The Potential Co-use of Aquaculture and Offshore Wind Energy Structures

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Abstract

The demand for fish and algae products is increasing continuously while the production from direct, worldwide fisheries stagnates. The stagnant sea-fishing amounts are compensated to a significant degree by aquaculture production where in contrast growth rates are much better predictable. Another possible countermeasure to bridge the sea food supply gap arises when a co-use of aquaculture and offshore wind energy structures are taken into account. This idea has the advantage that existing support structures in a high nutrition environment could be utilized. In the present study the manifold interactions between such an aquaculture fish cage and a tripile foundation are investigated by means of physical model test in a length scale of 1:40. A first aspect of the analysis comprises the change of wave induced particle velocity and its distribution around the support structure due to the fish cage. Secondly, the central focus remains obviously the additional forces exposed to the tripile as a result of the additional fish cage bearing by means of force measurements under monochromatic waves. Finally the additional effects to potential scour around the tripile are also investigated. The sea state at the location of interest is approximated with monochromatic waves for a mean event and an event with 50 yearly exceedance probability.

Keywords: Aquaculture, offshore wind energy converter foundation, co-use

I. Introduction

The global annual demand for aquatic food has increased dramatically within the last few decades. The food and agriculture organization of the United Nations (FAO) reports that the total production of fisheries and aquaculture intensified from 21 million tons at the beginning of the 1950ies to 160 million tons in the year 2004. While productivity of the fisheries sector grew until 1988, the following years were marked by stagnation. By contrast, the production of aquaculture has continuously increased its production reaching a total quantity of 55.1 million tons in 2009 ([1]). As a consequence, ocean domestication is of key importance to maintain the ocean as a sustainable source of food, both economically and ecologically ([2]).

Within the German context, the development of oceanic aquaculture is still limited to very few species at some sites in the German bight. Besides obvious user conflicts among potential participants especially rough environments as well as geographical, topographical and commercial hindrances prevent an optimal growth of aquaculture industries. Hence, it is anticipated to investigate the potential co-use of aquaculture and offshore wind energy converter (OWEC) structures (cp. Fig. 1). The feasibility depends not only on technical aspects but also on socio-culture, marine biology and economics. In this paper the effects of an aquaculture fish cage combined with a tripile foundation of a wind energy converter is investigated by laboratory means. The study is structured as follows. The background and the scientific literature are presented in Chapter II. The methodology is described in Chapter III while results are given in Chapter IV. Finally conclusions are drawn.

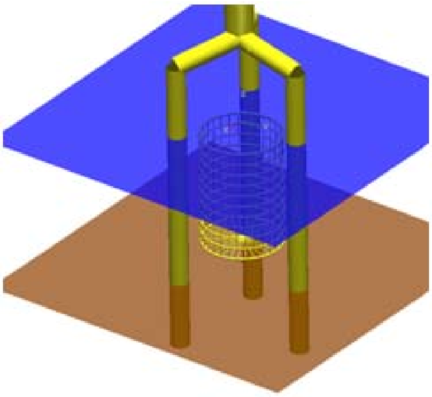

Figure 1. Schematic overview of the co-use of aquaculture fish cage and offshore wind energy converter structure (Institute for Steel Construction, Hannover)

II. Background

In view of the presented study objective the general term aquaculture which includes all kinds of artificial cultivation of fish, crustaceans, molluscs and aquatic plants. Mariculture instead specifies the cultivation of products in the marine environment in underwater habitats only. For those conditions a number of approaches exist to cultivate marine products. Predominantly moored fish cages, combined fish cages and mussel lines are applied in sheltered conditions such as fjords or narrow bays. Alternatively cage systems for open ocean environments which are exposed facing high-energy wave climate are currently tested. These open ocean aquaculture technologies are moored, towed or floating fish cages (e.g. AquaPod™).

Experimental and numerical approaches have been chosen to assess motion of and forces on enclosures due to waves and currents as a design base. An early theoretical study is reported by [3] who investigated current forces on floating fish farms made of net cages with the aim to reduce cage damages and reduce the risk of genetic pollution as well as spreading of diseases into the wild stock of species. The findings of velocity distributions in and around the net cages allow for an approximation of the oxygen distribution in the far field of the fish farms. The fluid-structure coupling problem of a flexible net exposed to currents or waves is solved numerically by [4] and applied to floating fish farms. Results of the method agree well with laboratory measurements and deformations can be efficiently predicted. As numerical and physical models often ignore the random nature of the open ocean, modeling results are compared with in-situ measurements in order to deepen the understanding of scale effects on the motion response of fish cages to natural sea states by [5] and [6]. Hence, numerical and physical modeling as well as in-situ measurements facilitates methodologically the investigation of fish cages under the attack of waves and currents. Nevertheless, so far no findings exist on the question how fish cages interact with offshore wind energy converters and how large additional forces could grow in the presence of waves.

III. Methodology

Based on the present literature a two-stage laboratory investigation is chosen. In a first step, scale effects of nets and screens are investigated in a 20 m long and 1 m wide current flume. As a measure of scale effects here the energy head loss is chosen. Various screens with length scales of 1:1 to 1:40 are investigated. Nets with length scales of 1:1, 1:2, 1:3.3, 1:5 and 1:13.3 are also considered. The knowledge of quantitative scale effects allows for the later evaluation of velocity and force measurements at the overall system.

In a second step the mechanical system of the fish cage and the OWEC-structure is investigated under wave attack with respect to a) the deviations in the velocity field resulting from the fish cage underneath the OWEC, b) the additional forces introduced by the fish cage and c) the potential for scour evolution at the sea bottom of the OWEC location. Therefore a 110 m long and 2.2 m wide wave flume is applied. The experiments are scaled with Froude similitude at a length scale of 1:40. The water depth at the wave maker equals 1.0 m, yet to investigate scour evolution at the OWEC-structure a 0.25 m deep sand pit (fine sands of d_{50} = 0,148 mm) is installed at a distance of 42 m of the wave maker. At the end of the wave flume a gravel slope acts as passive wave absorption. An overview of the wave flume and the installations is given in Fig. 2.

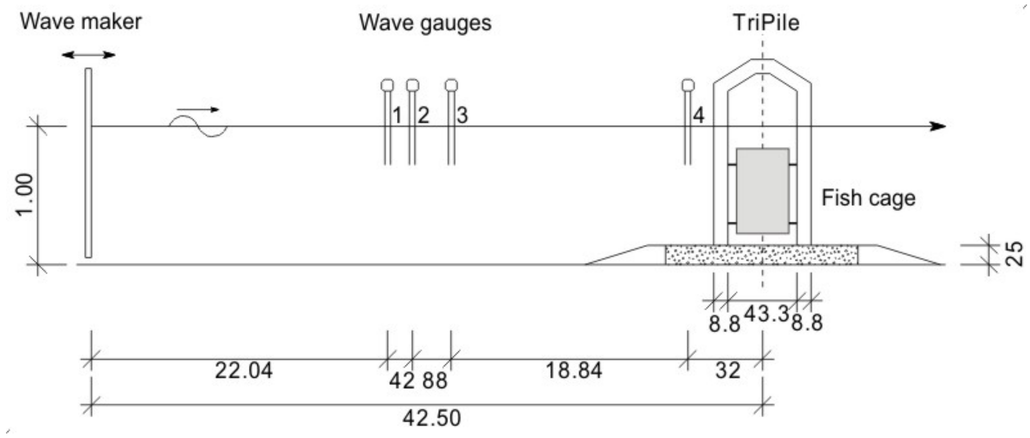

Figure 2. Schematic experimental setup with wave maker, instrumentation and the tripile position

In this paper only two regular waves are considered. Based on a potential building site in the German bight at Veja Mate, a frequent (mean) and an extreme wave with a 50-yearly reoccurrence interval have been chosen. In model scale investigated wave heights are H = 0.04 m with T = 0.95 s for the frequent case and H = 0.28 m with T = 2.2 s for the extreme wave condition respectively. Surface elevations are measured with wave gauges at various positions. Deviations in the velocity field around the structure and the fish cage are recorded by either ADV probe inside the fish cage or by stereo PIV measurements around the fish cage. Wave-induced forces at the constructional conjunctions between fish cage and tripile legs are taken by force transducers measuring normal forces. Force measurements are designed to consequently separate horizontal and vertical forces. Therefore all conjunctions between the fish cage and the tripile legs are designed as pendulum rods whereas the vertical forces are assumed to be gathered by a single tension rod connected to the upper tripile intersection.

IV. Results

A. Velocity measurements

Velocity measurements are accomplished to investigate the velocity regime in the vicinity of the OWEC-structure and its deviations by means of a fish cage installed inside the tripile legs. Foremost, this part of the experimental program is intended to derive basic knowledge on how velocities evolve inside the fish cage under wave attack in order to allow marine biologists to evaluate if fish production is feasible at all and how strong velocities influence the natural behavior of potential marine species inside the enclosure. By means of the PIV technique ([7], [8]) measurements of the velocity field very near to the tripile structure are feasible. Fig. 3

shows an example of a velocity vector field during a propagation of a wave crest modeling extreme conditions for the cylindrical fish cage design.

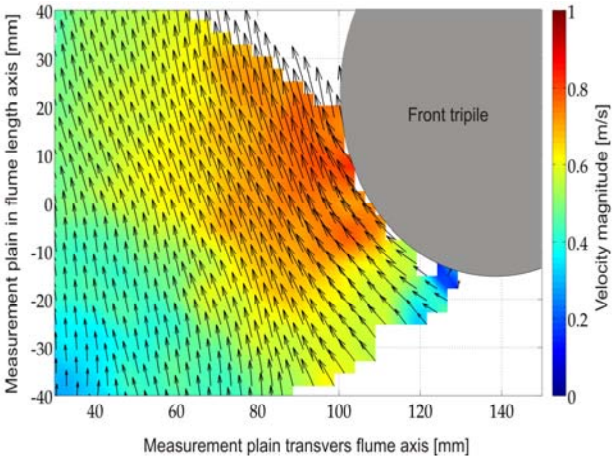

Figure 3. Vector field of horizontal velocities near the front tripile for extreme wave conditions, upper measurement plain during wave crest propagation along the tripile

Furthermore, the PIV-measurements which are recorded in stereo mode also allow for the extraction of 3D time series of velocities at a discrete position. For the evaluation of additional direct wave forces to the tripile legs the knowledge of velocity distribution is needed. Fig. 4 hence shows the time series of horizontal velocities taken from PIV-measurements directly in front of the wave facing tripile leg at the height of the fish cage cover. Though maximum velocities are not significantly altered, it is obvious that negative velocities during wave trough are increased. Additionally it is apparent that phase duration of positive velocities is extended. With respect to fish cultivated in such a high energy environment a result could be that potential candidates have to be able to withstand such velocity magnitudes unharmed.

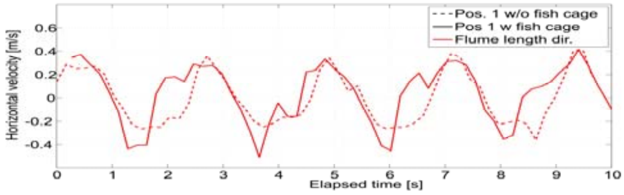

Figure 4. Horizontal velocity from PIV-measurements comparing setup with and without fish cages assembled

Besides horizontal velocity components, vertical velocities are similar to their horizontal counterparts increased during the wave trough phase of wave passage. ADV-measurements inside the cylindrical fish cage reveal more moderate velocity changes which could be contributed to the damping effect of the modeled net material. While horizontal velocity deviations between experiments with and without fish cages are not so pronounced, it is apparent that vertical fluctuations are in a range of ~0.2 m/s. This fact could especially influence health and behavior of flatfish which is one of the investigated candidates.

B. Force measurements

In this paper force measurement are analyzed in time domain only. Per definition, compression forces are positive while tension forces are negative. The mounting of the two modeled fish cages (cylindrical and spherical) is designed as stiff and unmovable for the sake of laboratory conditions. It is acknowledged that prototype conditions and design may result to alternative mounting techniques. Further investigations might be needed in this case. Force transducers are labeled FT_1 to FT_6, where transducers FT_4 to FT_6 are mounted in an upper measurement plain whereas the remainders are measuring forces near the bottom of the fish cages. At first an example time series of surface elevations at the tripile structure as well as time series of force transducers FT_1 to FT_3 are shown for an experimental run of extreme wave condition. Fig. 5 elucidates the temporal evolution of the measured values.

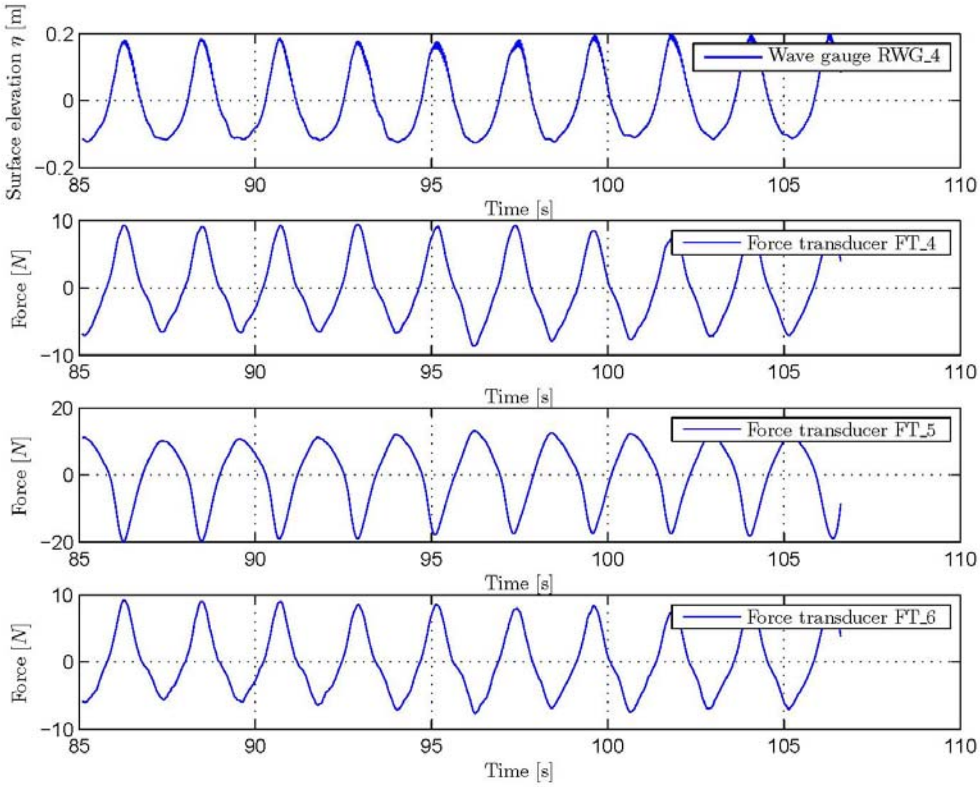

Figure 5. Time series of water surface elevation and forces for a representative period of the wave train, one net layer

Due to the distance of the wave maker and the underlying shoaling process along the slope in front of the sand pit where the tripile foundation is installed the water surface elevation differs from an ideal sinusoidal shape but is more comparable to a cnoidal wave train with higher wave crest and longer wave troughs. Highest tension forces appear at the wave-facing tripile leg during the passage of the wave crest. In parallel, these forces initiated by the wave at the front of the cylinder are also measured at the backward force transducers but with opposite sign and vectorially separated.

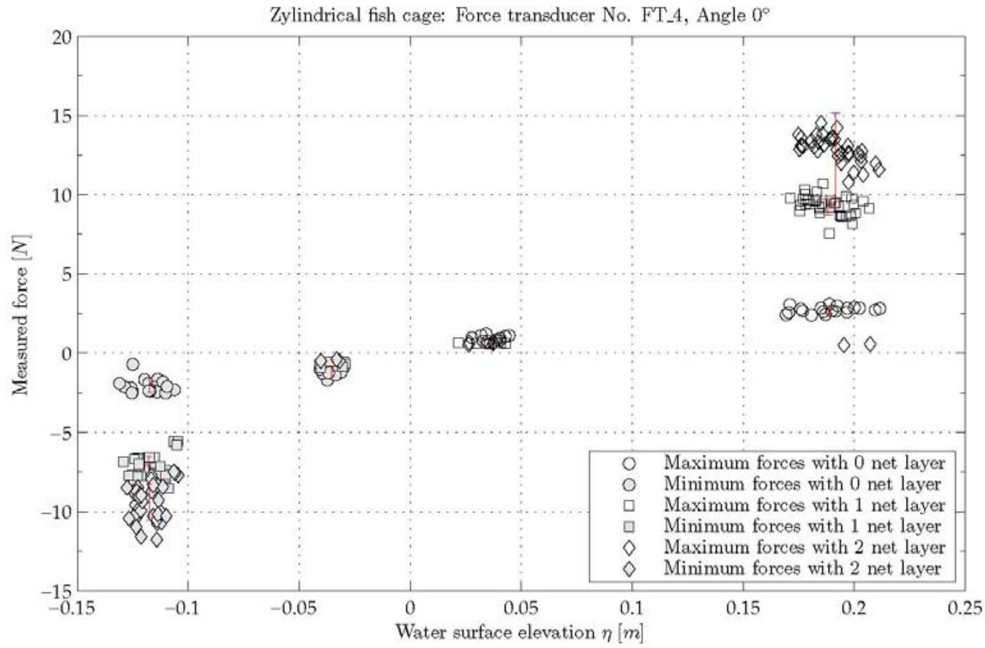

Figure 6. Correlation of maximum wave heights and measured forces for cylindrical fish cages for force transducer FT_4 with respect to the number of net layers

In order to analyze the correlation between the wave heights and the caused reaction forces a zero-crossing method has been applied to the water surface elevation measurement. Thereafter the maximum values of the surface elevation and the forces have been collected. Experimentally, three different flow resistances are considered. First, the fish cage is tested only with its support structure. Second, one and third, two layers of net material are fixed to the fish cage, subsequently. Fig. 6 shows an example of the correlation of maximum wave heights and the respective maximum force measured with respect to the number of net layers. In general it is apparent that the additional forces exerted to the tripile structure increase with increasing wave height. Though, the correlation is not linear but disproportionate. Due to the limited number of wave heights investigated it is not feasible to find a valid regression function. The influence of the flow resistance variation is clear obvious. While the increase of net layers from zero to one results in an increase of forces of more than 100 %, the further increase towards two layers of net material only results in further loading of approx. 40 %. The variation of let layer numbers is yet important to investigate how loadings develop under emerging marine fouling.

C. *Scour evolution*

The scour evolution has additionally been tested within the scope of the project. In literature a number of theoretical approaches exist to deduce the maximum scour depths at piles (e.g. [9], 錯誤! 找不到參照來源。). In this special case, where a tripile structure with additional fish cage is considered, the analytical approaches are not easily applicable. Hence an optical method is applied which consists of sediment gauges and image capturing. A manual post-processing routine is chosen to estimate the local sea bed evolution. The local water depth of the modeled OWEC structure and the chosen monochromatic waves limit the scour tendency. Scour evolution is yet possible under the assumption that swell generated in a far field arrives at the location of interest. Hence additional experiments with an elongated wave period of T = 3.0 s are conducted. In this case scour around the tripile legs can be observed clearly. Under the assumed boundary condition relative scour depth of S/D = 0.54 is determined at the front leg of the tripile whereas relative scour depth of S/D = 0.36 is found below the tower of the OWEC for a setup without a fish cage. A slightly different result is obtained when a fish cage is introduced. Relative scour depth of S/D = 0.48 (front leg) and S/D = 0.25 (central below tower of OWEC) are found. The observed reduction of scour depth below the tower can be explained by a reduction of wave-induced flow velocities and shear stresses in this area. Nevertheless, it is still unclear how such a combined structure behaves in the presence of waves and currents.

V. Conclusions and Outlook

Various aspects of the interaction between fish cages and OWEC structures have been addressed n this study. Variations of flow velocities under waves in the vicinity of the OWEC structure and inside fish cages have been found. With respect to open ocean environment, these findings allow for a first evaluation of potential candidates in aquaculture. Furthermore, additional forces to tripile foundations have been determined that facilitate cost and economic efficiency analysis with regard to future prototype technologies. Finally, scour measurements have been accomplished to assure that fish cages does not affect the safety of OWEC foundations negatively. Yet, further research has to be initiated in this field in order to develop aquaculture technologies ready for the market.

Acknowledgments

Funding for this research was provided by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, grant no. 0325206. The authors would like to thank M. Schubert and T. Freitag for support on this project.

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