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# Mooring systems analysis of floating wind turbines in Italian seas

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**Abstract.** In recent years, interest in exploiting wind power in deep waters has grown, with the realization of floating structures that could accommodate a turbine and produce electricity. One of the many challenges that these projects face is the position keeping of the system in a defined part of the sea: this is carried out with mooring systems, designed to withstand extreme marine conditions. The first aim of this work is to analyze these systems, to find a general solution for a floating wind farm in the Italian seas. Of importance is to suggest a design that could be fabricated in an Italian dry dock and towed to site. A numerical model of the floating structure and the environment has been realized using the software, OrcaFlex, and simulating the 50- and 100-year return period conditions in the Adriatic Sea and in the Strait of Sicily, with different mooring combinations of present-day technologies. The model's implementation requires environmental and structural parameters: the former have been obtained with a statistical analysis of actual recordings of wind speed and wave height and with the official Italian cartography. Structural details have been derived by looking at existing floaters, finding the most suitable one for the Italian environment. After simulations, the results are interpreted with a comparison of tension in the lines, vertical forces at the anchors, wire length and mooring footprint, finding out that depth has the greatest impact on these factors. With respect to this, the proposed numerical model can provide a simple indication for the mooring of floating wind turbines in two different areas of the seas surrounding the Italian peninsula: for the Adriatic Sea (shallow waters), suction anchors with chains should be preferred, while, for the Strait of Sicily (deeper waters), traditional anchors may be considered, with lines composed of chains or a combination of chains with synthetic fibers.

## 1. Introduction

The principal sources of energy in most parts of the world are non-renewable resources like oil, coal, natural gas and nuclear power. However, these resources present disadvantages and critical issues: burning fossil fuels produces greenhouse gases and other pollutants harmful to the environment, and these sources are subjected to limitations and price volatility. Nor is nuclear power free from serious problems: accidental radioactive leaks, nuclear proliferation and safe storage of wastes are only a few of the challenges to be considered.

On the other hand, renewable sources like wind have great potential and advantages: they are virtually inexhaustible, they produce power without the pollutant emissions, and they are freely available in every part of the world. This is in accord with the global goal of reducing greenhouse gas emissions,



following international agreements, like the Paris one [1] or the European Union Renewable Energy directive [2]. However, renewable sources present disadvantages for power production, such as intermittency and predictability.

In recent years, installations of wind farms have grown, not only on the mainland but also offshore, with a series of advantages:

- the turbine's size is not limited by the existing infrastructure in the manufacturing process, when it can be assembled near the shore;
- large sea areas are available, meaning that the installations do not cause land consumption or soil degradation;
- the wind generally blows more strongly and steadily over the sea surface, meaning higher and more constant power production;
- the visual impact and noise pollution can be eliminated by the turbines' installation at a sufficient distance from the coastline.

However, the previous factors are balanced by some issues:

- the turbines must not only withstand the wind load, they must also resist environmental challenges like waves and currents, resulting in an increased design complexity, which also affects the cost;
- the turbines have to be maritized, and the support structure must be designed, installed and, in the future, decommissioned;
- offshore wind farms are harder to access than those on land, increasing the maintenance challenges and costs.

Before 2017, all commercial offshore wind farms were placed within 50 meters of sea depth, connected to the seabed with structures like monopiles and jackets. These solutions are not economically profitable in deeper waters, where floating structures take the lead. In recent years, the research has focused on developing the concept of floating wind turbine farms, unlocking the potential of the wind in open seas and exploiting the oil and gas industry's experience in terms of mooring and floating structures' design.

The technical realization and profitability of floating structures has been demonstrated by the oil and gas industry with long-term floating structures. However, the development of floating wind turbine designs, capable of conquering a part of the energy market, requires extensive analysis. In the offshore environment, in addition to wind load, new aspects must be considered: hydrodynamic loads are the most evident, but debris, ice and marine growth build-up must also be covered. The analysis has to account for the coupled motion of the floater and the turbine and the mooring systems.

2017 was a turning point: the world's first floating offshore farm began electricity production near the Scottish shores in October. The project, known as "Hywind Scotland", was developed and constructed by Equinor in Norway and towed off the Aberdeenshire coast during the summer. It consists of five spar-type turbines floating in the deep waters of the North Sea, moored to the seafloor and connected to the Scottish electricity grid through a submarine cable.

The Italian environment lacks a future or potential project of the Hywind-kind [3], [4], even though the potential, that the seas surrounding the Italian peninsula offer, is great. This, coupled with the reduced visual impact (which is and always has been the main opposition to wind turbine installation in Italy), could lead to the creation of a new and renewable power source, with economic and occupational advantages.

A numerical model was developed using the commercial software, OrcaFlex, a fully 3D, nonlinear, time-domain, finite element program, capable of dealing with a wide range of offshore applications, like floating wind turbines and their moorings.

In the process of achieving the main target, several objectives were set:

- identifying the mooring difference between two locations with different sea depths, wind speeds and wave heights;

- finding the environmental design parameters concerning wind speed and wave height, with the application of extreme value statistic theory to a dataset of real recordings in the selected areas;
- identifying the most suitable floating wind turbine concept, with respect to characteristics of the Italian seas;
- exploring the possibility of the realization in Italy of the chosen concept from the inception to the construction phase.

The paper is divided into four main chapters, after the introduction, followed by the conclusions. Chapter 2 presents the process for obtaining the environmental design parameters, for the selected locations of the study in the Mediterranean Sea: the Adriatic Sea near Ancona and the part of the Strait of Sicily near the southern shores of the island. First, descriptions are given of the sources of the data for sea depth, wind speed and wave height. Thereafter, the results of the statistical analysis, in which the theory of the extreme values is applied, are given.

At the beginning of Chapter 3, a general overview of Italian power production is provided, along with the potential for the realization of floating farms. After that, the characteristics of the most prominent types of wind farm are summarized. Finally, the choice of the structure to be modelled is made, considering compatibility with the Italian seas and potential construction in an Italian shipyard.

In Chapter 4, the theory behind the numerical model is explained: mooring line types and their characteristics. The real mooring hardware to be modelled is also presented: wire, chains, synthetic ropes, anchors and suction anchors.

In Chapter 5, the results and the previously presented theory come together in the actual model and its results. Static and dynamic simulations follow; tension in the wires and forces at the anchors are examined, and results are produced. Finally, looking at the previous steps, different locations and simulations are compared and discussed, with the purpose of finding the most suitable mooring solutions. The final discussion in the conclusions (Chapter 6) leads to considerations with respect to the original objectives, in relation to the actual results. Suggestions for further work, based on the issues and limitations that were highlighted during the investigations, are also described.

## 2. Environmental design parameters

A reliable data source for wind speed and wave height has been found in the Italian agency, ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale), which runs an extensive monitoring network across the Italian peninsula and the seas around it. This agency operates several monitoring networks, two of which have been used in this work: The Rete Mareografica Nazionale (National Sea Network, also known as RMN), for the wind speed, and the Rete Ondametrica Nazionale (National Wave Network, also known as RON), for the wave height.

We have looked at wind data (1998 to mid-2017) near to an intermediate depth location in the Adriatic, in the harbor of Ancona (LAT: 43° 37' 29.16" LONG: 13° 30' 23.46") [5] and data for the period 1999 to mid-2017 close to a deep water location in the Mediterranean, at Porto Empedocle, at the southern shores of Sicily (LAT: 37° 17' 8.72" LONG: 13° 31' 36.64") [6]. For months with a ratio of data measured over data expected being less than 75%, the data are disregarded [x thesis]; however, we consider the data available to be representative for extreme statistics analysis. Two wave buoys are available for retrieving wave data at the locations studied: from 1999 to 2014 near Ancona, in the Adriatic Sea (LAT: 43° 49' 55.2" LONG: 13° 42' 36") [5] and from 1998 to 2014 near Mazara del Vallo, in the Mediterranean Sea, south of Sicily (LAT: 37° 31' 4.8" LONG: 12° 31' 58.799") [7].

In this work, the Gumbel distribution (concerning the maximum) was used to obtain the values of wind speed and significant wave height, considering return periods of 50 and 100 years. To estimate the distributions' parameters, the maximum goodness of fit (MGE) method was used, by including significant waves with heights larger than 3.0m. The waves corresponding to the design heights have a peak period with the same magnitude as those recorded by the stations for the biggest waves.

The resulting design wind conditions at 10 m height (10 min averaging) are given in Table 1, and the resulting wave conditions are given in Table 2. These values are used in the mooring analysis for the

floating wind turbines. Note again that the main goal of the present work is to analyze and to find a solution for a mooring system connected to floating wind turbine structures in the Italian seas.

**Table 1.** Design wind speed (at 10 m height above SWL) at the selected measurement stations.

| Return period | Design wind speed (m/s), |                 |
|---------------|--------------------------|-----------------|
|               | Ancona                   | Porto Empedocle |
| 50 years      | 20.90                    | 22.41           |
| 100 years     | 22.64                    | 23.83           |

**Table 2.** Design significant wave conditions (Jonswap spectra) at the selected measurement stations.

| Return period | Design wave height (m) |                  | Design peak period (s) |                  |
|---------------|------------------------|------------------|------------------------|------------------|
|               | Ancona                 | Mazara del Vallo | Ancona                 | Mazara del Vallo |
| 50 years      | 5.62                   | 6.21             | 9.5                    | 11               |
| 100 years     | 6.01                   | 6.66             |                        |                  |

We have investigated the potential of offshore wind power in a simplified 3D numerical model of the floater. The mooring and the environmental design conditions has been developed and the combined loads of wind and waves in the open sea simulated. The results from the simulations are evaluated, considering several factors: wire length, mooring footprint, tension in the lines, forces at the anchors and their interactions.

### 3. Wind turbine foundation design, construction and installation

We have investigated the potential of offshore wind in Italian waters and have reviewed the capacity of Italian and Mediterranean yards to construct the different floating wind turbine concepts. The WindFloat design is the most flexible to construct and install, as it can be fabricated in a dry dock, towed to site and installed without the use of large crane vessels. Mooring is by a traditional mooring system with the use of chains, wires or polyester lines. The concept is composed of a semi-submersible floater with plates at the base of each column; see Figure 1.



**Figure 1.** WindFloat hull and turbine [8, 9].

Dry docks play a great part in the construction of the semi-submersibles, and the possibility of the realization of a possible floating wind turbine project in Italy has been explored by collecting and comparing the dimensions of Italian dry docks. To improve the number of suitable construction sites and to create competition between shipyards, similar information has been searched and collected in the Mediterranean area [10]. The larger Italian and other Mediterranean docks (with a width of more than 50m) are listed in Tables 3 and 4, respectively.

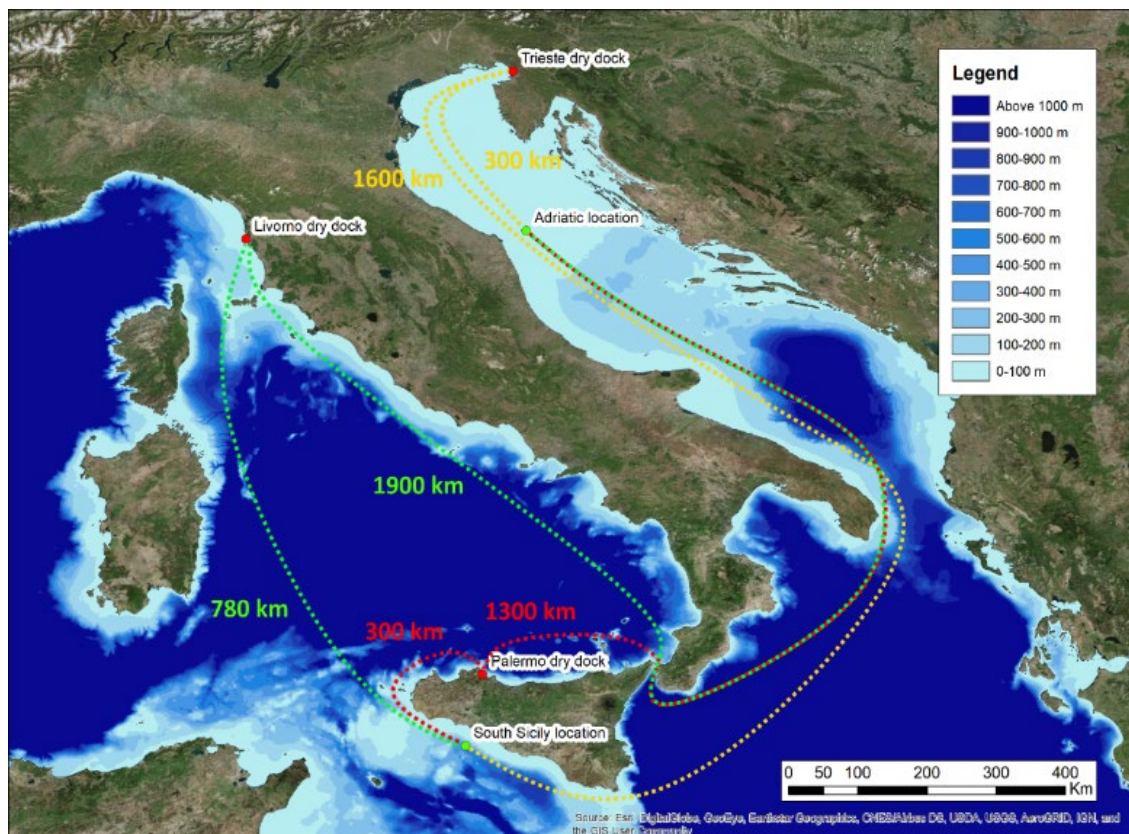
For the realization of a semi-submersible structure, a selection of EU shipyards is available, and Italian construction is possible: the larger availability of dry docks means increasing the competition between companies. For example, considering the Palermo dry dock and the ideal 5 MW WindFloat [8], [9] at the same time, four semi-submersible structures can be built in the same shipyard, with conventional cranes and techniques. For towing to locations from Italian construction sites, see Fig. 2.

**Table 3.** Dry docks in Italy with a width of more than 50 m.

| Location | Name           | Length (m) | Width (m) | Depth (m) |
|----------|----------------|------------|-----------|-----------|
| Palermo  | Graving dock 4 | 370        | 68        | 11.35     |
| Livorno  | Accosto 77     | 350        | 56        | 9.7       |
| Trieste  | Graving dock 4 | 295        | 56        | 11        |

**Table 4.** Dry docks in Mediterranean Area with a width of 50 m or more.

| Location   | Country | Name           | Length (m) | Width (m) | Depth (m) |
|------------|---------|----------------|------------|-----------|-----------|
| Marseille  | France  | Forme 10       | 465        | 85        | 9.2       |
| Skaramagas | Greece  | Dock 1         | 421        | 75        | 5.5       |
| Valletta   | Malta   | Graving dock 6 | 362        | 62        | 9.3       |



**Figure 2.** Italian ports for WindFloat design construction, and towing distances to the study locations.

#### 4. Mooring

Over the years, steel chains, steel wires and synthetic ropes have been used to connect floating objects to the seabed: the lines compose a catenary shape, that acts on its tension (increasing or decreasing it as the catenary lifts off or lies on the seabed) to stabilize the platform subjected to sea forces. The catenary mooring system has been deployed with success in shallow waters. With the need to exploit resources in deep waters, the suspended weight of the lines is becoming a limiting factor; steel chains are currently less used in deep water applications, now being replaced by synthetic fiber ropes [11], which reduce the mooring line length, the overall tension and the total costs. The many advantages that this type of mooring has over traditional catenary systems should be realized: the lines are considerably lighter, more flexible and can absorb dynamic motions through extension without causing excessive tension. Another significant advantage of taut rope mooring is a reduction in the line length and in the space occupied on the seabed. Anchoring of the floating wind turbines is achieved by drag anchors or suction anchors.

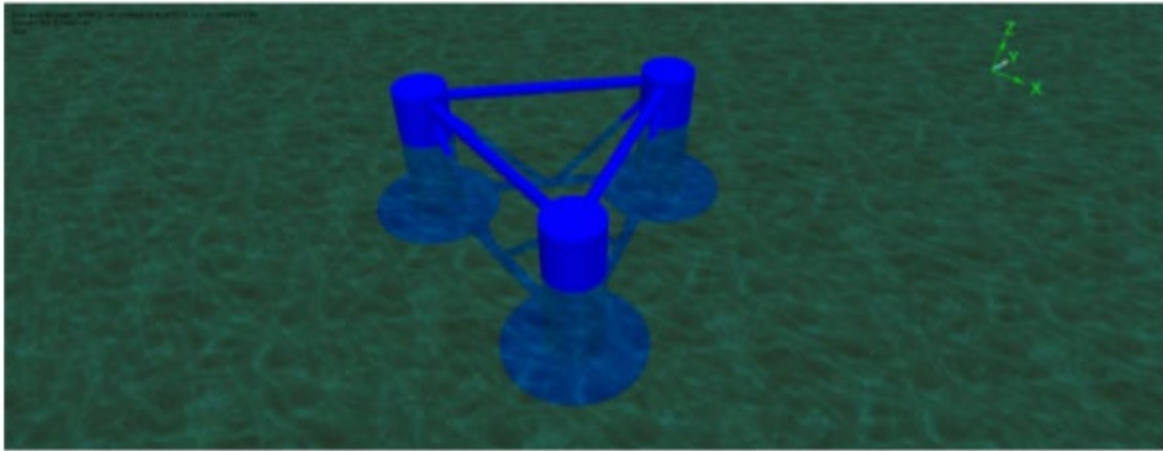
The mooring spread could be symmetrical or asymmetrical: even if the former is the simplest in terms of design, it might not necessarily be the best in terms of performance. Some considerations must be made [8]:

- directionality of the weather: if the weather actions come from a dominant direction, it could be useful to use an asymmetrical mooring system to balance those forces;
- directionality of the currents: the same consideration of the directionality of the weather can be made for currents; an asymmetrical mooring system can balance the forces applied by strong currents;
- subsea spatial layout: equipment positioned on the seabed could restrict the available positions for the moorings;
- other space restriction: it could be useful to couple mooring lines to gain further space.

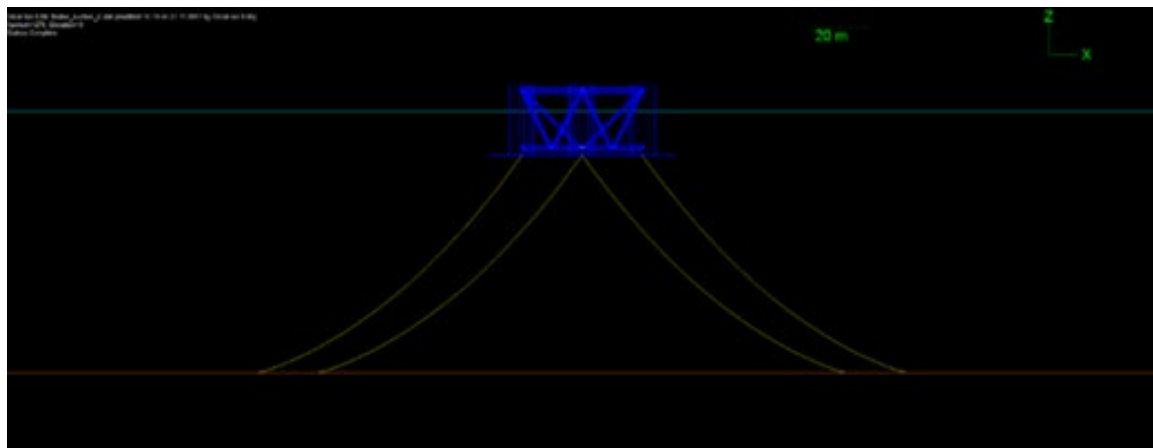
#### 5. Mooring modelling

The environmental conditions at the two sites have been defined and then simulated in terms of water depth, wave representation with JONSWAP spectrum and mean wind speed values while distinguishing the conditions for return periods of 50 and 100 years [10]. Then, a description of the implemented floater is given, which includes the chosen WindFloat design with all its characteristics, such as columns, connections and water entrapment plates. The water depth chosen is 100m for the Adriatic Seas and 400m for the Sicilian location.

The floater's response to waves is provided through the Response Amplitude Operators (RAOs), and the wind response is implemented in the software, using the areas subjected to the wind forces and specifying the application point on the structure. Since the RAO's generation is a long and elaborate process, and in view of the fact that the present study is focused on the mooring, an existing RAO has been used. This set of equations has been taken from an example available on the Orcina website, regarding a structure like WindFloat one: a generic semi-submersible platform used in the oil industry [13], with RAO specified for 0°, 45° and 90° directions. The structural similarities along the wind response modelling are taken to give reliable answers regarding the mooring systems and their loads. It should be noted that, for a real design, the specific RAOs must be developed and possibly tested in a wave tank. While the wind load analysis in our model is based on the simplified mean wind load, the wave response analysis does account for all the hydrodynamic effects. The overall response analysis is therefore considered adequate for the preliminary investigation of the mooring line loads. See Figure 3 for OrcaFlex Model of the floater and Figure 4 for a suction anchor mooring system.



**Figure 3** 3D OrcaFlex model



**Figure 4** Suction anchor mooring system with chains (yellow). In OrcaFlex the mooring lines are modelled as finite line elements.

Wind loads are proportional to the areas subjected to the flow; in the OrcaFlex model we specify the surge area, the sway area and the yaw area moment. The surge area comprehends the whole area covered by the rotor's blades and the yaw area moment, see Table 5. Here,  $A_{\text{surge}}$  is the surge area,  $A_{\text{sway}}$  is the sway area,  $Y$  is the yaw area moment and  $L$  is the length between perpendicular of the floater. The wind loads are applied at the position of the nacelle, to influence realistically the floater response in such situations. Note that the wind load is based on extrapolating the wind speed at 10 m to the appropriate height. A comprehensive discussion regarding statistical analysis of wind velocities is given in [10], Chapters 2.4 and 5.5. In the finding of the environmental design parameters concerning wind speed and wave height, the best results were obtained with a Gumbel distribution, having parameters estimated with maximum goodness of fit procedure. Since the difference concerning wind speed between the values found for 50 years and 100 years of return period is very little in both locations, the analysis of the result focused on 100 years return period scenarios. The wind speed at 10 m height above SWL used was 23.8 m/s.

**Table 5.** Wind load calculation.

| Parameter                            | Values |
|--------------------------------------|--------|
| $A_{\text{surge}}$ (m <sup>2</sup> ) | 12561  |
| $A_{\text{sway}}$ (m <sup>2</sup> )  | 394    |
| Yaw area moment (m <sup>3</sup> )    | 15681  |
| Length between perpendiculars (m)    | 40     |



Traditional anchors and suction anchors have been represented in the model. Different solutions concerning the mooring lines have been explored: chains, chains with synthetic fibers and synthetic fibers only. The first two cases led to a catenary design for the wires and, in the last one, the possibility of a taut mooring has been tested. Dimensions and the material's parameters are implemented, considering the environmental differences between locations. Table 6 and give parameters for mooring lines.

**Table 6.** Mooring chain parameters [14, 15].

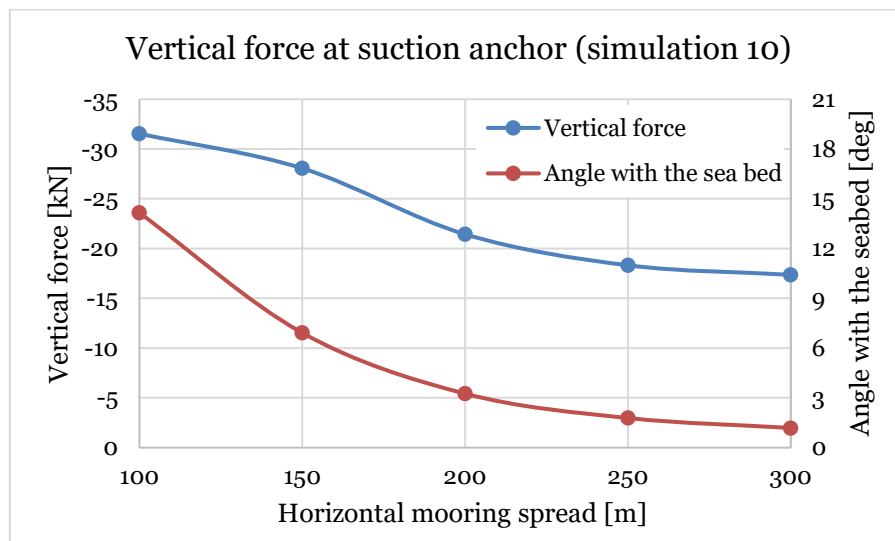
| Parameter              | Value     | Value              |
|------------------------|-----------|--------------------|
| Mooring type           | Chain     | Synthetic rope     |
| Bar diameter (m)       | 0.05      | 0.08               |
| Link type              | Stud-link | 8-strand polyester |
| Grade/ Standard        | R4        | ISO 10556          |
| Weight in air (kN/m)   | 0.537     | 0.050              |
| Displacement (m)       | 0.071     | 0.037              |
| Weight in water (kN/m) | 0.466     | 0.013              |
| Breaking load (kN/m)   | 2740      | 1091               |

The mooring lines follow a catenary shape, and two simulations for each return period have been performed with two different wire compositions: the first using a chain and the second using chains, in proximity of the anchor and the floater, and synthetic ropes in the middle; see Table 7.

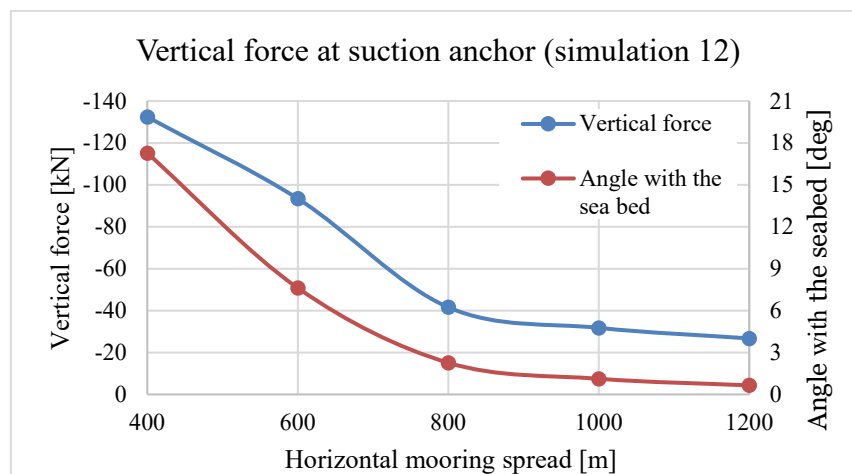
**Table 7.** Mooring wire lengths for chain-only simulation (top) and for chain and synthetic fiber combination.

| Length                     | Value (m) |
|----------------------------|-----------|
| Adriatic Sea, Chain length | 500       |
| South Sicily, Chain length | 2000      |
| <b>Adriatic Sea</b>        |           |
| Top chain length           | 70        |
| Synthetic rope length      | 360       |
| Bottom chain length        | 70        |
| <b>South Sicily</b>        |           |
| Top chain length           | 200       |
| Synthetic rope length      | 1600      |
| Bottom chain length        | 200       |

Static and dynamic mooring analysis are carried out [10]. The first provides the equilibrium position of the system and the starting point for the dynamic simulation, in which the wave loads are applied. In the static results, the vertical component of the forces at the anchor is analyzed to obtain a starting parameter for a possible design for the anchor itself. Concerning the case with a chain-only simulation, an attempt to reduce the vertical forces has been made, progressively increasing the horizontal spread of the mooring lines from one time to three times the water depth. The same line characteristic has been kept: the touchdown point has always been maintained at the suction anchor. Results show a clear pattern: increasing the mooring spread and decreasing the angle between seabed and wire at the proximity of the suction anchor, the vertical forces decrease. In this process, the chain becomes more and more close to a traditional anchor system. The decrease in vertical forces permits the use of a less performant (and so less expensive) suction anchor, at the cost of using more material and forming a larger footprint on the seabed. This process is confirmed in both locations and can be seen in Figures 5 and 6, along with the angle between the wire and the seabed.



**Figure 5.** Vertical force at suction anchor (Adriatic Sea, suction anchor mooring system with chains, 100 years return period).



**Figure 6.** Vertical force at suction anchor (south Sicily, suction anchor mooring system with chains, 100-year return period).

In the dynamic simulations [10], the forces in both the wires/ropes and at the anchors, are analyzed for the two values of the return period of the environmental loading. In the dynamic analysis, OrcaFlex carries out a time simulation of the response of the system to waves and wind, based on user-defined inputs. The dynamic simulation uses the static analysis as its initial configuration, and time then evolves forward from there. The analysis of the result has focused on the tension in the wires and on the forces at the anchors: simulation has been performed for both return periods and for every wire and anchor, then the obtained design data have been compared.

These results have been obtained through the analysis of the time history of the simulation that produces cycles of loading and unloading on the wires and the anchor: the peak values have been implemented in a statistic concerning the extremes, using the OrcaFlex option, “extreme values statistics” [13]. In this procedure, the Generalized Pareto distribution gave results and their consequent confidence limits, for both tensions and anchor forces, simulating two storms, lasting for three and six hours.

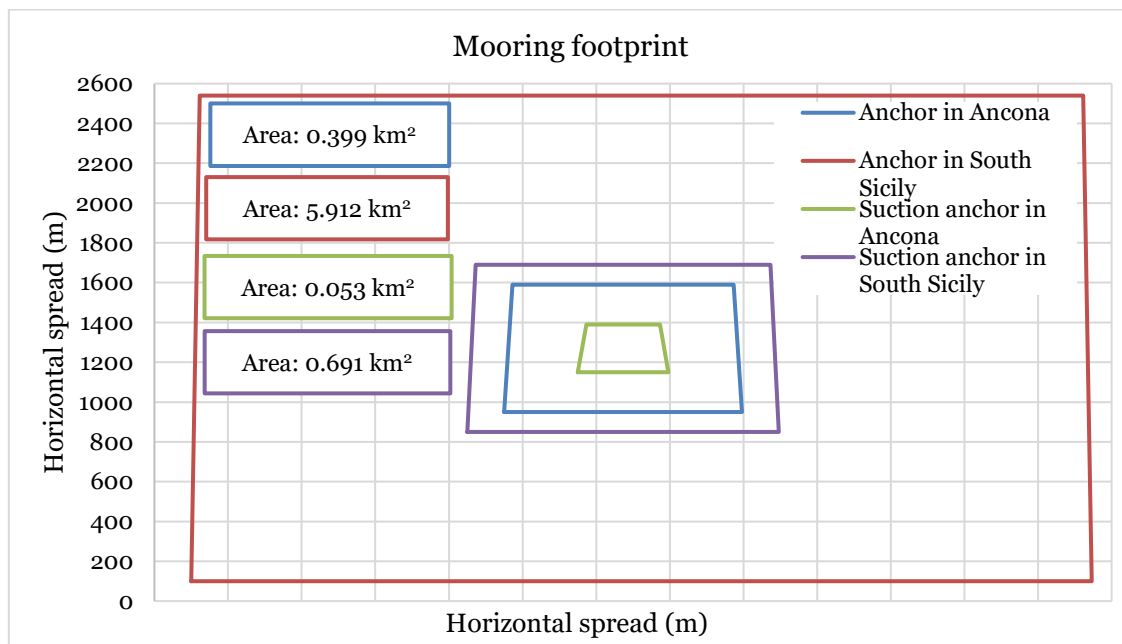
The resulting values for tension present common patterns for both the Adriatic Sea and South Sicily: the most stressed part in the wire is in the proximity of the floater, the limit loads are never exceeded. The difference between a simulation with a 50-year return period and one with a 100-year return is negligible, and the variation of the storm duration affects the results poorly.

The values concerning the loads at the anchors, present differences between traditional and suction anchors: in the first case, they are almost not affected by the simulation, and the values are very close to the static analysis ones; in the second case, they present peaks of loading and unloading. There is also a difference for simulated suction anchors with chains and taut: the vertical load from the dynamic analysis in the first case differs from the static values more than for the second case [10]. As for the tension values, the difference between results obtained with a storm lasting three hours and one lasting six hours, and with environmental loads with 50- and 100-year return periods, is negligible. The values used as our design values are the return parameters (tension or vertical load), found by using the maximum likelihood fitting procedure. The values, along with confidence intervals (CI) with a confidence level set to 95%, mean that the reported return parameter is defined as the parameter whose expected number of exceedances in the specified storm duration is one [13]. In the present study, the values of CI come from a peak over threshold method analysis, in which the threshold used is the one suggested by the software, with no further considerations. An exceedance probability of one per storm should be acceptable, as the actual design of the mooring lines takes into account load factors to be multiplied with the load and material factors, reducing the allowable capacity of the mooring line tension.

In the found design values, some considerations are to be made considering the loads at the anchor: a traditional anchor must, in every case, avoid vertical loads, and a suction anchor must be designed to withstand a certain dynamic vertical load. This capacity will depend on soil conditions and anchor design, aspects not considered in this study. These considerations, along with the uncertainty of the statistical analysis, must be considered during the detailed design of the mooring system. For the traditional anchors, the dynamic simulations [10] showed loads close to the static ones: the difference between the mean load values and the peaks is around 10 N. In addition, most of the load is distributed, like in the static conditions, in the horizontal directions with no sign of vertical forces that could lead to an uplift of the anchors.

A discussion of the results is then given, comparing mooring length, footprint, tension and vertical forces at the anchors, along with a proposal for mooring solutions for the locations of the study. As the sea depth increases, the mooring footprint is heavier (Figure 7); the area used for suction anchors in the South Sicily location is 15 times larger than that used in the Adriatic Sea. A remarkable difference is present between traditional anchors and suction anchors: the former requires a much larger area than the latter, in every case.

The small suction anchor footprint is increased when we require a reduction in the vertical forces at the anchor: keeping the touchdown point of the mooring wire at the anchor, then a rise of the mooring spread and a contemporary decrease of the angle between the line and the seabed occurs, causing the vertical force to drop. So, at the cost of a larger footprint and a longer wire line, which uses more material, the decrease in vertical forces allows the use of a less performant and cheaper anchor. The decision of whether or not to apply this solution of vertical forces' reduction must be analyzed in terms of costs and environmental impact: the enlarged footprint of the suction anchor is near to that of a traditional anchor, and the increase in wire length could not be compensated by a cheaper anchor. Ultimately, the advantages of a suction anchor could disappear, and this could make the use of a traditional anchor more convenient in terms of cost-efficiency.



**Figure 7.** Mooring footprint in the Adriatic Sea and south Sicily.

## 6. Conclusions

This paper deals essentially with finding the most suitable mooring solutions for the realization of a floating wind turbine farm in the Italian seas, focusing on two different locations. This was obtained through the implementation of a 3D numerical model in the OrcaFlex software, which comprehends a common geometry of the floater, environmental loads and site characteristics in the two chosen study areas.

For the last two aspects, it emerged that a different return period for wind speed and wave height made little difference in the results. The parameter that most affected the outcomes, differentiating the two areas, was sea depth: when the depth increased, the lines' length, the mooring footprint, the mooring lines' tension and the vertical forces at the anchors, for the suction ones, were higher.

A similar consideration can be drawn from the simulations for the mooring solutions: in the same depth conditions, when a traditional anchor was used, the lines' length and the mooring footprint were higher, while wires' tension was lower than a suction anchor. A suction anchor must also cope with vertical forces, not present in the traditional ones.

A general indication from the simulations was also obtained for suction anchors: vertical forces at the anchors could be reduced with the increase of the horizontal spread of the moorings and the consequent reduction of the angle between seabed and lines.

Considering the advantages and disadvantages of the previous aspects and the technical challenges of the installation and the design, finally, the proposed numerical model was successful in providing a simple indication for the mooring of floating wind turbines in two different areas of the seas surrounding the Italian peninsula: for the Adriatic Sea (shallow waters), suction anchors with chains and, for the Strait of Sicily (deeper waters), traditional anchors with chains or chains with synthetic fibers.

Generally, it can be derived that, for shallow waters, the suction anchors should be the preferred solution: the smaller occupied area and the shorter lines compensate for the design difficulties of a similar device and the higher tensions of the wires. On the other hand, for deeper waters, the enlarged footprint and longer wires are the price to pay for the simplicity and the lower tension of traditional anchors.

In the findings of the environmental design parameters concerning wind speed and wave height, the best results were obtained with the Gumbel distribution, having parameters estimated with maximum goodness of fit procedure. An important issue emerged in the available data from the wave-monitoring

networks: the recordings are often discontinuous, due to operational problems for the “Rete Ondametrica Nazionale”, which has since been dismantled.

The modelled structure is the one that appears to be the most suitable in the Italian environment, with the current grade of development: a semi-submersible structure with the WindFloat design, developed in Portugal by Principle Power. It is particularly suitable for the Italian seas: its low draft allows transport and installation in shallow waters, like the Adriatic ones, without the need for specific vessels, apart from simple tugboats, or good weather conditions.

Italy can build this type of floating wind turbine in ports, such as Palermo, Livorno and Trieste, with suitable drydocks for the construction of similar structures. The possibility of commissioning in other EU countries in the Mediterranean area has also been explored: ports are available in Marseille (France), Skaramagos (Greece) and Valletta (Malta).

Numerical models like the one used in this work can be a powerful tool in the assessment of a specific aspect of a possible project, like moorings. Their accuracy is mainly based on the hypothesis made at the beginning of the elaboration process and the data gathered about the environment, or, in other words, creating a numerical model means recreating a simplified version of the reality, but, for the moment, some aspects are still missing. These features can be a starting point for future works with the goal of improving the results, and they are listed below:

- two main environmental variables have not been analyzed: currents and seafloor composition; once located in a more definite area, these aspects should be implemented in future works. Currents will be part of the external loading on the structure, and seafloor composition will influence the anchors' performance, especially influencing the design of the suction ones;
- other approaches could be followed in the statistical analysis of environmental factors: the use of all records instead of the monthly maxima. If the data coverage is good enough, considering all the recordings could improve the data at one's disposal. This may require additional monitoring networks;
- a more detailed modelling of the floater with a wind turbine and a dynamic response analysis should be performed in a real project. If the natural frequency of the floater is close to the peak wave frequency, the resulting resonance could endanger the structural integrity. Further analysis of blades and tower are also needed, in order to ensure limited response due to turbulence as well as to the mean wind speed.
- the RAO used in this paper has not been computed specifically for a semi-submersible floating wind turbine: future works should face this issue with a specific numerical analysis and testing in tanks with scaled models of the floater-turbine system;
- this work does not address system economics: manufacturing, installation or decommissioning considerations or optimization of the floating wind turbine mooring system. These aspects could be a crucial factor in the realization of a floating wind farm project.

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