mean drift loads were made against the standard predictions based on potential-flow solution with the correction from the mentioned empirical formula.

Main Objectives: Starting during the project-thesis work and continuing during master-thesis work, the candidate should continue the logical steps of this study with the aim to highlight relevance and features of potential and viscous, nonlinear flow effects on wave drift loads for the selected FOWT.

More specifically the student must:

1. Summarize steps and findings of the previous master thesis, possibly complementing the literature study on mean and slow drift loads and related studies for FOWTs.
2. Analyse the OpenFOAM results in relevant scenarios examined in the previous master thesis in terms of flow features to assess importance of nonlinear potential and viscous flow effects and relate them to the mean-drift loads results.
3. Examine the selected FOWT as fixed in bi-chromatic waves and the subsequent nonlinear mean and slow drift loads.
4. If time allows, other relevant aspects could be analysed, connected with the influence on the experienced drift loads when to a) the FOWT has a mean position with a non-zero mean pitch angle as expected in operational conditions due to the wind and when b) a turbulent-flow model is included in the numerical solver.

Topic is proposed in collaboration with Dr. Finn-C.W. Hanssen and Dr. MA Siddiqui that will contribute to the supervision of A) and B), respectively.

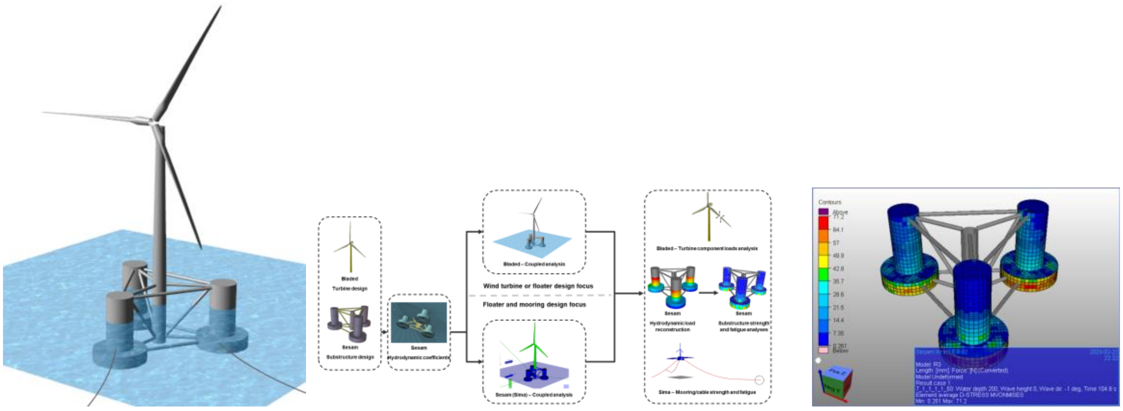
2. **On the importance of non-linear hydrodynamic effects and handling of inconsistencies between different modules in the analysis of a floating offshore wind platform.**

<u>Background.</u>

DNV – Digital solutions has a program system, Sesam, for analysis of structures in the sea. During recent years the focus has been on analysis of offshore wind structures, in particular the support structure for floating offshore wind turbines. The workflow for this analysis goes all the way from modeling through hydrodynamic, coupled, and structural analysis to post processing (fatigue and code checks). In the current version of the workflow most computations are done under the assumption of linear theory. This makes it relatively easy to handle consistency between the different tools. The workflow needs, however, to be extended to non-linear analysis. This calls for investigation of the importance of non-linear effects, but also for handling inconsistencies between tools.

A core part of the workflow is to first run a coupled analysis followed by a hydrodynamic analysis for computation of the loads on the support structure. The coupled analysis has some non-linear options while the hydrodynamic solver has others. Two main questions are:

1. What is the importance of the non-linear effects?
2. How can we minimize the effect of the inconsistencies on the structural analysis?



<u>Main Objectives</u>

Starting during the project-thesis work and continuing during master-thesis work, the candidate should learn to use the software tools in the workflow, investigate the importance of non-linear effects in the hydrodynamic analysis and look at ways to handle possible inconsistencies in the workflow.

More specifically the student must:

1. Learn to use the different software tools in the workflow, with main focus on SIMA and HydroD. Describe the main features of the tools relevant for topic 3 and 4.
2. Describe the available non-linear options for the hydrodynamic analysis.
3. Investigate the importance of the non-linear effects for the loads on the structure
4. Investigate various ways of handling the inconsistencies between the coupled solver (SIMA) and the hydrodynamic solver (HydroD/Wasim) with the purpose of minimizing the consequences of the inconsistency on the structural analysis.

Topics 1 and 2 are likely to be covered in the project work, while topics 3 and 4 will be the primary focus of the master thesis.

Topic Proposed by DNV AS – Digital solutions

Contact person Torgeir Vada, Senior Principal Specialist (torgeir.vada@dnv.com)

3. **Nonlinear wave energy converter hydrodynamics**

Background

Ocean waves represent a substantial source of renewable energy and will be part of the solution when transitioning to emission-free energy systems world-wide. The Swedish company CorPower Ocean, one of the leading companies in wave energy conversion, is currently in the demonstration phase with a system that incorporates technology originating from NTNU. Through a combination of innovative mechanical solutions and methods for model-based optimal control, the power output is maximised while survival is ensured.

CorPower Ocean™

The motion of the wave energy converter is characterised by excursions larger than the wave amplitude. This implies that both hydrodynamic and hydrostatic forces become non-linear. Accurate representation of these hydrodynamic non-linearities is important both in the modelling of dynamic loads and for the power-maximising control of the device.

Scope

The focus of this project will be on characterisation and modelling of the non-linear effects in the hydrodynamics of a wave energy converter. The aim is to improve and/or simplify models currently in use, or to propose alternative approaches.

Potential tasks for the 5th year project

- Familiarisation with current in-house hydrodynamic models and assumptions
- Literature review on non-linear hydrodynamic corrections relevant to wave energy converters, including an on-going collaboration project between CorPower Ocean (CPO) and University of Western Australia (UWA)

Potential tasks for the master thesis

- Model and simulate the experimental setup of CPO-UWA project, to try and capture the non-linearities.
- Assess the accuracy of existing models
- Propose and test alternative approaches

Prerequisites

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References

- https://corpowerocean.com/
- https://www.oceanenergy-europe.eu/

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4. **Potential re-use of in-place concrete sub-structures for generating renewable energy form ocean waves.**

<u>Background.</u>

A patent has been granted to Mr. Bjørn Sjetnan for an invention enabling the generating of electric power from ocean waves (see side Figure). The power is generated through the utilization of decommissioned concrete platforms in the North Sea environment converting them in sort of Oscillating Wave Column (OWC).

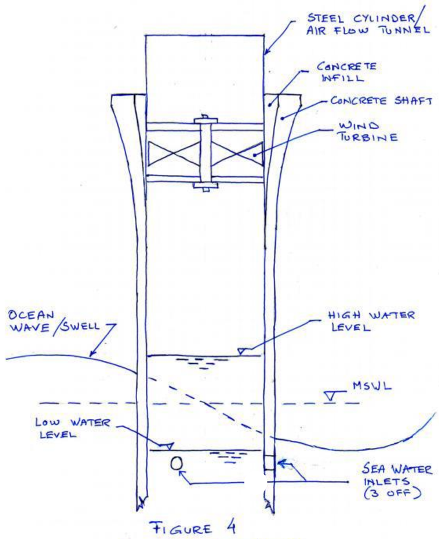

FIGURE 4
CONCRETE WAVE POWER PRINCIPLE DRAWING

There is a number of 20-25 concrete platforms located in the North Sea, Norwegian side, that represent a potential for generating electric power from ocean waves. Each of these are designed as a substructure with 3 or 4 monolithic concrete shafts supporting the oil and gas production top side structures. Along with the depletion of oil and gas reservoirs an increasing number of platforms will be closed and decommissioned.

The top side structure will, under the governing legislations for abandoned O&G fields, be removed and recycled. However, the concrete sub structure can remain in place. It is considered far too expensive and environmentally inconceivable to remove the colossal structures from their field location. This was laid down in the OSPAR convention before the year 2000. Hence after decommissioning a large potential remains in the North Sea to utilize between 60 and 80 concrete shaft structures for wave power generation.

<u>Objective (within hydrodynamic framework).</u>

To develop a potential re-use of in-place concrete sub-structures for generating renewable energy form ocean waves. This applies to decommissioned platforms. It should be assessed that the ocean wave energy can be contained and controlled in the form of an oscillating water column inside of the individual shafts of a concrete platform.

Proposed steps within Project/Master degree thesis:

1. Perform a literature study on OWCs technology (e.g., in terms of features, operativity, efficiency) and on theoretical, numerical and experimental studies that can be relevant to carry on the analysis within this topic.

2. Examine a single-shaft scenario. Perform wave dynamic analysis based on wave statistics from Statfjord Field, readily available from the Norwegian Meteorological Institute, to demonstrate the changing levels, maximum and minimum of the oscillating water plug, and calculate the resulting wave energy maximum, minimum and average, contained in the shaft over one year's operation.

3. Consider similar type of analysis as in step 2 to assess the influence of 3 and 4 shafts on one and the same platform.

This topic also concerns research/technological questions connected with other disciplines (e.g. structural mechanics, energy conversion, etc.), part of these aspects could be examined within step 1 in terms of gathering relevant information and available knowledge.

Topic Proposed by	Mr. Bjørn Sjetnan
Contact person	Bjørn Sjetnan (bjosje@gmail.com)

5. **Failure mechanism for oil boom devices for spilled oil.**

Background: Oil spills represent a huge risk for the marine environment and ecosystems (see left of the Figure). This is even more frightening in delicate areas like the Artic, where exploitations and operations are growing. Oil booms are in general a good alternative for containment and recovery of spilled oil. However, they can experience failure in certain range of waves and current. Failure means that part of the oil can leave the containment zone. An available two-dimensional experimental study on three different boom geometries (see the center and right of the Figure), suggested an influence of the vortex shedding from the bottom of the boom on the failure occurrence and features.

Figure: Left: Oil spills in real life. Center and right: Oil-boom shapes examined experimentally.

The following project/master theses can provide work for one or two students. The detail of the work will be finalized with the student/students.

Project thesis: The project thesis should consider

1. A literature study on the investigations carried on oil booms numerically and experimentally and the state-of-the-art knowledge gained.
2. A CFD method for multiphase viscous flows will be selected among possible available (e.g. OpenFOAM), studied and applied for some preliminary investigation of a 2D boom in the experimental conditions but assuming no oil and the free-surface as a rigid wall to investigate the features of the vortex shedding phenomenon, performing a convergence analysis of the results. Examine influence of using laminar and turbulent flow condition for the finest examined grid.

MSc thesis: In the MSc thesis

1. A short summary of the Project thesis will be done, reporting with main findings.
2. The numerical investigations started in the project work, will be continued considering alternatively the following strategies:
   A. Influence of environment on the failure: Study of the failure mechanisms for the same boom geometry used in the project by reproducing the experimental conditions with different oscillatory inflow conditions. Compare with the experiments the flow features (e.g. evolution of vortical structures from the boom), the occurrence of failure and the amount of oil involved in the failure.
   B. Influence of body geometry on the failure: Study and compare of the failure mechanisms for the three boom geometries studied experimentally at least one experimental oscillatory inflow condition. Compare with the experiments the flow features (e.g. evolution of vortical structures from each boom), the occurrence of failure and the amount of oil involved in the failure.
3. If time allows perform additional numerical simulations to complement the analyses from the experiments for the A/B studied case, draw the conclusions, and provide suggestions for future work.