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PROJECTE FI DE CARRERA

TÍTOL:

DISEÑO Y CÁLCULO DE UN MÁSTIL OFFSHORE

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RESUM (màxim 50 línies)

El presente proyecto, pretende poder presentar las virtudes y carencias que existen en la utilización de materiales compuestos frente al acero.
La necesidad de afrontar nuevos retos tecnológicos en la producción de electricidad mediante la energía eólica en emplazamientos offshore (marinos), es lo que ha provocado la realización de este proyecto.

This project is intended to present the pros and cons of the use of compound materials against steel, as well as to show the necessity of facing new technological challenges in the production of electricity by means of wind energy in offshore sites.

Paraules clau (màxim 10):

offshore	wind turbine	lightness	wind
Dyneema®	aerogenerador	ligereza	Eólica

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1. REPORT

1.1. OBJECTIVES

The objective of this Final Year Project is to intend mast for an offshore wind turbine, analysing different aspects that may contribute to its design and looking for a solution which provides it with simplicity and lightness.
Once the solution is found, and it accomplishes the previously-mentioned premises of simplicity and lightness, as well as its own requirements and the requirements of the environment where the structure will be placed, a comparative between the use of steel and a composed material (in this case, the use of a ultra-high-molecular-weight polyethylene compound, whose commercial name is Dyneema ®, to its construction) will be carried out.

In order to achieve this objective, the following points have been taken into consideration:

-Localization of a site in Spain. This site shouldn't be connected to the electric public distribution network and should have experienced a considerable increase of its electric power.
-Search of wind data, to select the best site and extract the environment information needed to calculate the structure requirements.
-Selection of the most suitable material and the geometry for the mast of the wind turbine, in order to achieve the desired lightness and simplicity of structure.
-Decide the use of a wind turbine, representative of the type of the planned ones for offshore use.
-Definition of the requirements that will be supported by the mast.
-Performance of the analytical calculations of the structure, for the selected material.
-Testing of the completed elements.

1.2. JUSTIFICATION OF THE PROJECT

The hereto project is due to the current necessity of advancing in the creation of new offshore wind farms, both because of their great potential and because the overcoming of new technological challenges.

One of these challenges is supporting the masts of wind turbines that will be over 80 meters high; a second challenge is to reach new designs and to use new materials for the construction of wind towers that will reduce the weight of the masts structures.

This reduction of weight is necessary to reach locations with higher wind potential. These locations are found in places whose seabed is more than 70 meters deep, being necessary the use of floating platforms for their installation, as the use of anchored platforms will considerably increase the price of the production of electricity.

1.3. PREMISES

1.3.1. WIND ENERGY

1.3.1.1. INTRODUCTION

Wind energy is one of the called renewable energies. This name is used to define any these energy sources whose use doesn't imply a reduction of its presence in the Planet.

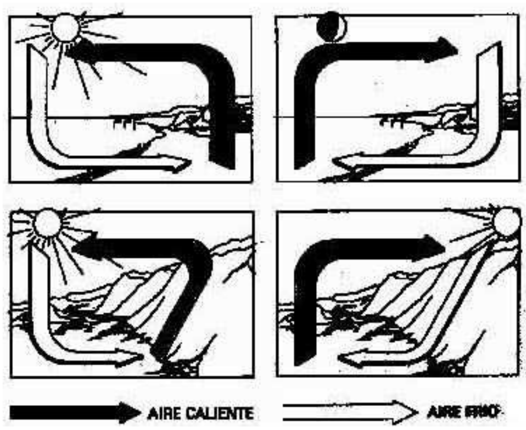
Wind energy comes from the transformation of solar energy: the energy from the sun warms the earth, forming areas of different temperatures. Because of that, wind flows are created. These wind flows generates wind energy.

Through history, wind energy has been used to mill grain and to extract water. It was not until the 19th century that the first wind towers were created, being the power they generated merely testimonial. During the 70s and the 80s, after the first oil crisis and because of the people's rejection to nuclear energy, the interest on the generation of electrical energy by means of wind energy grew, as an attempt to reduce the dependence from third-party countries and fossil fuels.

1.3.1.2. OPERATION OF A WIND TURBINE

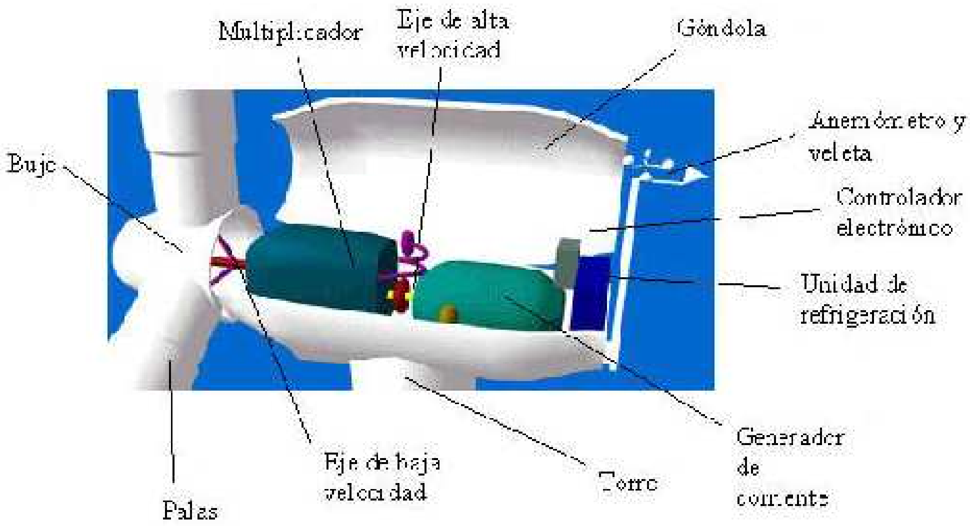
The operation of a wind turbine, onshore or offshore, is the same and very simple: The movement of the shovels of the wind turbine is produced by airflows. These airflows are generated by temperature changes in the site (earth or water). The directions of these airflows are shown in the picture below.

Picture 1.3.1.2.a. Airflows generated by temperature changesdue to sunshine.



Thanks to these airflows, the shovels of the wind turbine are moved and electricity is generated. This electricity is generated by the movement of the rotor of the shovels, which is connected to the gearbox, situated into the nacelle. The gearbox multiplies the rotation speed of the rotor of the shovels in order to achieve higher rotation speeds. The axis of the gearbox impels the generator that uses magnetic fields to convert the rotational energy into electrical energy.

Picture 1.3.1.2.b.: Components of a wind turbine. Source:www.windpower.org/es/tour



1.3.1.3. PROS AND CONS OF WIND ENERGY

Pros of wind energy:

At present, some populated areas and ecosystems have reached a level of saturation that can endanger the health of people and animals inhabiting them. Some reasons for these dangers are the contamination of the earth and the water, the use of fossil fuels to generate electricity, and the industrialization of processes for manufacturing and production.
This contamination has caused a change in the mentality of the people, a change that has been turned into the willingness of searching energy sources that don't generate more contamination and also into the will of reducing the dependency from fossil fuels, thereby reducing the dependency from third-party countries.

Following, there are some pros offered by wind energy:

-Electricity can be generated without the use of fossil fuels. The use of a renewable energy, such as wind flows, has a positive effect on the environment.

-The production can be local, avoid big losses of electricity caused by the heating of the conductors.

-The transport of fuels to power stations is null, so the risk of contamination caused by this transport is also non-existent.

-The use of wind energy could imply a less dependency of second or third party countries, producers of fossil fuels, as wind energy allows the use of a country's own resources.

-The production of electrical energy by wind turbines avoids the risks of contamination by fuel spills. Also, the towers don't need to use water from aquifers or being located near a water body for their refrigeration.

-The technology of wind turbines is relatively simple, thereby easily accessible by countries with tight economic resources.

Cons of wind energy:

During the establishment of wind farms, the site where they are placed can suffer some impacts. However, these impacts can be partially reversible.

Following, there are some cons offered by wind energy:

-The impact on the establishment area is caused by the works of foundation and installation of the wind towers. In ground areas, this impact is caused by earthmoving to lay the foundation of the masts or towers, to prepare access roads, build control buildings, etc. In sea areas, the impact is caused by the preparation of the seabed for the establishment of the foundations, control equipment, etc.

-Effects on birds migratory routes. It is important to bear this factor in mind, as the higher generation of electricity is normally caused by wind flows with a constant air supply. These wind flows are usually the ones used by birds in their migrations. In order to avoid these interferences, it is necessary to study the location of the wind farm in the project stage.

-Visual impact on the landscape or on the sea horizon, this last one being the most frequent. This impact must be taken into consideration on the project stage, so it can be minimized. The picture below shows an example of an establishment without a planning that could have avoided the previously-mentioned visual impact.

Picture 1.3.1.3.a: Tehachapi Wind Farm, California, built in the 80s.

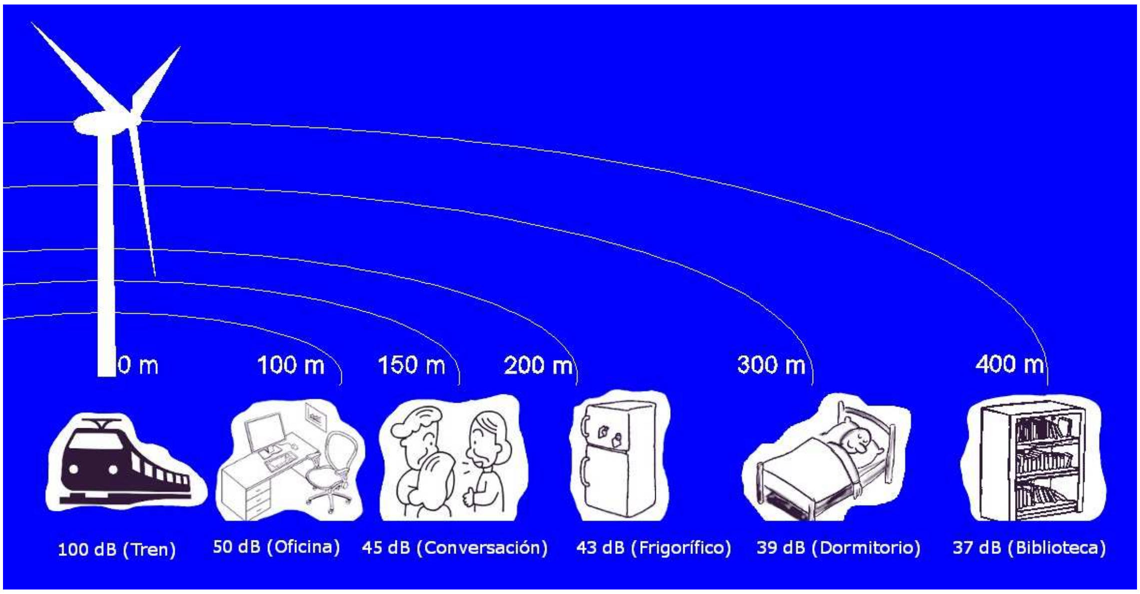
Below the result of an offshore establishment.

Picture 1.3.1.3.a.: The bigger wind farm in Denmark: 80 wind turbines of 2 MW

-Noise produced by wind turbines because of their continuous movement. This problem should also be studied in the project stage, to minimize the negative effect and allow people and animals inhabit the area.

The following image represent the approximate equivalence of noise produced by the wind turbine and the distance at which it should be placed for not being annoying.

Picture 1.3.1.3.c: Noise value based on distance



-Lack of continuity. As it depends on sunshine and its effect on the surface, it is not possible to predict with accuracy the potential production of energy on a concrete moment. This issue is being studied with some specific software, which is able to predict with more exactitude the power that can be generated.
This lack of prediction makes that, indistinctly from the amount of power needed, in points of minimum request, a big amount of energy is generated and, when the request is higher, the power generated is not enough to fulfil the needs of the population, industry, etc. of the area.

In this respect, a solution to gather electricity under the form of hydrogen is being studied, this study focused in hydrogen cells and in the use of hydrogen as a fuel for internal combustion engines. This hydrogen is created by means of the electricity generated by the wind turbines and that would only be used when needed.

1.3.2. EVOLUTION OF WIND TURBINES

Nowadays, there are two models of wind turbines: with horizontal axis and with vertical axis. The most used currently are the ones with horizontal axis, due to their bigger use of the swept area of their shoves. This category includes three different models: with one, two or three shovels.

Some pictures showing the differences can be found below:

Picture 1.3.2.a. (1) Darrieus wind turbine, vertical axis. (2) Wind turbine with horizontal axis and three shovels.

(1) (2)

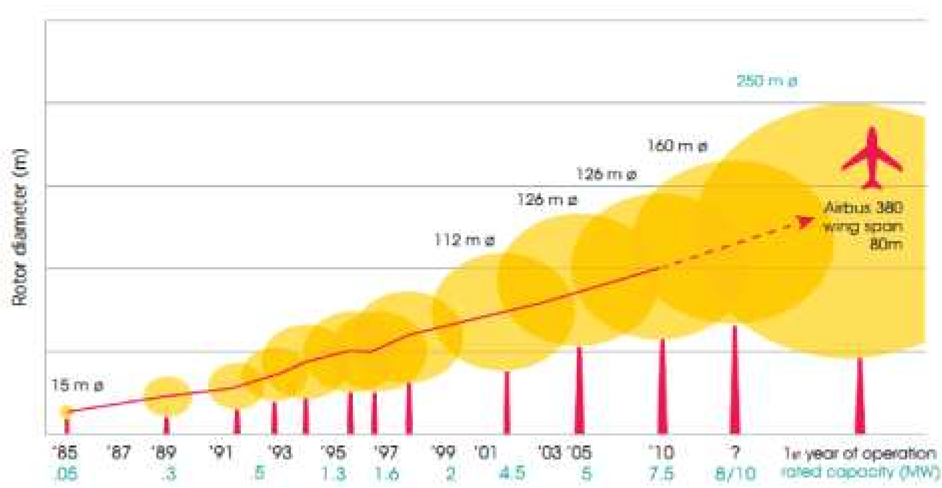
Picture 1.3.2.b. Wind turbines with horizontal axis and one shovel (1) or two shovels (2)

(1) (2)

In the family of wind turbines with horizontal axis, the most common model is the one with three shovels. This model of wind turbine has been chosen to perform the study in this project.

The dimensions of wind turbines have increased lately due to the overcoming of technological challenges, such as the necessity of a higher production of electricity to increase the profitability of wind farms.
The following picture shows the evolution in the dimensions of wind turbines, both in power that can generate and in the dimensions of the swept area of their shoves, which should also evolve in order to reach the required production.

Picture 1.3.2.c.: Evolution of power and dimensions of wind turbines' rotors. Source: UpWind 2011.



Due to this increase in power and in the dimensions of the swept areas, the height of the towers masts have also increased. This way, the shoves don't collide with the surface and also produce a bigger amount of energy.

1.3.3. TYPOLOGY OF MASTS OR WIND TOWERS

The typology of masts or wind towers is infinite, as technology is constantly evolving to reduce their weight, production costs and also to overcome the new technological challenges presented by the establishment of wind turbines. The most important challenge faced is to overcome the power of 7,5MW, which also implies the increasing of the swept area of the shoves.

Following, there are some examples of wind turbines currently installed, from the ones producing lower power to the ones generating a higher amount of power.

In low-power wind turbines (included in the so-called "mini-wind" because they generate a power lower than 100kW), tubular masts and latticed masts can be found. There are different models of each type, but most of them must have tensioning devices to guarantee their stability against drafts.

The following pictures show a tubular and a latticed mast:

Picture 1.3.3.a. (1) tubular mast, stepped and with tensioning devices; (2) latticed mast without tensioning devices.


(1) (2)

The increasing of power needs has created new technological challenges that can be overcome thanks to masts with new geometries, such as tubular, cylindrical, conical, mixed, etc. The variety is also increased by the use of new materials or by the union of several different ones in order to improve technological aspects.

The following pictures show only some of the most common typologies used onshore and offshore:

Onshore wind towers:

Picture 1.3.3.b. (1) Tubular wind tower made of steel. (2) Tubular wind tower made of concrete.


(1) (2)

Picture 1.3.3.c. (1) Prototype for a hybrid wind tower made of steel and concrete, studied by BergerABAM. (2) Construction made of wood, created by the Timber Tower company.

(1) (2)

Offshore wind turbines:

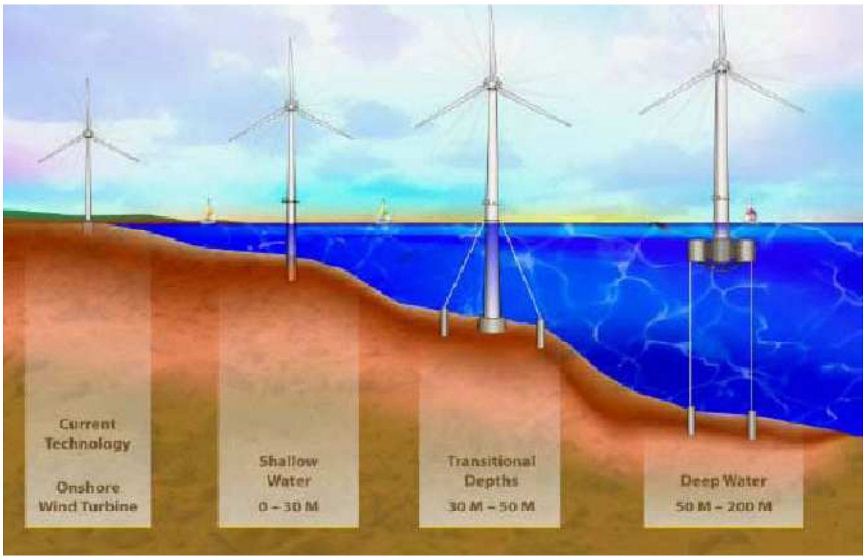
For offshore wind turbines, the most common geometries are cylindrical and conical, for a best adaptation to the site and an easier maintenance of the facility.

Picture 1.3.3.d. Wind farm located in Denmark

1.3.4. *TYPES OF OFFSHORE FOUNDATIONS*

The types of offshore foundations depend on the depth of the seabed in the site of installation and on the height of the mast of the wind turbine. The types are as follows:

Picture 1.3.4.a Different types of foundations.



The most used foundations are:

Foundation by gravity: This type of foundation consists on a block of concrete to which the structure of the wind turbine is joined. The concrete block is transported empty to the site of to installation and, once there, it is filled with sand, concrete and gravel.

Due to its weight increase, the bloc settles in the seabed by itself and fulfils the requirements by the environment and by the structure of the wind turbine. This type of foundation is valid only for seabeds less than 10meters deep.

Picture 1.3.4.b. Construction of the concrete block in an onshore facility.

Monopile: This design is simpler than the previous one, as it consists on a pile driven to the seabed (directly or by means of a transition piece), and joined to the structure of the wind turbine. This type of foundation is valid only for seabeds less than 30 meters deep.

Picture 1.3.4.c. Driving of the monopile by aspecialized boat.

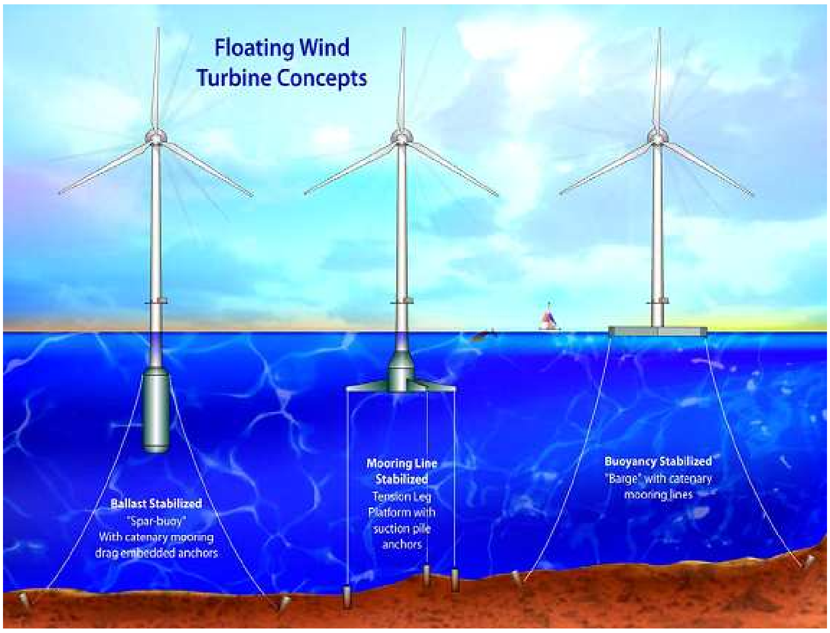
Tripod: It consists on a main structure, placed under the water, that have three small piles anchored to the seabed in order to avoid the movement of the structure. As in the foundation by gravity, the structure is transported empty and, once the emplacement is reached, the main cylinder is filled with grout so it has weight enough to sink. This type of foundation is used in seabeds more than 20 meters deep

Picture 1.3.4.d. Transport of thetriop structures by a tugboat. Alpha Ventus wind farm, Germany.

Jacket structure: This system is similar to the one used in high-tension towers. The fixing to the seabed is made by means of four small piles with the same shape of the ones used on the tripod. Its main advantages are the reduction of the steel needed and the fact that it can be used in any of the previously-mentioned depths.

The problem with this kind of foundations is that their price increases when the depth of the seaside is higher than 50 meters; in addition, they are not practical for these depths. When this is the case, there is a new solution that may be taken into account: the floating structures or floating platforms.
This solution is on development stage. The typologies to study, or that are being currently studied, are the following:

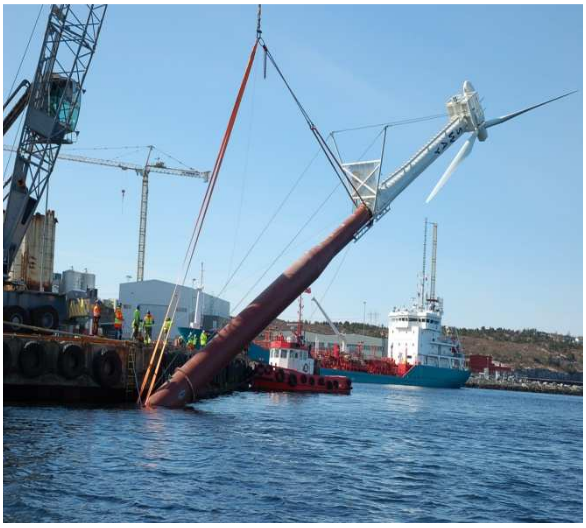
Picture 1.3.4.e Types of floating platforms.



Ballast Stabilized: This system consists on a big cylindrical casing, located in the lower part of the structure and made of steel or concrete. The fixing of this structure to the seabed is made by means of several cables, whose function is to reduce the structure movements and to maintain it on its emplacement.

Picture 1.3.4.f. (1) Representation of a Ballast Stabilized platform.Image from “Estudio, caracterización y comparación de tipologías de plataformaspara el soporte de aerogeneradores en alta mar”.(2011) (2) Installation of the platform prototype; image from http://ww.gii.udc.es.

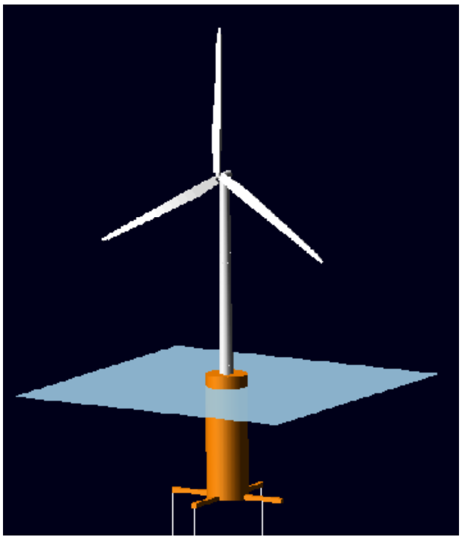
(1)



(2)

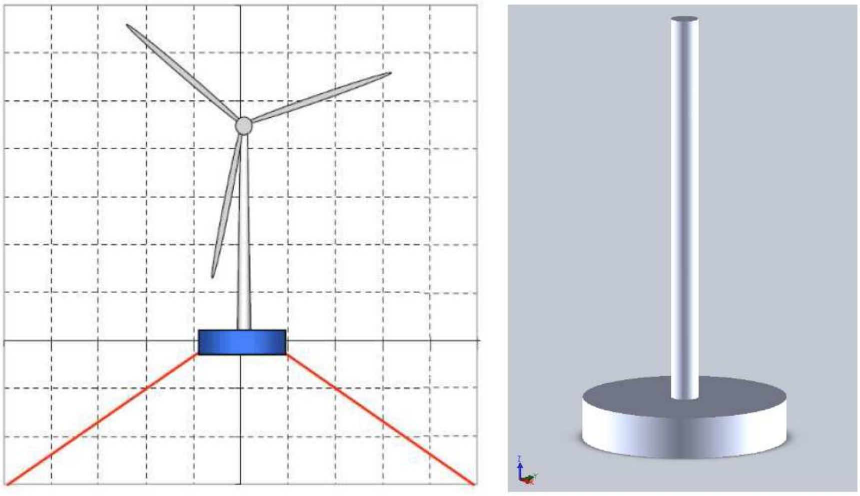
Mooring Line Stabilized: This system is composed by a vertical floating platform, fixed by four solid cables (one for each leg of the platform), which are secured to the seabed. To maintain the cables in continuous tension, the platform is constantly floating. The tension of the cables is responsible for the stability of the turbine and also for maintaining its vertical position, despite the emplacement’s weather conditions.

Picture 1.3.4.g. Representation of a Mooring Line Stabilitzed platform. Image extracted from “Estudio, caracterización y comparación de tipologías de plataformas para el soporte de aerogeneradores en alta mar”. (2011)



Buoyancy Stabilized: This system consists on a stabilized floating platform. This design is easier to install and more profitable, as it is a light structure and has a flotation area big enough to stabilize the structure in loading conditions. The union to seabed is made by means of a cables fixed to it, in order to avoid the upset of the platform or its displacement under extreme environment conditions.

Picture 1.3.4.h. Representation of a Buoyancy Stabilized platform. Image extracted from "Estudio, caracterización y comparación de tipologías de plataformas para el soporte de aerogeneradores en alta mar". (2011)



In this project, the emplacement of the wind turbines is an area with a seabed deeper than 50 meters, as detailed in point 1.4.2.2. The solution planned is a floating platform.

1.4. EXPLANATION OF THE PREMISES

1.4.1. INTRODUCTION

Below, the different premises studied to the choice of the wind turbine, the emplacement, the calculations and the design of the mast are detailed.

1.4.2. PREMISES TO FULFIL

1.4.2.1. ELECTION OF THE WIND TURBINE

For this project, it is planned to use a wind turbine that is an exponent of the current trends for this kind of offshore emplacements both because its power and the technology used.

Because of that, the chosen wind turbine is the following one:

Table 1.4.2.1.a. Election of the wind turbine.

Manufacturer:	GAMESA
Model:	G128-5.0 MW Offshore
Power:	5.0MW
Class:	IIA (winds of 7,5m/s to 8,5m/s)
ROTOR	

Diameter	128m
Scavenging area	12.868m^2
SHOVELS	
Number of shovels	3
Longitude	62,5m
MULTIPLIER	
Ratio	1:37,88
GENERATOR	
Swing speed	448rpm
WEIGHT	
Weight of the nacelle	72Tn
Weight of the rotor	153Tn
Weight of the shovels	45Tn

1.4.2.2. SITE SITUATION

The site to the emplacement of the offshore wind farm must fulfil the following requirements:

1- Must be in Spain.
2- Can't be located in a nature reserve.
3- The system to which the farm will be connected can't be connected to the electric public distribution network of the Iberian Peninsula.
4- The system must have had the necessity of increasing its supplying power during the last 20 years.
5- The installation must reduce the CO_2 emissions caused by the use of fossil fuels to generate electricity.

Following the detailed premises, and once studied the Spanish territory, the conclusion is as follows:

The most suitable emplacement for the installation of the offshore wind park is the island of Menorca, as it fulfils all the previously-detailed premises. The justification can be found in the "Justification of emplacement" annex.

1.4.2.3. STATE OF LOADS

To calculate the state of loads to support, the following hypothesis have been studied, trying to bear in mind all the loads produced by the weight of the components of the wind turbine on the mast, the mast itself and the loads produced by the environment. The justification of the following values can be found in the "Justification of requirements" annex.

The requirements born in mind by the components of the wind turbine themselves are:

1- Bending moment produced by the shovels on the mast:

Mshovel = 3*15000*9,81*7,48 = 3.302.046Nm

2- Weight of the rotor:

F_{rotor}= 1.500.930 N

3- Weight of the nacelle:

$F_{nacelle}$= 706.320 N

The requirements produced by the environment are:

1- Load caused in the swept area of the wind turbine's shoves:

Fwshoves= 171,45 N

2- Wind load generated in the mast.
For a best approximation, the mast has been divided in three stretches, as detailed in the following table:

Table 1.4.2.3.a. Stretch distance.

Stretch	Distance
Stretch2	13-35m
Stretch3	35-60m
Stretch4	60-88m

Being the strengths caused by wind on each of the stretches as follows:

Table 1.4.2.3.b. Strengths caused by wind on the different stretches

Stretch	Strengths caused by wind
STRETCH 1	N/A
STRETCH 2	Fw stretch 2= (1/2) $(6,62)^2$*0,5*$(\pi * \sqrt{h_{strech}^2 + (D-d)^2} * (D+d)$)/2
STRETCH 3	Fw stretch 3= (1/2) $(13)^2$*0,5*$(\pi * \sqrt{h_{strech}^2 + (D-d)^2} * (D+d)$)/2
STRETCH 4	Fw stretch 4= (1/2) $(13,53)^2$*0,5*$(\pi * \sqrt{h_{strech}^2 + (D-d)^2} * (D+d)$)/2

3- Loads generated by ice and snow.

$F_{ICE\ AND\ SNOW}$ = 14,4KN

1.5. GEOMETRY OF THE MAST

To choose the geometry of the mast, a study of the requirements for both a cylindrical and a conical frustum has been carried out. The study's purpose was to select the most suitable geometry to support the requirements and also try to reduce the weight of the structure.

1.5.1. SELECTED GEOMETRY

Once performed the analytical study of every stretch of the mast, the selected geometry has been the **conical frustum geometry**, as it fulfils one of the main objectives of this project: a reduction on the weight of the structure.

The dimensions obtained with the analytical calculations of the mast are as follows:

Table 1.5.1. Analysis of the selected geometry.

Geometry	Conical frustum
Upper outer diameter	2,1m
Lower outer diameter	2,5m
Structure weight	10,62Tn
Steel type	S460G4+M

1.6. CALCULATIONS

1.6.1. ANALYTICAL CALCULATIONS

Once performed the analytical calculations, in which the effects caused by the requirements of the environment and of the whole, together with the weight of the mast have been taken into account, it is confirmed that the geometry that better suits the project is the **conical frustum one**. The materials used to perform the analytical calculations are S460G4+M and S355J2W+N steels, being the detailed in this point the one that better fulfils the requirements of the project.

The effects studied are listed below:

1. Highest tension
2. Horizontal displacement
3. Vertical displacement
4. Natural frequency
5. Buckling

The obtained data that fulfil the boundary conditions are:

Table 1.6.1.a. Behaviour stretch 4.

STRETCH 4	do (m)	e(mm)	Do (m)	FULFILS THE CONDITIONS S460G4+M?
HIGHEST TENSION	2,1	5	2,25	Y
HORIZONTAL DIS.	2,1	5	2,25	Y
VERTICAL DIS.	2,1	5	2,25	Y
FREQUENCY	2,1	5	2,25	Y
BUCKLING	2,1	5	2,25	Y

Table 1.6.1.b. Behaviour stretch 3.

STRETCH 3	do (m)	e(mm)	Do (m)	FULFILS THE CONDITIONS S460G4+M?
HIGHEST TENSION	2,25	5	2,38	Y
HORIZONTAL DIS.	2,25	5	2,38	Y
VERTICAL DIS.	2,25	5	2,38	Y
FREQUENCY	2,25	5	2,38	Y
BUCKLING	2,25	5	2,38	Y

Table 1.6.1.c. Behaviour stretch 2.

STRETCH 2	do (m)	e(mm)	Do (m)	FULFILS THE CONDITIONS S460G4+M?
HIGHEST TENSION	2,38	5	2,5	Y
HORIZONTAL DIS.	2,38	5	2,5	Y
VERTICAL DIS.	2,38	5	2,5	Y

FREQUENCY	2,38	5	2,5	Y
BUCKLING	2,38	5	2,5	Y

For more information, see the "Analytical calculations" annex.

1.6.2. CALCULATIONS BY FINITE ELEMENTS

To perform the study by completed elements, the number of effects taken into account in the structure has been reduced. These effects are considered the most critical ones and, depending on one of them, it would be necessary to modify the geometry of the structure.

The effects to study are:

1. Highest tension (Von Mises)
2. Horizontal displacement
3. Natural frequency

1.6.2.1. VERIFICATION OF ANALYTICAL CALCULATIONS

In order to verify that the results obtained in the analytical calculations can be considered as valid, a verification by completed elements has been performed.

The results of this verification are shown below:

Table 1.6.2.1.a. Behaviour stretch 4.

STRETCH 4	do (m)	e(mm)	Do (m)	FULFILS THE CONDITIONS S460G4+M?
HIGHEST TENSION	2,1	5	2,25	N
HORIZONTAL DIS.	2,1	5	2,25	N
FREQUENCY	2,1	5	2,25	N

Table 1.6.2.1.b. Behaviour stretch 3.

STRETCH 3	do (m)	e(mm)	Do (m)	FULFILS DE CONDITIONS S460G4+M?
HIGHEST TENSION	2,25	5	2,38	N
HORIZONTAL DIS.	2,25	5	2,38	N
FREQUENCY	2,25	5	2,38	N

Table 1.6.2.1.c. Behaviour stretch 2.

STRETCH 2	do (m)	e(mm)	Do (m)	FULFILS THE CONDITIONS S460G4+M?
HIGHEST TENSION	2,38	5	2,5	N
HORIZONTAL DIS.	2,38	5	2,5	N
FREQUENCY	2,38	5	2,5	N

1.6.3. RESIZING OF THE STRUCTURE. STEEL

As shown in the "Calculation by completed elements" annex, the resizing has been performed for the complete mast, without dividing it into stretches. That is because the same type of deformation happened on every stretch and also because the natural frequency must be studied in the whole structure, without any divisions, as this factor is determined by the geometry of the complete structure.

To perform this resizing, the average existing in all the mast has been taken into account to extract the strength generated by wind in the mast itself.

Dimensions obtained after the resizing are shown below:

Table 1.6.3.a. Dimensions with steel.

MATERIAL	**Upperdiameter (m)**	**Base diameter (m)**	**Thickness (mm)**	**Number of reinforcements**	**Dimensions of the reinforcements Width x Thickness (mm) Height (mm)**
STEEL	**2,53**	**2,875**	**40**	**N/A**	

1.6.4. RESIZING OF THE STRUCTURE. COMPOSED MATERIAL

Once performed the sizing of the structure in steel, this material has been substituted by a composed one.

In order to successfully perform the study, the axis with higher resistance has been oriented in Z-direction, being the inserted values as follows:

Table 1.6.4.a. Fibres orientation.

	X	Y	Z	Unidad
Módulo de Young	3000	3000	116000	N/mm^2 (MPa)
Coeficiente de Poisson	0.00189	0.001189	0.46	
Módulo de corte	1482.37	1482.37	39726.02	N/mm^2 (MPa)
Coeficiente de expansión térmica				1/C
Conductividad térmica				W/mm-C
Esfuerzo máximo en tensión	30	30	3600	N/mm^2 (MPa)
Esfuerzo máximo en compresión	10	10	100	N/mm^2 (MPa)
Tirantez máxima en tensión				
Tirantez máxima en compresión				

Dimensions obtained after the resizing are shown below:

Table 1.6.4.b. Dimensions with compound material.

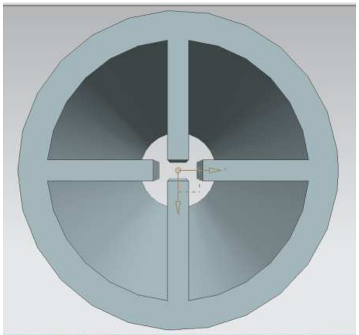
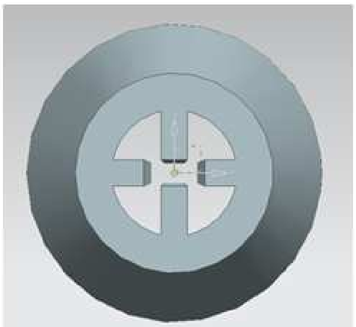
MATERIAL	Upper diameter (m)	Base diameter (m)	Thickness (mm)	Number of reinforcements	Dimensions of the reinforcements Width x Thickness (mm) Height (mm)
DYNEEMA®	3	6	550	4	Upper part 461x400 729x400 x2 75000 Total height x2 1975x400 2242x400 Base part

1.7. ADAPTATIONS OF THE GEOMETRY DEPENDING ON THE MATERIAL

As shown in previous points, there has been an increase on the dimensions of the structure, from the dimensions obtained with analytical calculations to the redesign created with steel and with the composed material.

The table below shows the different views of the structures, once redesigned by completed elements, depending on the material used.

Table 1.7. Adaptations of the geometries depending on the material.

MATERIAL	View from the base	View from the upper part
STEEL		
DYNEEMA®		

1.8 COMPARATIVE OF THE RESULTS

The table below shows the values of the different effects that are supported by the structure, depending on the material used.

The values of these effects are as follows:

Table 1.8. Comparative of the results.

MATERIAL	VON MISES (MPa)	HORIZONTAL DISPLACEMENT (mm)	NATURAL FREQUENCY (Hz)	WEIGHT (Tn)
STEEL	Higher: 11,38MPa Lower:0,014 9MPa	Higher: 9,585*10^-5mm Lower: -1.958*10^-4mm.	0,6241	196,98Tn
DYNEEMA®	Higher: 5,885MPa Lower: 0,0339MPa.	Higher: 3*10^-3mm Lower:-1.983*10^-3mm.	2,541	631,7Tn

As shown on the table above, very low values in von Mises yield criterion and horizontal displacement have been achieved; the parameters showing the biggest differences between both materials are natural frequency and weight.

The big difference existing in the natural frequency is due to the increase on the thickness of the composed-material structure, in order to reach von Mises yield criterion levels which are not damaging for the structure.

Regarding the weight, the increase on the thickness to maintain the von Mises yield criterion has caused a thickness so disproportionate that it has caused a dramatic increase on the weight of the composed-material structure.

For more information, see the "Calculation by infinite elements" annex.

1.9. ESTIMATE

The estimate based on the obtained data is as follows:

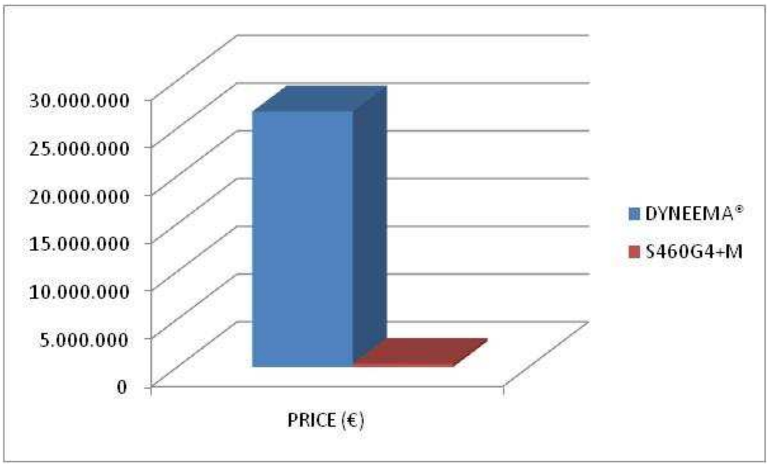
Table 1.9.a.Comparative.

MATERIAL	PRICE	QUANTITY	TOTAL PRICE
STEEL S460G4+M	1.800€/Tn	196,98Tn	345.564€
DYNEEMA ®	42,38€/kg*	631.700kg	26.771.446€

*The price of Dyneema is only in textile format

Note: The price for the materials is approximate, as it depends on the purchased quantity, the providers, etc.

Graphic 1.9.a. Comparative prices.

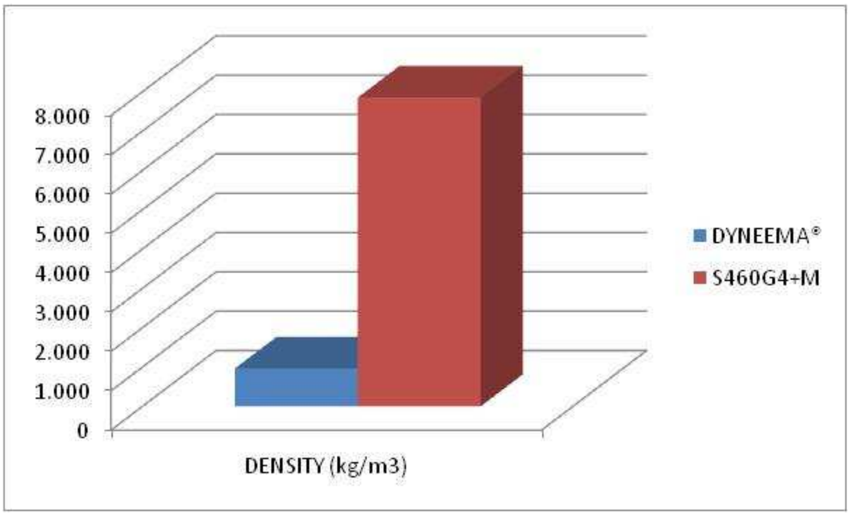


1.10. CONCLUSIONS

Based on the study performed and the estimate obtained, it can be confirmed that the wanted premises of simplicity and lightness have been achieved with the use of S460G4+M steel; though, these premises haven't been fulfilled with the use of the Dyneema ® composed material.

The purpose of using this composed material was to make the structure lighter, as its density is lower than steel's. The graphic below shows a comparative of both densities.

Graphic 1.10.a. Comparative densities.



However, the mechanical characteristics of the composed material (being this orthotropic and used without superposition of layers, as the study has been carried out with one-way fibres) have resulted in an undesired increase of the structure's geometry. This increase fails to fulfil the premises of this project: simplicity and lightness of the structure.

Because of that, it can be affirmed that the use of the composed material with the used methodology is not suitable for this kind of structures. Nevertheless, it is important to keep on researching in the use of composed materials for this type of structures, in order to obtain simpler and lighter designs that overcome new technological challenges.

To sum up, it is fair to affirm that this study should not be considered as a failure because it hasn't achieved the wanted purpose of replacing steel by a composed material. It is important to bear in mind that valuable information has been drawn from it, information that can open new ways for the use of new materials, previously considered as unthinkable for this type of structures.