# Large Flexible Floating Structures

## Will they wrinkle?

**This article is based on the master thesis and the first months of PhD work of Hugo Verhelst. On the 22th of July, 2019, Hugo graduated in a double degree program with the masters Maritime Technology (Ship and Offshore Structures) and in Applied Mathematics (Computational Science and Engineering).**

**By Hugo Verhelst**

The concept of large-scale floating solar panels in the offshore domain is a concept idea that was proposed recently in academic literature[1]. Most of the offshore solar platforms are islands which carry solar panels and which are designed to deform with the ocean surface. Since solar panels can be considered as a light payload, only a small thickness is required to keep these platforms afloat, contributing to flexibility to follow the waves. Concepts as proposed by Patterson et al.[1] can have in-plane sizes in the order of kilometers, but very low thickness (i.e. 0.1 to 1 meter) to balance costs and structural strength.

Compared to conventional ships and offshore structures, these structures are very thin. They operate on the interface between air and water and they are as flexible that they follow the waves of the ocean. Scaling up these concepts, the question arises if we are still able to design them. In other words, do we have the tools and knowledge to design large flexible floating structures, for whichever application operating on the interface between water and air? And what are the failure modes associated with these structures?

In our research, we develop mathematical models to model the complex phenomenon of wrinkling of thin floating membranes under several loading conditions, applicable to large membrane-like floating structures such as offshore solar platforms. Wrinkling and consequently folding is equivalent to buckling of membranes and is caused by combinations of tensile, compressive or indenting loads. When wrinkles develop into folds, they can influence global structural stability, hence reliability.

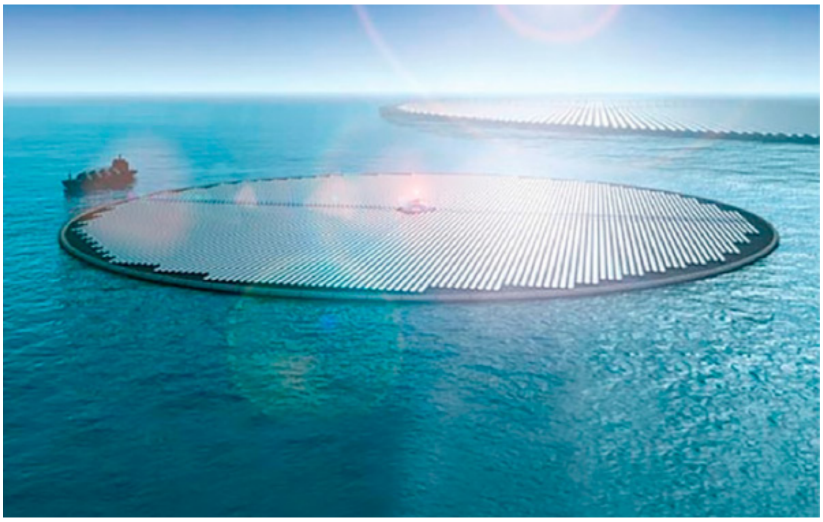

Figure 1: Artist impression of a floating offshore solar platform, by Patterson et al.[1]

### The Wrinkling Phenomenon

The phenomenon of wrinkling is everywhere. Wrinkles appear in your skin when you are surprised, when you laugh, but they also appear in an apple's skin when it is aging[2]. Furthermore, wrinkles occur in the sheets of your bed after the wildest dreams, and sailors might associate wrinkles with improperly trimmed sails. In 2002 and 2008, two pioneering works were published, on the physics of wrinkles in a sheet under tension and wrinkling of a membrane on a foundation, respectively (see Figure 2). The work by Cerda et al.[3] Identified the wrinkling formation and disappearance of a thin membrane under tension (analogy with the sheets of your bed or the sails of a boat), whereas Pocivavsek et al.[4] investigated the effect of the stiffness ratio between the foundation of the support and of the membrane on the wrinkling and folding behaviour (analogy with wrinkles on your skin or on an apple). Besides these two studies, few other studies have been performed, including the investigation of wrinkling formation due to indentation of a beach ball[5] (see Figure 3).

The relation between the aforementioned wrinkling phenomena and maritime and offshore structures might seem vague. But in case of flexible floating structures, the bending stiffness could be such low that similar effects as in the study of Pocivavsek et al. (see Figure 2, right) could occur, and thus wrinkles could develop into folds. Furthermore, complex load combinations within the flexible structures could lead to complex wrinkling patterns, sacrificing local or even global stability of the structure when developed into folds.

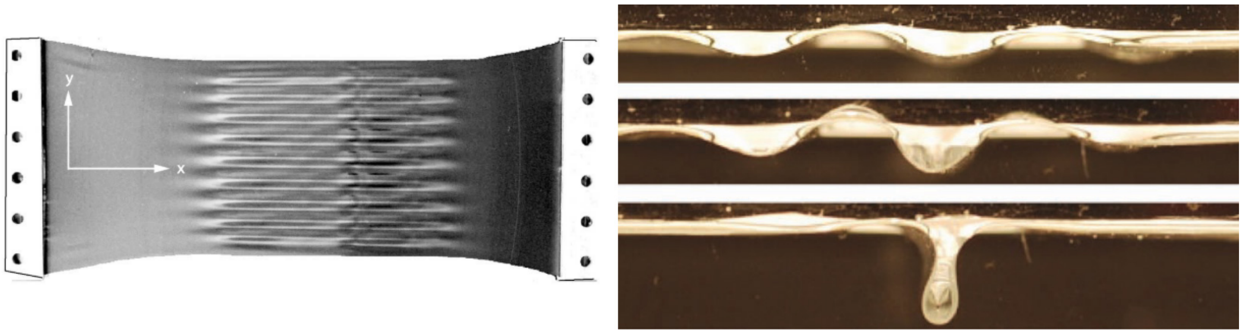


Figure 2: Left: wrinkling of a thin sheet under tension[3], Right: wrinkle to fold transition of a thin membrane on a fluid[4]

## Numerical models for wrinkling

Analysis of deflection patterns of wrinkled membranes is a topic of research for a few years now. Experiments such as those in Figure 2 have been executed to understand the physics of wrinkling via scaling laws[2–4]. Analytical mathematical models have been developed for relatively simple cases and the first steps have been taken to model wrinkling behaviour of membranes with numerical models[6–8]. The latter are of particular interest when considering engineering of membrane structures. In case of maritime engineering, both the loading conditions (indenting loads, tension, shear, compression, but also hydrostatic pressure) as well as the design (possible reinforcements, holes for for the transfer lighting or green water) require numerical tools that compute the wrinkling response of thin membrane structures in a generalized sense.

In our research, we develop robust and efficient mathematical models to facilitate wrinkling computations of membrane structures in the maritime domain. That is, we develop mathematical models to assess the wrinkling behaviour of thin membranes with reinforcements, holes and other design parameters, subject to combinations of loads. The basis of our model are relatively new Isogeometric shell formulations[9], which utilize the smoothness of B-splines to model shell formulations efficiently. Additionally, we aim to apply shape and topology optimization methods to find optimal allocation of reinforcements and holes in the design of membrane structures in seas.

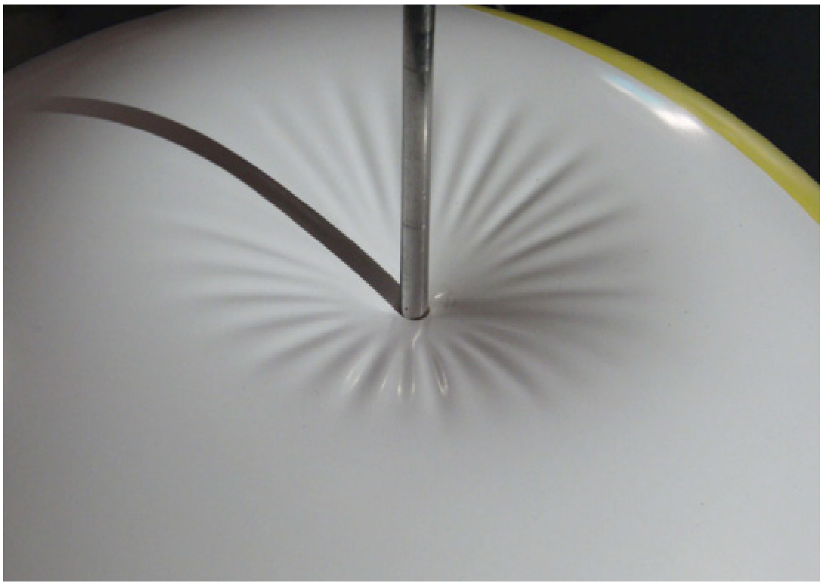

Figure 3: Wrinkles in a pressurized beach ball due to an indentation load[5]

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