UpWind

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Assessment of bottom-mounted support structure types with conventional design stiffness and installation techniques for typical deep water sites

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(WP4: Offshore foundations and support structures)

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Abstract: This document discusses various support structure concepts and subjects them to an evaluation. The preliminary design process and installation methods are also presented.

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This report is the result of work jointly carried by several participants in the Task 4.2 “Concepts for deep-water sites”. Contributions from the University of Stuttgart (M. Kühn, T. Fischer), DTU/Risø (J.D. Sørensen), DONG A/S (C. Mørch), GEGR-E (P.W: Cheng), Garrad Hassan (T. Camp), GL Wind (K. Argyriadis), RAMBOLL A/S (H. Carstens) and Shell bv (A. Ploeg) are kindly acknowledged.

Summary

This report is the first deliverable for work package 4.2, dealing with support structure concepts for offshore wind turbines in deeper waters. It starts out with a brief review of existing support structure types as well as types that may be envisaged in the near future. The following selection of support structure types, comprising bottom founded structures with conventional design stiffness, very soft structures and floating structures, are addressed:

- Monopile
- Tripod
- Jacket
- Gravity base
- Suction bucket monotower
- Compliant structure
- Barge floater
- Tension leg platform
- Spar floater

Subsequently, an assessment of the aforementioned support structure types is performed. The aim is to give a preliminary, qualitative assessment of these support structure concepts with respect to their suitability for certain water depth ranges, as well as to gain more insight into the problems associated with the design of such support structures. The assessment was performed using an evaluation matrix in which the weighted score for various parameters was determined for different water depths for each concept. This matrix was filled out by a number of participants of the work package. It was found that certain effects were difficult to express in numbers and also the effect of increasing water depth was difficult to assess for certain parameters. Furthermore there were differences in the results the different contributors. However, from the averaged results, the following can be concluded. The monopile performs progressively worse for increasing water depths, while the jacket support structure performs well relatively constant for all water depths. Floating structures perform best in deep water. The outcome of this assessment may not serve as a basis to disregard certain concepts for further study, yet the experience gained will help to perform effective qualitative and quantitative assessments in later stages. A brief description of the preliminary design process for three bottom-founded support structure types is given. The layout of the monopile, tripod and jacket structures is explained and the steps in the preliminary design process are elaborated upon. Furthermore, current installation methods for offshore wind turbines are discussed. This focuses mainly on the monopile, but where there are differences for the tripod and jacket structures, these are also touched upon. Finally, design considerations for the next phase are presented. Wind, wave and soil data have been obtained and assessed for a selected location in the North Sea. Also a list of turbine parameters that are required for the design of a support structure is given.

Contents

STATUS, CONFIDENTIALITY AND ACCESSIBILITY										
Status				**Confidentiality**				**Accessibility**		
S0	Approved/Released	X		**R0**	General public			Private web site	X
S1	Reviewed			**R1**	Restricted to project members	X		Public web site	
S2	Pending for review			**R2**	Restricted to European. Commission			Paper copy	
S3	Draft for commends			**R3**	Restricted to WP members + PL				
S4	Under preparation			**R4**	Restricted to Task members +WPL+PL				

PL: *Project leader* **WPL:** *Work package leader* **TL:** *Task leader*

1. Introduction

This document is intended to give an overview of the different support structure concepts for offshore wind turbines that exist today or may be envisaged in the near future. It starts by discussing the different support structure concepts and their principal features. This is followed by an evaluation of the selected concepts. This evaluation is executed in the form of an evaluation matrix that has been filled out by several members of the work package. The results are analysed and the conclusions that can be drawn from this analysis are briefly discussed. In chapter 4 the focus is on the preliminary design process for bottom founded support structure types. First, the design procedures for the monopile, tripod and jacket concepts are explained. Subsequently, the steps in the design process are elaborated upon. In chapter 5 installation methods for bottom founded support structures are discussed. The next chapter focuses on certain design considerations, mainly the processing of raw data from environmental databases into useful design data. Design data is gathered for a selected location in the North Sea. This data will serve as input for the preliminary design of the various support structure concepts in the next phase of this research project. Also, turbine design parameters relevant to support structure design are listed. Finally, concluding remarks and an outlook for the next phase of the project can be found in chapter 7.

2. Review of support structure concepts

2.1 Definition of support structure

Before any support structure concepts are introduced a definition should be given of 'support structure'. In its broadest sense it can mean the entire structure that carries the turbine, as depicted in Figure 1A. It may also be useful to define the foundation as the part of the structure that fixes it to the seabed. In this case everything from the seabed up to the turbine is defined as the support structure. This is shown in Figure 1B. In practice, the turbine tower is supplied by the turbine manufacturer. This component is thus not the responsibility of the offshore contractor. It may therefore be convenient to exclude the tower from the definition. Figure 1C gives a representation of this definition of the support structure. This last definition will be maintained in this chapter as it makes it easy to exchange one support structure concept for another.

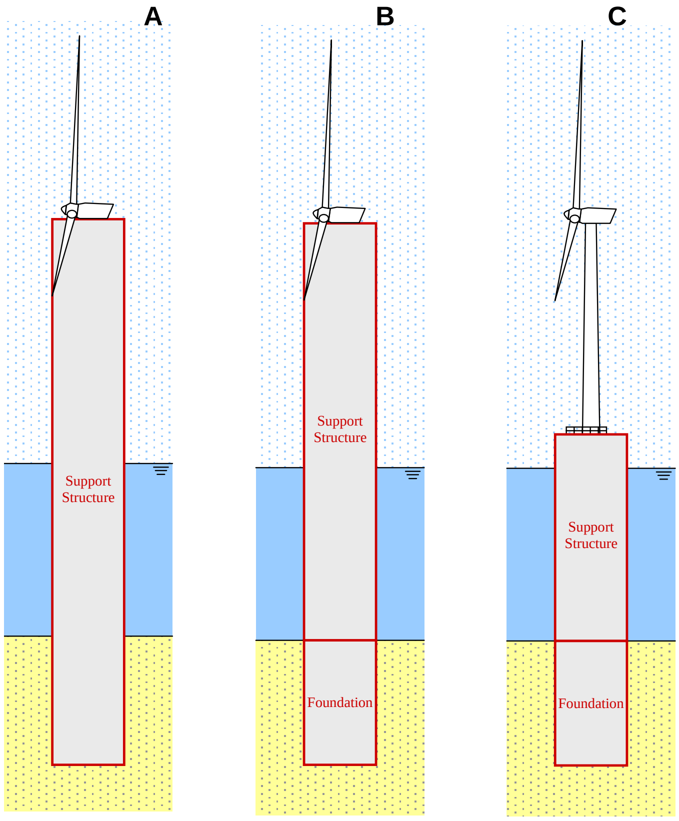


Figure 1: *Definitions of 'support structure'*

2.2 Concepts

In search of economic solutions for deeper water several new foundation concepts have been proposed. For inspiration, designers turned towards the offshore oil and gas sector. This sector has several decades of experience with various support structure types for all sorts of purposes; from the large deep water production platforms to small scale wellhead and monitoring platforms. Although loads on a turbine are very different than the loads on offshore platform topside facility, the concepts might be adapted to suit the needs of offshore wind energy production. These concepts can be divided into five main categories [1]:

- Monotower structure
- Tripod structure
- Jacket structure
- Gravity structure
- Floating structure

Apart from different support structure concepts, various foundation concepts can also be envisaged. Common solutions in the offshore oil and gas industry for bottom founded structures are:

- pile
- suction can
- gravity base

And for floating structures:

- (drag) anchor
- pile
- suction can

From an academic point of view it would be attractive to combine all of the support structure concepts with all of the foundation concepts. However, within the five main support structure categories there are many potential variations. The number of possibilities would become impractical. Therefore only a limited number of representative concepts were selected. These concepts are described in the remainder of this section. The accompanying figures show a certain choice for the foundation. This is not the final word about the foundation concept, but to keep the ensuing evaluation down to an acceptable amount of work the evaluation is done with these foundation concepts in mind.

The following concepts are studied:

- Monopile
- Tripod
- Jacket
- Compliant structure
- Gravity base structure
- Suction bucket monotower
- Barge floater
- Tension leg platform
- Spar floater

The monopile, by no means a new concept, is included in this list to serve as a reference for the other concepts. Furthermore, it should be noted that no monopile foundations for offshore wind turbines have been applied in water depths larger than 25 m up till now. Figure 2 shows the first four concepts listed above.

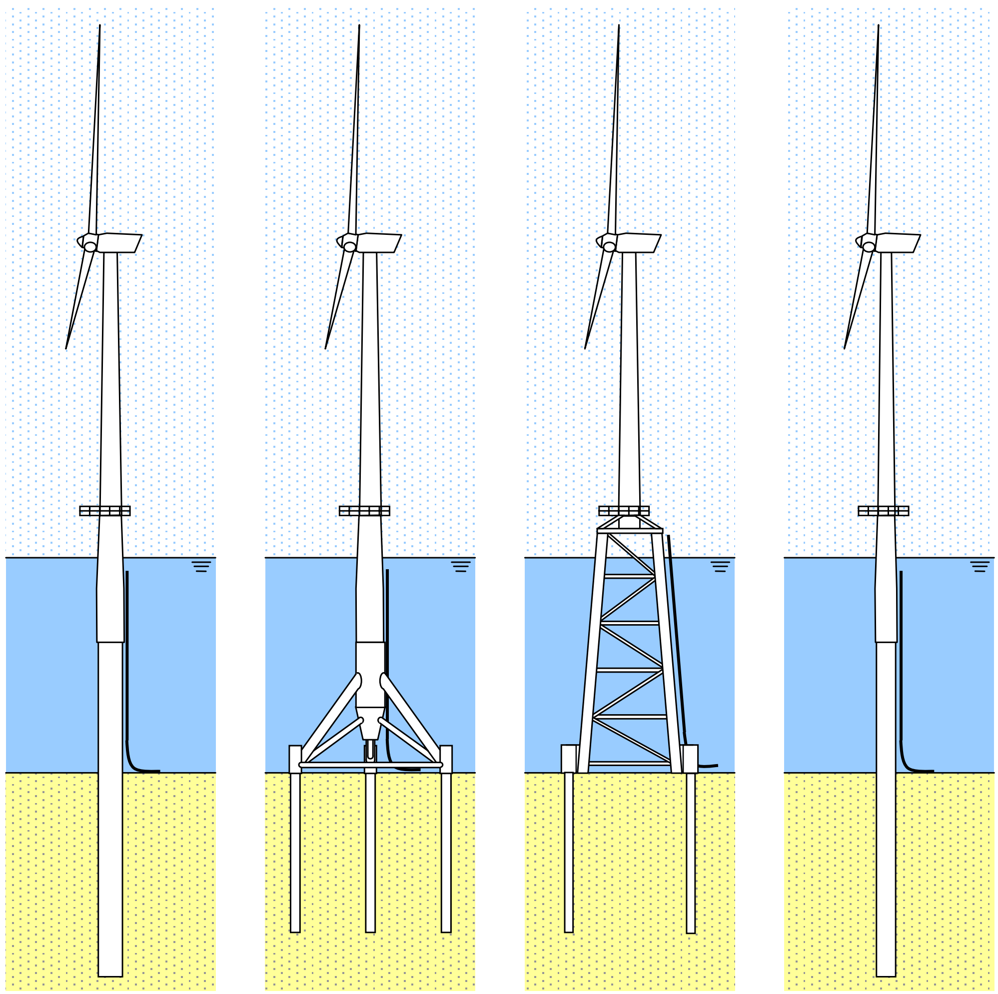


Figure 2: *Four support structure concepts. From left to right: monopile, tripod, jacket and compliant structure*

2.2.1 Monopile

The monopile foundation is more or less an extension of the onshore turbine tower below the sea surface and into the seabed. The vertical loads can easily be transferred to the soil through wall friction and tip resistance. The lateral loads, in comparison much larger, are conveyed to the foundation through bending. The loads are subsequently transferred laterally to the soil. To provide enough stiffness the diameter of the monopile foundation has to be large enough. This attracts relatively high hydrodynamic loads. On the other hand, the monopile foundation is easy to fabricate and install. It is expected that monopile foundations will not be applicable beyond certain water depths. Stiffness requirements will result in such large diameters that it will be impossible to fabricate such a structure, due to limitations on the size of the steel plates that can be produced by steel mills. Difficulties due to limited sizes of pile driving equipment may also be expected.

2.2.2 Tripod

The lower portion of a tripod foundation consists of a framework of relatively slender members, connected to the main tubular by means of a joint section. This framework is fixed to the seabed by piles which are driven through pile sleeves at the end of each of the tripod legs. The main difference between the tripod and the monopile concepts is the way the loads are transferred to the seabed. From the main joint downwards the transfer of loads relies mainly on axial loading of the members. The piles are also mainly loaded axially. This allows the tripod foundation to be shallower and lighter than the monopile foundation. The main advantages are that the tripod has a larger base, which gives it a larger resistance against overturning. The base is also stiffer, leading to an overall stiffer structure. As the base is made up of relatively slender beams, it is transparent, allowing water mass to pass through the structure relatively unobstructed. However, this is not the case for the structure from the main joint upwards. Furthermore, the main joint is a complex element that is susceptible to fatigue and requires much effort in designing and engineering. The triple leg configuration makes directionality of wind and wave loads more of an issue, when compared to the monopile. From an installation point of view, the tripod poses challenges as it cannot be transported as easily as a monopile foundation.

2.2.3 Jacket

A jacket structure is made up of four legs connected by slender braces, making it a highly transparent structure. Loads are transferred through the members mainly in axial direction. The foundation is provided by piles driven through the pile sleeves at the bottom of each of the legs. The term ‘jacket’ has its origin in the oil and gas industry and is used to indicate a spaceframe structure which has the piles driven through the legs. The configuration as shown in Figure 2, which has the piles driven through pile sleeves at the base of the structure, would be termed a ‘tower’. However, the term ‘jacket’ will be maintained to avoid confusion with the turbine tower. The large base offers large resistance to overturning. The space frame structure allows for light and efficient construction. However, each of the joints has to be specially fabricated, requiring many man-hours of welding. Furthermore, transportation will be an issue, particularly when installing a large number of turbines. A demonstrator project has been undertaken near the Beatrice oil field off the coast of Scotland, where two 5 MW turbines are installed on jackets in 45 m water depth.

2.2.4 Compliant structure

The principle behind the aforementioned concepts is to have the first natural frequency above the wave frequencies with high energy to avoid resonance and thus high fatigue loads. In other words, the structure should be stiff enough. For a compliant tower the principle is opposite. The intention is to have the first natural frequency below the wave frequencies with high energy, in order to avoid resonance. This means a very soft structure is created. In turn, this implies that a light and slender structure can be achieved. Such a structure does not require a large diameter and therefore attracts relatively low hydrodynamic loads. On the other hand, due to its complexity, the concept has only been used a couple of times in the oil and gas industry and no projects are running or planned to apply this type of structure in the offshore wind industry. Apart from the complexity, other issues will have to be addressed. These include assessment of the stiffness and response of the upper section in relation to the turbine and in particular the blades. It should also be assessed whether the second natural frequency coincides with high energy wave frequencies. Another aspect that might pose problems is that the wind contains the most energy at low frequencies.

2.2.5 Gravity Base Structure

A Gravity Base Structure (GBS) relies on a low centre of gravity combined with a large base to resist overturning. As the GBS requires a large mass it generally made of concrete as it is much cheaper than steel. The GBS is placed directly on the seabed. It can be equipped with vertical walls that protrude from below the actual base, called skirts, which penetrate into the soil below the base. These skirts increase resistance to base shear and help to avoid scour below the base. Liquefaction of the soil beneath the base due to cyclic loading is an issue that must be addressed when assessing the stability of the foundation.
The GBS can be extended to the platform level, thereby reducing the number of offshore installation activities, as no separate transition piece needs to be installed.

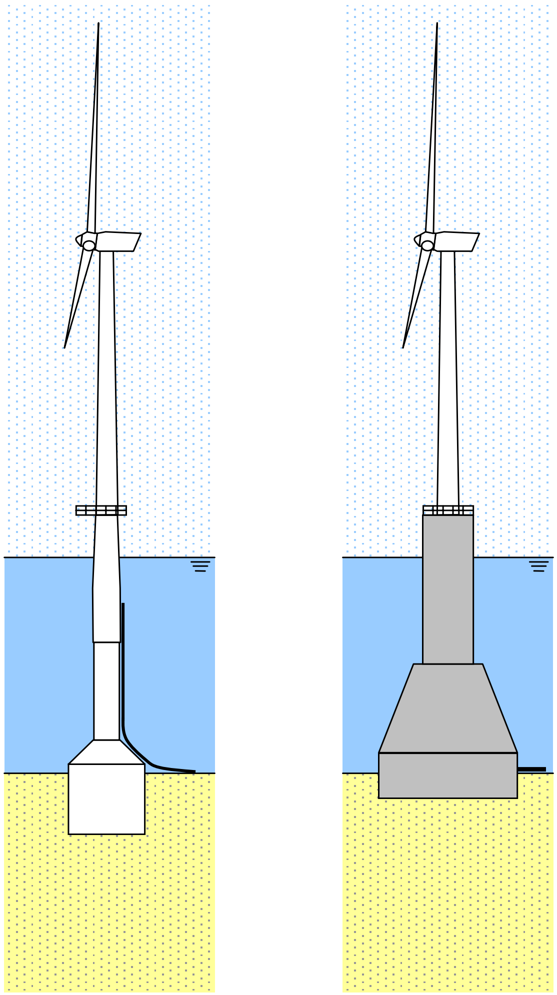


Figure 3: *A suction can monotower (left) and a gravity base structure*

2.2.6 Suction bucket monotower

The suction bucket concept is a monotower with a suction bucket at its base. A suction bucket is a large diameter cylinder with a closed top. It is installed by placing it on the seabed and subsequently activating a pump that removes water from within the suction bucket. This creates a pressure difference with respect to the ambient pressure, which results in a downward force. This causes the suction bucket to be pressed down into the soil. Once the pump is deactivated skin friction and end bearing will keep the foundation in place and provide the required bearing capacity. Because it is reliant on the pressure difference for installation, this concept is not suitable for very shallow water. It may be practical to integrate the suction bucket with the transition piece to reduce the number of offshore installation activities.

2.2.7 Barge floater

A floating structure relies on buoyancy to keep the turbine above the water. Different configurations, again derived from the oil and gas industry, can be envisaged. For instance; a turbine could be placed on a barge and attached to the seabed with anchor lines. The anchor line configuration can be either catenary or taut. The mooring can be completed using drag anchors, driven piles or suction anchors. The offshore wind turbine can be assembled on the barge floater at an onshore location. The assembly can be towed out to the required location. This concept may be suitable for large scale production as it can easily be adapted to different water depths. However, it may require at least a certain depth before the mooring concept can be applied. Furthermore, a barge type floater may have serious motion issues. Its large cross section at the water line makes it sensitive to hydrodynamic loads, which in turn makes it susceptible to heave, pitch, roll and sway.

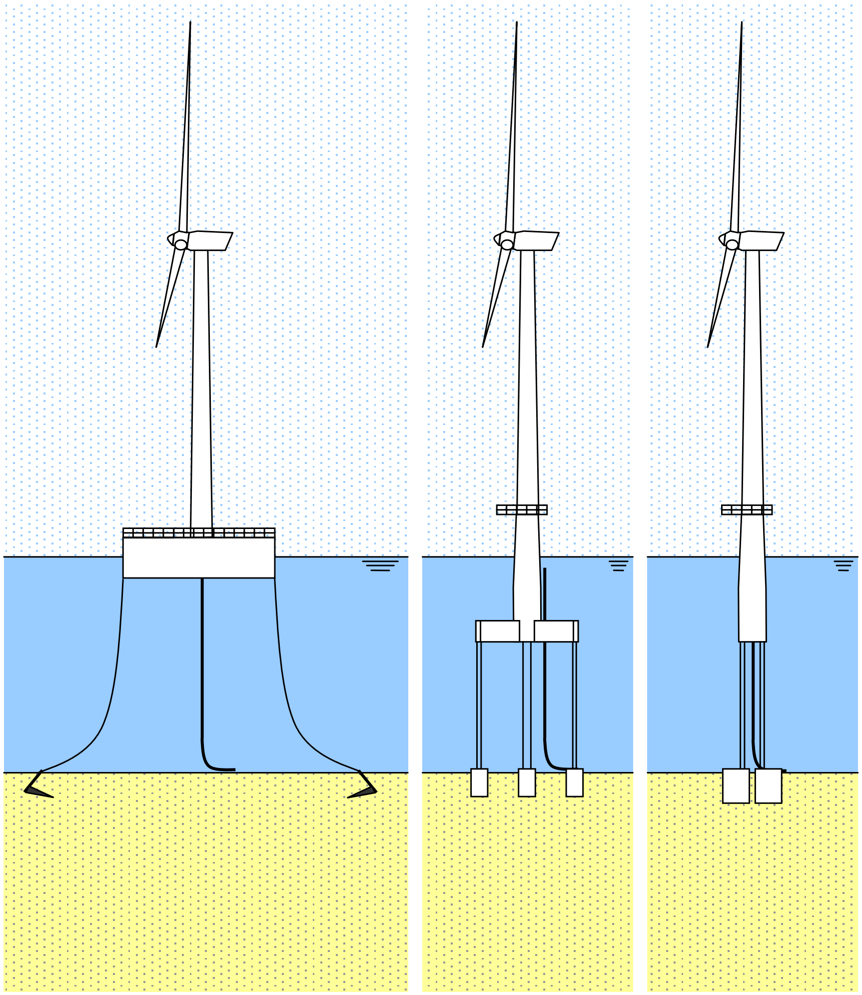


Figure 4: *A barge floater (left) a tension leg platform (middle) and a spar floater*

2.2.8 Tension Leg Platform

Another option for a floating structure is a mini Tension Leg Platform (TLP), which is tethered to the seabed by means of pre-tensioned cables. The pre-tension greatly reduces heave motion and to a certain extent horizontal motion. The cables can be fixed to a template on the seabed or to individual piles or suction buckets. The TLP has a small cross section at the water line, keeping the hydrodynamic loads relatively small. The TLP requires well engineered connections of the cables to the floater. The tension legs will not be very suitable for shallow water

2.2.9 Spar floater

A spar type floating structure obtains its buoyancy from a cylinder that protrudes below the water line. This cylindrical body is generally long and slender in order to minimize the cross section at the water line. This greatly reduces the wave induced motion. It can be anchored to the seabed with chains in a catenary shape. A spar typically has a small surface cross-section, reducing heave motion. The draft of a spar is usually relatively large to ensure sufficient buoyancy. This may pose problems in small water depths. Because of this the spar may not be very cost effective for shallow water.

3. Evaluation of support structure concepts

3.1 Introduction

One of the main objectives of this report is to give a preliminary assessment of the possible design and installation solutions for deep water support structures for offshore wind turbines. At this stage in the project, no full quantitative analysis of various aspects of the support structure concepts described in chapter 2 can be performed. Therefore it was decided to perform a qualitative assessment of the support structures, based on the expert opinions of the work package participants. A further objective of the analysis is to gain insight in the problems involved in designing support structures for offshore wind turbines in deeper waters

3.2 Approach

The assessment was done on the basis of an evaluation matrix in which the different support structure concepts were scored for various parameters. The first step was to define a number of assessment parameters. These parameters are spread over several categories that cover the different phases in the life cycle of an offshore wind turbine. Subsequently, weights were assigned to each of the parameters to allow the relative importance of the parameters to be taken into account. As the aim is to create more understanding of the suitability of support structure concepts as a function of water depth, it had to be decided which water depth to use in the assessment. After discussion among the work package members the following water depths were assumed: 30m, 45m, 80m and 120m. An evaluation matrix was created, which was distributed among several members of the work package to fill out. The results were collected and analysed. Any serious differences in the results were discussed to eliminate differences of interpretation. From the reviewed results a preliminary conclusion was drawn.
It should be noted that the results from this evaluation serve as a first indication of the suitability of the support structure concepts for different water depth ranges only. In a later stage, when more knowledge and insight have been gained and the opportunity exists to assess the concepts in a more qualitative manner, the process will be repeated. In this next assessment, parameters may be dropped or added or the approach may be altered altogether.

3.3 Assessment parameters

To obtain the assessment parameters, various categories were proposed. The categories correspond to different stages in the life cycle of an offshore wind turbine, such as design, fabrication, installation, maintenance and decommissioning. Two other categories were proposed. A *site*-category was included to account for effects of varying site conditions on the suitability of a concept. It was also decided to include a category labelled *overall* to include a parameter accounting for the reliability of the concepts (whether or not a concept can be viewed as proven technology. A list of the parameters follows below. A description can be found in Appendix A.

- Site
  - Varying soil conditions
  - Poor soil conditions
  - Bedrock
  - Ice
- Design
  - Mass of support structure
  - Tower head motion
  - Effect of turbine mass

- Fabrication
    - Number of welds
    - Complexity of the joints
- Installation
    - Transportation inland
    - Transportation offshore
    - Lifting
    - Foundation
    - Connections
    - Cable installation
- Maintenance
    - Scour protection
    - Corrosion protection
    - Access
- Decommissioning
    - Disconnecting
    - Foundation removal
    - Environmental impact of remains
- Overall
    - Reliability of concept

3.4 Weights

Two approaches have been considered for determining the weights associated with the assessment parameters. The first is the *bottom-up* approach in which a weight is assigned to each parameter. The weights of all parameters within a category are added to obtain the weight of the category. The relative importance of the categories with respect to each other is thus determined by the ratio of the weight of a category and the total weight of all parameters. The other approach is the *top-down* approach. In this method a fixed number of points is divided over the categories to determine the relative importance of each of the categories. Subsequently, the assigned points are divided among the parameters within the categories. As the bottom-up approach may lead to overrepresentation of certain categories, the top-down approach is adopted.

3.5 Evaluation matrix

The evaluation matrix is created using a spreadsheet program. It contains a section in which the user can enter the score, ranging from 1 to 10, for each parameter and each support structure concept. Another section presents the weighted score for each parameter and support structure. For each support structure the total score can be found at the bottom of this section. For each category a normalised score is given, whereby the value 1.0 indicates that the concept has earned the maximum score for that category. This makes it easy to see at a glance how well a concept has scored for a certain category. The evaluation matrix has been drawn up for a range of 4 different water depths. The aim is to investigate how well a concept scores when the water depth varies. The matrix is displayed in Figure 5. The submitted matrices can be seen in Appendix B.

	Score										Weighted Score								
	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar	Weight	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar
Site																			
Varying soil conditions										8									
Poor soil conditions										7									
Bedrock										5									
Ice										4									
										24	0	0	0	0	0	0	0	0	0
Design																			
Mass										10									
Tower head motion										7									
Turbine mass										8									
										25	0	0	0	0	0	0	0	0	0
Fabrication																			
Number of welds										6									
Complexity of the joints										8									
										14	0	0	0	0	0	0	0	0	0
Installation																			
Transportation inshore										1									
Transportation offshore										6									
Lifting										7									
Foundation										9									
Connections										9									
Cable Installation										6									
										38	0	0	0	0	0	0	0	0	0
Maintenance																			
Scour (protection)										4									
Corrosion (protection)										5									
Access										7									
										16	0	0	0	0	0	0	0	0	0
Decommissioning																			
Disconnecting										4									
Removal of foundation										5									
Environmental impact of remains										3									
										12	0	0	0	0	0	0	0	0	0
Overall																			
Reliability (proven technology)										6									
										6	0	0	0	0	0	0	0	0	0
										Total									
										Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 5: *Support structure evaluation matrix for one water depth*

3.6 Analysis of submitted matrices

The evaluation matrices of each of the contributing work package members have been analysed. It was noted that results from different contributors showed some significant differences. The participants felt that it was difficult to determine the value of each entry in the matrix. The filling out of the matrix thus became a more subjective exercise.
The total weighted score per support structure was determined for each water depth for each contributor. The results were averaged over the different contributions. Table 1 shows the averaged score for each support structure.

Table 1: *Averaged score per support structure type for 4 different water depths*

Depth [m]	*Monopile*	*Tripod*	*Jacket*	*Gravity base*	*Suction bucket*	*Compliant tower*	*Floating: Barge*	*Floating: TLP*	*Floating: Spar*
30	921	861	861	826	799	745	748	669	626
45	794	843	855	791	721	701	756	676	761
80	628	772	817	717	603	659	785	711	808
120	519	714	822	736	593	692	900	803	944

During the filling out of the support structure evaluation matrix the following issues were noticed:

- It was difficult to express certain effects in numbers
- There were differences in results of different contributors
- The effect of increasing water depth was difficult to assess for certain parameters

However, certain trends in the results were clear. Figure 6 visualises the final results. The total score averaged over the different contributing results is given for four different water depths. Overall, the following can be concluded:

- Monopile scores progressively worse for increasing water depth
- Jacket score remains relatively constant for different water depths
- Floating structures perform best in deeper waters

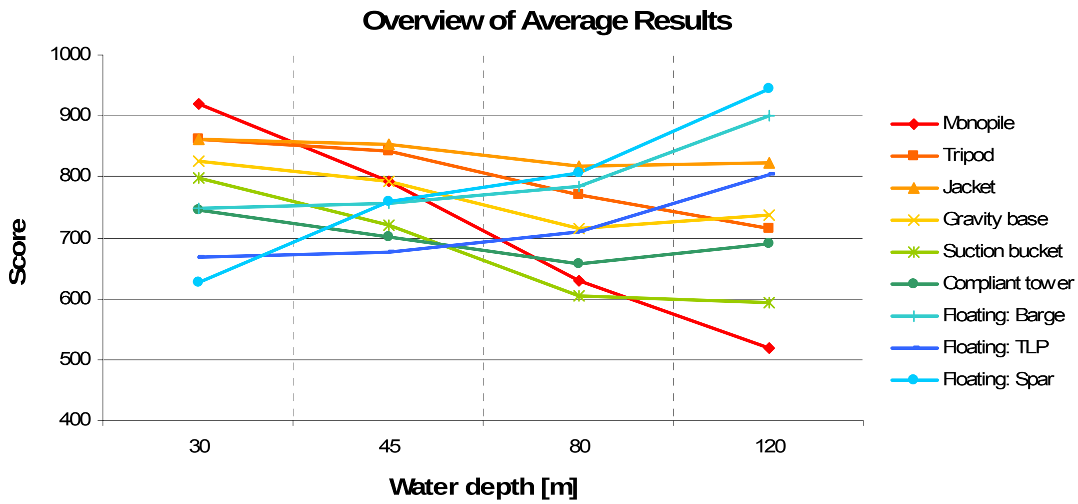


Figure 6: *Average score per support structure type for four different water depths*

3.7 Conclusions

Based on the analysis in the previous section a number of remarks can be made. The results are only preliminary. They are not a basis for disregarding concepts for further study. One objective was to gain more affinity for the problems involved with deep water support structure types. This has been achieved.

Furthermore, the clearest results concerned the monopile, the jacket and the floating concepts. It was found that the monopile scores progressively worse for increasing water depth. The jacket score is relatively constant for different water depths. Floating structures perform best in deeper waters.

4. Preliminary design of bottom founded structures

4.1 Introduction

This chapter describes the preliminary design process. First the design process is given schematically for a monopile, tripod and jacket support structure. This is described in sections 4.2, 4.3 and 4.4. These sections include a discussion of the support structure components and layout. The data required to make the preliminary designs is given in section 4.5. Subsequently, section 4.6 addresses the determination of the key design levels, the key elevations, such as the platform height and the hub height to which the rest of the support structure is designed. The following section discusses the required natural frequency. Foundation stability is the subject of section 4.8, while buckling checks are described in section 4.9. Finally, section 4.10 deals with the issue of fatigue.

4.2 Monopile preliminary design

4.2.1 Design steps

The process for making a preliminary design of a monopile support structure follows the six steps given below. This is illustrated in Figure 7

- Determine the design levels
- Determine the allowable natural frequency
- Determine preliminary geometry (diameter, wall thickness)
- Determine extreme loads
- Determine penetration depth
- Perform buckling check
- Perform fatigue check

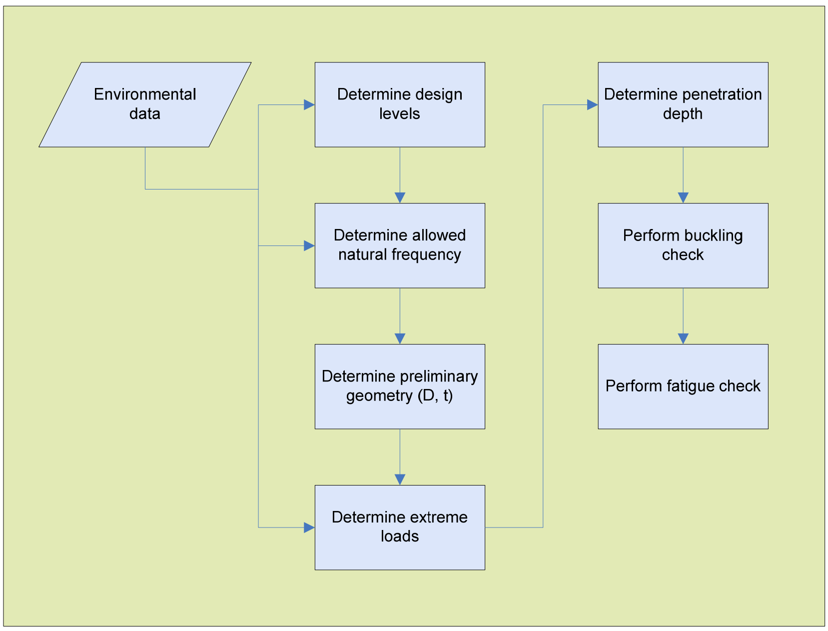


Figure 7: *Monopile preliminary design process*

The design levels are determined based on the environment and the turbine size as is explained in section 4.6. Using the turbine properties and a wave spectrum that is representative for fatigue, the allowable natural frequency band can be determined. This is discussed in section 4.7. Based on this allowable frequency band a target natural frequency is set. Subsequently, the diameter and the wall thickness of the support structure are chosen such that the target frequency is attained. This is an iterative process in which a set ratio between the diameter and the wall thickness is maintained. The diameter, having the largest effect on the natural frequency, is varied until the desired natural frequency is obtained. With the geometry known, the extreme loads can be determined. The extreme loads are due to wind, wave and current loads. Usually a combination of an extreme wind speed and a reduced maximum wave height or a reduced wind speed and an extreme wave height is applied. Conservatively, the maximum wind speed, current and wave height can be combined. The appropriate design standards should be consulted. Using the thus determined loads, the penetration depth can be determined. To this end the lateral and axial stability of the foundation is considered. This is described in section 4.8. For a monopile foundation the lateral stability is generally governing. Subsequently, buckling checks are performed. If the buckling check is not satisfied, the wall thickness of the support structure must be increased. Generally, the subsequent fatigue check is governing. Therefore the wall thickness should not be optimized with respect to buckling. Finally, the wall thickness of the support structure is checked for fatigue. If the wall thickness is too small the wall thickness must be increased. On the other hand, if it is significantly larger than required, the wall thickness may be reduced. Section 4.10 deals with the fatigue check.

4.2.2 Definition of Components

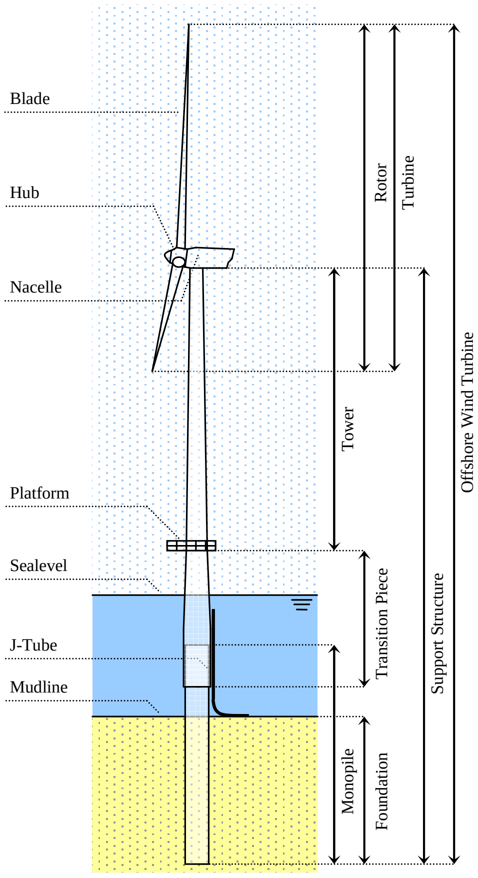


Figure 8: *Monopile support structure components*

Figure 8 shows the components of a monopile support structure. On the right hand side of this figure a number of definitions are given to allow unambiguous naming of various parts of the structure. The rotor is defined as the assembly of blades and hub. The turbine consists of the rotor and the nacelle. The turbine tower is the part of the support structure that starts at the platform and continues up to just below the nacelle. The transition piece runs from the lower end of the overlap between transition piece and foundation pile to the level of the platform. The foundation pile extends from a level above the seabed down to a certain depth below the seabed. The part of the foundation pile that extends below the seabed is defined as the foundation, whereas the assembly of the foundation pile, the transition piece and the turbine tower is called the support structure. The entire structure including the support structure and the turbine is referred to as the offshore wind turbine.
The platform and the J-tube are attached to the transition piece. A boat landing and a ladder, not included in Figure 8 are also attached to the transition piece.

4.3 Tripod preliminary design

4.3.1 Design steps

For the main part the procedure for making a preliminary design for a tripod support structure follows the same steps as the procedure for a monopile support structure. For clarity the full sequence of steps is listed below. The process is depicted schematically in Figure 9.

- Determine the design levels
- Determine the allowable natural frequency
- Determine layout of support structure
- Determine preliminary geometry (diameter, wall thickness)
- Determine extreme loads
- Determine foundation pile geometry
- Determine penetration depth
- Perform buckling check
- Perform fatigue check

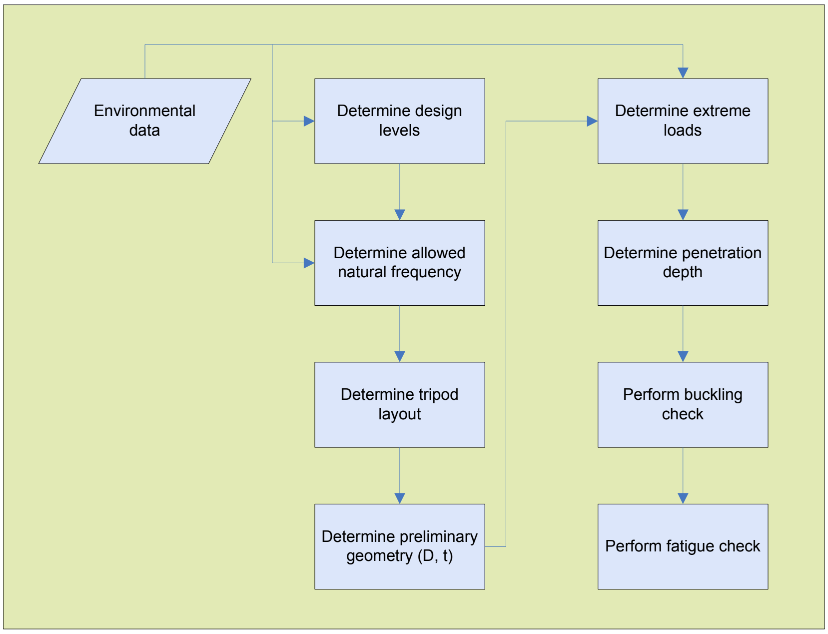


Figure 9: *Tripod preliminary design process*

The design levels and the allowable natural frequency can be determined in the same manner as for the monopile support structure. This is described in sections 4.6 and 4.7 respectively. An important difference with respect to a monopile support structure is the number of choices that must be made to obtain the layout of the support structure. It is important to define the layout of the tripod support structure at this stage as it influences all subsequent steps. Subsequently, the geometry must be determined. In order to reduce the number of possible variations, the diameter and wall thickness of the braces are related to the diameter and wall thickness of the main column. Furthermore, the wall thickness of the main column is related to the diameter of the main column. Together with the environmental data and the turbine properties, the support structure geometry allows the calculation of the extreme loads. These loads are used in combination with the vertical loads due to self weight to determine the dimensions of the foundation piles. Once this has been determined, the penetration depth can be determined using the extreme loads. To this end the vertical and lateral stability of the foundation piles is checked. The axial stability is deemed to be governing for a tripod support structure. Finally the wall thickness of all members should be checked, by performing a buckling check and subsequently, a fatigue check.

4.3.2 Layout and Geometry

To avoid any ambiguity the components of a tripod support structure should be defined. Firstly, the layout is defined as how the support structure is composed. It should be noted that many different tripod layout options can be envisaged. However, if one were to take all conceivable layout options into account this would result in an almost infinite range of possibilities. Therefore just one layout is chosen. This layout is deemed to be representative for the tripod support structures that will eventually be built. Figure 10 shows an offshore wind turbine with this support structure layout. The red box in this figure indicates the part of the support structure that will be subject to parameter variations. This part is depicted in greater detail in Figure 10. Also requiring definition are the following elements:

- *Main joint:* uppermost joint.
- *Bottom joint:* joint at the bottom of the central tubular.
- *Column (I):* central tubular between the main joint and the bottom joint.
- *Column (II):* central tubular from the main joint upward up to the bottom of the tower.
- *Leg (III):* tubular that joins the pile sleeve to the column. Connects at the main joint.
- *Inner brace (V):* tubular that joins the pile sleeve to the column. Connects at the bottom joint.
- *Outer brace (IV):* tubular that joins the pile sleeves. The outer braces lie in a horizontal plane.

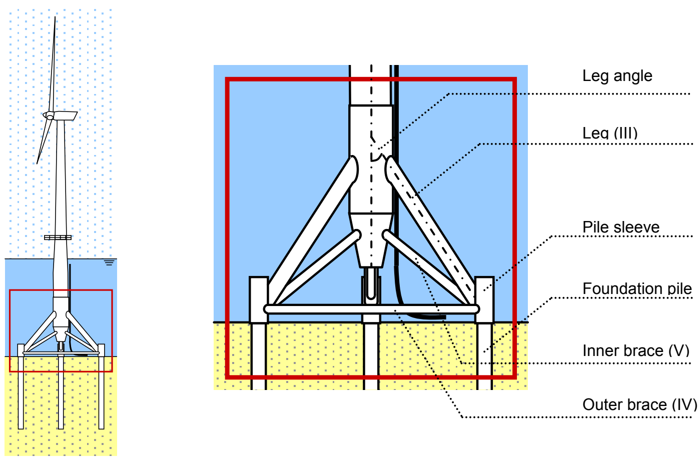


Figure 10: *Tripod support structure components*

A small number of parameters is required to define the layout as shown in Figure 10. these are listed below.

- Height of main joint above the seabed
- Angle between legs and main column
- Angle of inner braces with horizontal plane
- Diameter and wall thickness of main column
- Diameter and wall thickness of legs
- Diameter and wall thickness of braces

It is recommended to initially keep the diameters of the legs and braces at a fixed ratio with respect to the diameter of the main column. The wall thickness should be held at a fixed ratio with respect to the diameter of each member.

4.4 Jacket preliminary design

4.4.1 Design steps

In essence the preliminary design process for a jacket support structure follows the same steps as the tripod preliminary design. Figure 11 shows a diagram representing this preliminary design process.

- Determine the design levels
- Determine the allowable natural frequency
- Determine layout of support structure
- Determine preliminary geometry (diameter, wall thickness)
- Determine extreme loads
- Determine foundation pile geometry
- Determine penetration depth
- Perform buckling check
- Perform fatigue check

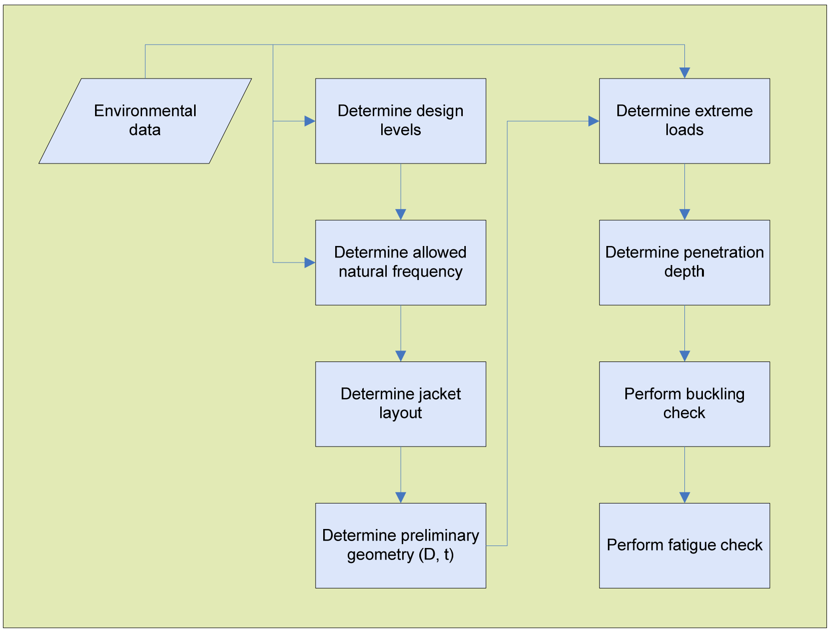


Figure 11: *Jacket preliminary design process*

This process is almost the same as for the tripod design process which is already given in section 5.3 and will therefore not be repeated here. The considerations for obtaining a layout for the support structure are explained in section 4.4.2.

4.4.2 Layout and Geometry

The layout of a truss type structure is defined by a number of parameters

- number of legs
- angle of the legs
- number of panels
- jacket/tower configuration
- brace configuration
- transition truss to turbine tower

The number of legs should preferably four. There is no need for additional legs, but a four-legged structure has an advantage with respect to on-bottom stability during installation compared to a three-legged structure. The angle or ‘batter’ of the legs should also be chosen on the basis of stability considerations. However, the size of the transportation barge may limit the size of the structure base. The number of panels is generally dependent on the water depth. It is preferable to maintain a more or less constant ratio between the width and height of a panel. The choice for a jacket type or a tower type construction is based on the way the forces are to be directed to the foundation. The same consideration underlies the choice for the brace configuration. There are basically three options: diagonal braces, X-braces and K-braces. This can be further extended to include combinations of the aforementioned options. Appurtenances can be easily located due to the open nature of the structure. The various components are indicated in Figure 12.

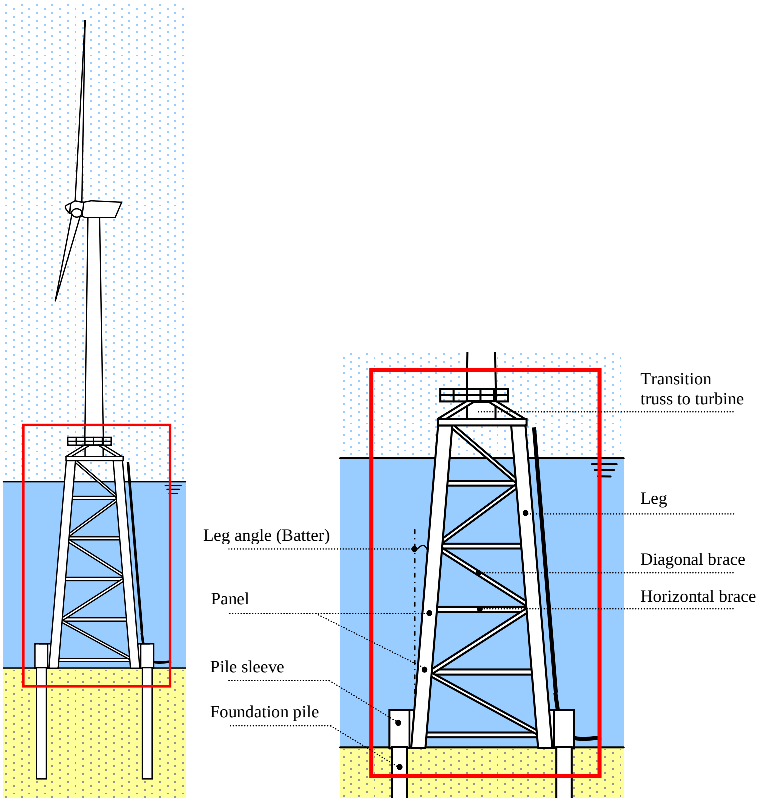


Figure 12: *Jacket support structure components*

4.5 Required data

Before the preliminary design process can be initiated, the design data should be gathered. The required data are:

- Water depth
- Tidal range
- Current velocity
- Soil characteristics
- Wind velocity for extreme loads
- Wave height for extreme loads
- Turbine characteristics
- 3-D scatter diagram containing combinations of wind speed V_w, significant wave height H_s, and zero-crossing wave period T_z

4.6 Design levels

The first step in the preliminary design process is the determination of design levels for the platform and the hub height. The platform level is of importance as it is located at the top of the transition piece and it is the location of the flange connection between the transition piece and the turbine tower. The hub height should be known as the wind loads are calculated at that level. Furthermore, the location of the centre of gravity of the nacelle mass is dependent on the hub height. Therefore this level should be determined at the earliest stage. Figure 13 indicates the various design levels for a monopile support structure.

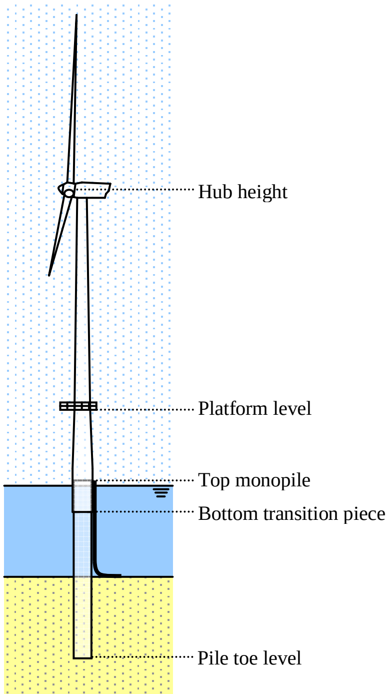


Figure 13: *Design levels for a monopile offshore wind turbine*

The reference level used for the preliminary design of the monopile is Lowest Astronomical Tide (LAT). The top of the monopile is set at LAT + 1m. The reason for this is to facilitate the positioning of the transition piece onto the monopile, which is easier when the top of the pile can seen above the sea surface. Furthermore, when using an external transition piece, which is common practice, the outer diameter of the transition piece is larger than the outer diameter of the monopile. Lengthening the monopile will result in a shorter transition piece. When the wall thicknesses are more or less equal, this in turn will lead to a smaller overall weight of the combined monopile and transition piece. Furthermore a smaller part of the transition piece will be submerged. This will have a beneficial effect on the wave loads as the drag force is proportional to the diameter of the structure and the (generally dominant) inertia force is proportional to the square of the diameter.

The required platform level can be found by adhering to equation 4.1:

$$z_{platform} = LAT + \Delta z_{tide} + \Delta z_{surge} + \Delta z_{air} + \xi^* \quad (4.1)$$

With:

$z_{platform}$ = Platform level
Δz_{tide} = Tidal range
Δz_{surge} = Storm surge
Δz_{air} = Air gap
ξ^* = Highest wave elevation above still water level

The highest wave elevation can be found with equation 4.2:

$$\xi^* = \delta H_D \quad (4.2)$$

In which:

H_D = Design wave height
δ = Wave elevation coefficient

The design wave height is equal to the maximum wave height with a 50-year return period $H_{max,50}$. However, H_D cannot exceed the wave breaking limit H_B, which has been empirically determined at 0.78 times the local water depth. The wave elevation coefficient δ can be found from Table 2 [1]. To determine the design period T_D equation 4.3 is [1].

$$11.1\sqrt{H_{s,50}/g} \leq T_D \leq 14.1\sqrt{H_{s,50}/g} \quad (4.3)$$

In which $H_{s,50}$ is the significant wave height associated with a return period of 50 years.

Table 2: *Wave elevation coefficient δ*

$d/(gT_D^2)$	$H_D/(gT_D^2)$					
	0.02	0.01	0.005	0.001	0.0005	0.0001
≥ 0.20	0.60	0.55	0.50	0.50	0.50	0.50
0.02	-	0.68	0.58	0.52	0.50	0.50
0.002	-	-	-	0.87	0.80	0.68

The hub height can easily be determined using the previously defined platform level as a starting-point. As can be seen in equation 4.4 the hub height is determined by the platform level, a blade clearance and the rotor diameter. The blade clearance $\Delta z_{clearance}$ is the distance between the blade tip in its lowest position and the platform. This distance should be sufficient to allow safe access to the platform for personnel and equipment.

$$z_{hub} = z_{platform} + \Delta z_{clearance} + 0.5 \cdot D_{rotor} \tag{4.4}$$

4.7 Natural frequency

The first natural frequency of the support structure is a very important parameter as it determines the dynamic behaviour of the offshore wind turbine. If the frequency of excitation is near the natural frequency, resonance occurs and the resulting response will be larger than in the quasi-static case. This leads to higher stresses in the support structure and, more importantly to higher stress ranges, an unfavourable situation with respect to the fatigue life of the offshore wind turbine. Therefore it is important to ensure that the excitation frequencies with high energy levels do not coincide with the natural frequency of the support structure. In the case of an offshore wind turbine excitation is due to both wind and waves. For fatigue considerations sea states with a high frequency of occurrence have the largest effect. These are generally relatively short waves with a significant wave height H_s of around 1 m to 1.5 m and a zero-crossing period T_z of around 4 s to 5 s. The wind excitation frequencies that should be avoided are those that coincide with the range of rotational frequencies of the rotor. This will be illustrated for the NREL 5 MW turbine which will be used during subsequent stages of this project. With a minimum rotational speed at the cut-in wind speed of 6.9 rpm and a maximum rotational speed of 12.1 rpm, the rotational frequency interval to stay clear of ranges from 0.117 Hz to 0.202 Hz. This interval is indicated with 1P. Furthermore, the blade-passing frequency interval should also be avoided. This interval, indicated with 3P for a triple bladed turbine is equal to the rotational frequency interval times the number of blades. Taking the above into account, the natural frequency is chosen at 0.29 Hz, as indicated in Figure 14.

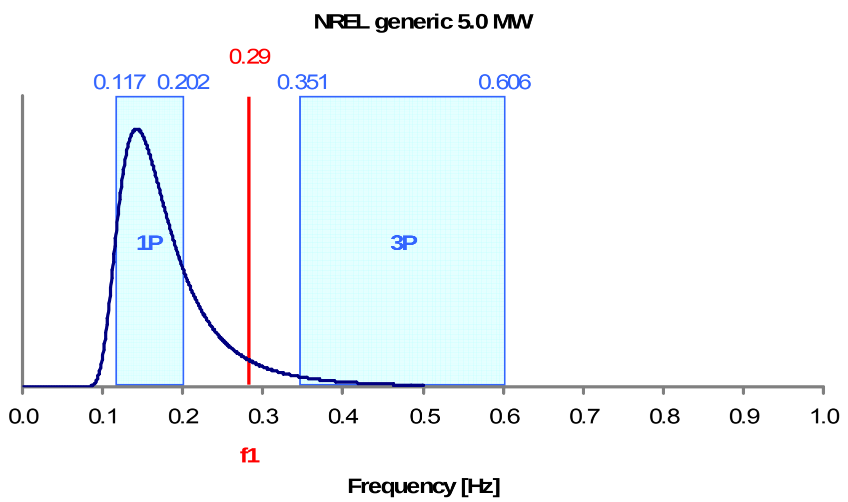


Figure 14: *Diagram showing natural frequency and excitation frequencies*

Using the selected natural frequency of 0.29 Hz as a target, the dimensions of the tubular elements of the support structure are adjusted. In the case of the monopile the diameter of the pile is varied. The diameter of the transition piece subsequently depends on the diameter of the monopile following equation 4.5:

$$D_{TP} = D_{MP} + 2(t_{TP} + t_{grout}) \tag{4.5}$$

Where

D_{TP}	=	Diameter of transition piece
D_{MP}	=	Diameter of monopile
t_{TP}	=	Wall thickness of transition piece
t_{grout}	=	Thickness of grout connection

4.8 Pile penetration depth and foundation stability

The penetration depth must be sufficient to provide both axial and lateral stability. For a monopile support structure, the lateral stability is generally governing. The lateral stability can be checked by applying the extreme loads to the structure and determining the horizontal displacement and the rotation of the pile. The pile-soil interaction is modelled using non-linear soil springs in the form of *p-y* curves. As long as certain criteria are satisfied, the lateral stability is guaranteed. To find an optimum penetration depth, the foundation pile is shortened until the criteria are not satisfied anymore.
The effect of scour needs to be taken into account while modelling the pile-soil interaction. The maximum design scour depth, when no scour protection is applied, is 2.5 D where D is the diameter of the foundation pile [1]. When scour protection is applied, a reduced scour depth can be used.
The axial stability of the foundation is delivered mainly through skin friction between the pile and the soil. Usually the skin friction on the outside of the pile is already sufficient to guarantee stability. Furthermore, the skin friction between the pile and the soil on the inside of the pile adds to the load carrying capacity as does the pile tip resistance.

4.9 Global and local buckling

When the penetration depth has been determined, further design optimisation can be performed on the wall thickness. A the bending moment first increases from the top of the pile toward the seabed due to hydrodynamic loading and then decreases as load is transferred to the soil, the wall thickness can vary along the length of the monopile. The wall thickness should be sufficient to prevent buckling. Two forms of buckling can be identified: global or bar buckling and local or sheet buckling. In the case of global buckling the structure collapses in its entirety, whereas in the case of local buckling the buckling occurs only locally. However, the occurrence of local buckling may initiate global buckling. The most important parameters in the buckling analysis are:

- The buckling length, which is different for local and global buckling,
- The normal force in the structure or element under consideration
- The bending moment in the structure or element under consideration
- A slenderness parameter

The outcome of the buckling check is a usage factor, which indicates to what extent the cross section is utilised with respect to the buckling capacity. This value can be used to optimise the wall thickness. Furthermore, the top of the pile usually requires a large wall thickness for proper transfer of the stress due to pile driving. The pile toe is usually also dimensioned with a larger wall thickness to prevent buckling during pile driving.

4.10 Fatigue

As the support structure is subjected to continuous load variations, the fatigue of the structure needs to be checked. Preferably all load combinations of wind and waves with their directions are incorporated in this check. But as the number of load cases is usually very large, it is desirable to use a reduced number of load cases. This can be achieved by two methods, preferably simultaneously. The first is by assuming that all loads act in the same direction. This approach is conservative as it leads to an accumulation of fatigue damage in a single location on the circumference of the pile. In reality, the fatigue damage is lower as the damage is spread over multiple locations on the circumference [1]. In the second method, all the environmental states in a wind speed bin are grouped. The corresponding H_s and T_z are associated with the state within the wind speed bin with the largest probability of occurrence. The probability of occurrence of the grouped state is the summed probability of all contributing states. Sometimes it may be more realistic to group the environmental states in a wind speed bin into two or more grouped states. Either way, the resulting number of environmental states that serve as input for the fatigue analysis is significantly reduced.
For each of these environmental states a time domain simulation is performed and the bending stresses in the support structure are recorded. Near welds, where there are discontinuities in the structure, the local stress should be multiplied by an appropriate stress concentration factor. Using a stress cycle counting method, the number of cycles in each stress range bin is counted. With this information and using an S-N curve corresponding to the weld detail under consideration the fatigue damage due to environmental loads can be determined. Furthermore, fatigue damage due to start-up and shutdown procedures and fatigue damage due to pile driving should be included in the final fatigue damage.

5. Installation methods

5.1 Introduction

In this chapter current installation methods for offshore wind turbines are described. The most frequently used support structure concept is the monopile. Therefore, the full installation sequence will be discussed for this type. The following sections deal with the installation of tripod and jacket structures. As the installation of the turbine tower and the rotor-nacelle assembly is already discussed in section 5.2, these sections will only deal with the part of the installation procedure that differs from the monopile installation procedure.

5.2 Monopile installation

In general, the installation procedure of a monopile offshore wind turbine follows the steps as listed below. However, it should be noted that in some cases a slightly different approach may be adopted. For instance, it may be decided that scour protection may not be required. It is also possible to install the nacelle with (some) blades attached.

- Foundation pile
- Scour protection
- Transition piece
- Turbine tower
- Nacelle
- Rotor / blades

In the following each of these steps is treated in detail.

5.2.1 Foundation pile

Installation of a foundation pile can be done in one of three ways: by driving, drilling or vibration.

Driving
The most common way is to install the pile by driving. The foundation piles are delivered to the offshore site on a barge, usually several at a time. The pile is lifted off the barge using a crane fitted with a lifting tool. The pile is lowered onto the seabed. The weight of the pile will usually cause the pile to penetrate the soil for a few meters. The pile is gripped with an alignment tool at a certain distance above the sea surface to ensure verticality of the pile during driving.

Figure 15: *Pile driving at Offshore Wind Farm Egmond aan Zee*

The hammer is lifted onto the pile, after which the pile driving can proceed. If required, driving can continue when the hammer is under water. Usually depth markings are applied to the pile before driving so that the penetration depth can be monitored visually. Driving can be done from a jack-up barge or from a stable floating system, although it should be noted that a floating system is very much dependent on favourable sea conditions. Figure 15 shows various stages of the pile driving process at the Egmond aan Zee offshore wind farm.

Drilling
When hard soils are encountered, drilling may be the preferred option. A hole is drilled at the desired location using a drilling tool operated from a jack-up barge. The pile can subsequently be inserted in the thus created hole. Alternatively, the pile is placed on the seabed and the drilling tool is inserted in the pile. The hole is drilled through the pile, while the pile is slowly lowered into the newly excavated space. The pile is aligned vertically using an alignment tool. Subsequently the pile is fixed in place by injecting grout into the space between the pile and the soil. During hardening of the grout the pile must be held in place to maintain the vertical alignment. When a foundation pile is installed by means of drilling the appurtenances can be pre-attached directly to the pile. Also the flange to which the turbine can be connected can be attached. In that case there is no need for a transition piece, reducing the number of offshore operations. Figure 16 shows the drilling equipment used at the Blyth offshore wind farm

Figure 16: *Drilling equipment at Blyth*

Vibration
In some cases it may be required that very little noise is produced during the foundation installation. In such situations installing the foundation pile through vibration is an option. This is a common way of installing sheet piles in urban areas. This technique has not yet been applied for offshore wind turbines.

5.2.2 Scour protection

If a pile is situated in a current, the current is locally increased due to the disturbance in the flow caused by the presence of the pile. In combination with wave action this can cause sand particles to be picked up from the seabed and deposited further downstream. Eventually this can lead to a significant scour hole around the pile. To prevent this scour protection can be applied. An example of a scour protection design is given in Figure 17. This is generally in the form of a filter layer of relatively small stones to keep the sand in place on top of which an armour layer is dumped consisting of larger rocks to keep the filter layer in place. The scour protection is installed with the use of dedicated rock-dumping vessels.
With respect to installation two different approaches can be envisaged: static scour protection and dynamic scour protection.

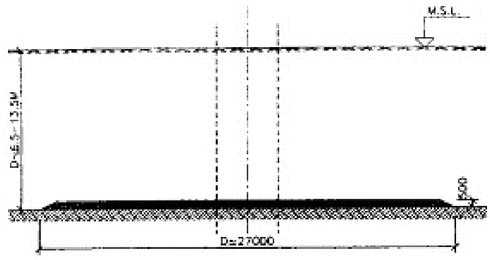


Figure 17: *Example of scour protection design*

Static scour protection
In the case of static scour protection, the filter layer is put in place prior to installation of the foundation pile. The pile is subsequently installed through the filter layer. Once the pile is in place the armour layer is applied. This approach is aimed at preventing the occurrence of a scour hole during the installation process.

Dynamic scour protection
When using dynamic scour protection the foundation pile is installed first. Only after the foundation installation is complete the scour protection is installed. Usually the scour protection is installed in one procedure for the entire wind farm. This implies that the installation of the scour protection is commenced once (almost) all of the piles have been installed. In this case it is likely that a scour hole will develop before the protective rock layers are installed. The scour protection then partially fills the scour hole.

No scour protection
Alternatively, it is possible to install an offshore wind farm without any scour protection. In this case the development of a large scour hole is taken into account in the design.

5.2.3 Transition piece

The transition piece sits on top of the foundation pile. Its main functions are to provide a flange for the connection of the turbine tower to the foundation, to correct any misalignment of the foundation and to hold the appurtenances, such as the boat landing, J-tube, ladder and anodes. A platform is located on top of the transition piece. The transition piece can be connected to the foundation in the following three ways: using grout, a flange or a slip joint. Transition pieces can be transported to the offshore location by barge along with the foundation piles. Alternatively, they can be carried by the installation vessel. Figure 18 shows the installation of a transition piece.

Figure 18: *Transition piece installation*

Grouted connection
This is the most common way to make the connection between the foundation and the super structure. The transition piece is lifted from the barge and is slid over the top of the foundation pile. Spacers ensure that the required space remains between the pile and the transition piece. Hydraulic jacks are used to align the transition piece vertically. Grout seals close off the annulus between pile and transition piece, after which the annulus is filled with grout. After the grout has hardened sufficiently the seals and jacks are removed.

Flange
The transition piece can also be connected to the foundation pile by means of flanges. The transition piece is lifted into place. Once the flanges are correctly aligned, bolts are used to connect the flanges. This procedure has the advantage that it can be performed quickly. However, great care must be taken to ensure that the flange is not damaged during pile driving.

Slip joint
A novel way of connecting two tubulars is by means of a slip joint. Both the top of the foundation pile and the bottom of the transition piece have a conical section of which the sides make a small angle with the vertical. The transition piece is lifted onto the foundation pile. Before the transition piece is slid into place, it must be ensured that it is exactly vertical. Once this is achieved the connection can be made by simply lowering the transition piece onto the foundation pile. The friction between the conical sections of the foundation pile and the transition piece due to the weight of the transition piece is sufficient to form a reliable connection. The advantage of this connection type is that it is simple to fabricate and allows for rapid installation. However, so far it has not been put to use for offshore wind turbines. Figure 19 shows a slip joint for an onshore turbine.

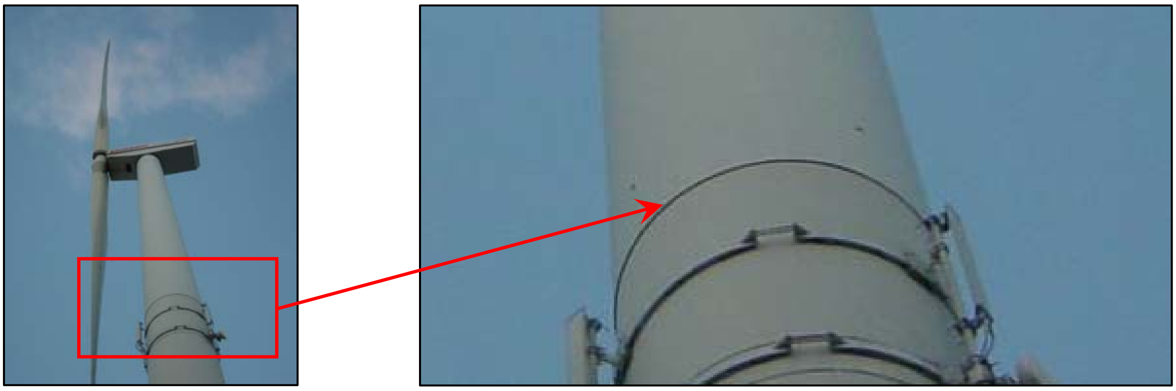


Figure 19: *Slip joint on an onshore turbine*

5.2.4 Turbine tower

The turbine tower is usually installed in two or three sections which are bolted together. Figure 20 shows such a tower section being lifted for installation. The connection between the transition piece and the turbine tower is also made by bolting two flanges together.

Figure 20: *Lifting of a tower section for installation*

5.2.5 Rotor – nacelle assembly

The rotor-nacelle assembly can be installed either separately or using the Bunny – Ear method. It should be noted that each turbine installation contractor has its preferred method.

Separate
The nacelle is lifted onto the top of the turbine tower. The flange beneath the yaw bearing of the turbine is bolted to the flange at the tower top when the nacelle is in place, the hub and the blades can be installed. These can be installed in one piece – the rotor assembly as shown in Figure 21, or separately. The blades are lifted in a frame that allows for easy manoeuvring. With the blade in a vertical position and with the blade root pointing upwards, the blade is carefully positioned in line with its connection point on the hub. The connection is achieved by bolting the blade to a flange in the hub. This procedure is repeated until all blades are connected.

Figure 21: *Installation of a rotor in one piece*

Bunny – Ear method
In case of a triple bladed turbine two blades can already be attached onshore. These blades protrude upwards at an angle giving the rotor-nacelle assembly an appearance which has led to the method's distinct name. The advantage is that the rotor-nacelle assembly can be lifted into place with two blades already attached. Only one blade needs to be installed offshore, saving a lot of valuable offshore installation time.

Figure 22: *Various stages in the installation of a turbine using the bunny-ear method*

5.3 Tripod installation

The tripod support structure is installed in a very different way compared to the monopile support structure. The installation sequence for the main components is listed below.

- Lifting and landing of tripod structure
- Foundation piles
- Turbine tower
- Nacelle
- Rotor / blades

The tripod support structure is pre-assembled in an onshore construction yard. The entire structure is placed on a barge and towed out to the offshore location. There, it is lifted off the barge with a large crane. With the help of a smaller crane it is oriented in the right direction. The support structure is slowly lowered onto the seabed, ensuring that the structure is entirely level. Mud mats at the three corners of the tripod ensure that the structure settles onto the seabed in a stable manner, while providing support until the foundation piles are in place. The three foundation piles are each driven through pile sleeves at the three corners at the bottom of the structure using a submersible hammer. When the piles are at the required depth, a connection between the top of the pile and the pile sleeve is made by filling the annulus with grout. The connection can also be achieved by means of a swaged connection.
Scour protection is generally not required as the foundation piles of a tripod support structure are loaded mainly in the axial direction. Therefore the effect of scour is relatively insignificant when compared to the monopile support structure, No separate transition piece is required, as the requirements for pile driving do not apply to the tripod and the appurtenances can be connected directly to the tripod support structure.
The turbine tower and the rotor - nacelle assembly are installed in the same manner as described in sections 5.2.4 and 5.2.5.

5.4 Jacket installation

The installation procedure for a jacket is very similar to the procedure for the tripod support structure. For the sake of completeness the sequence of installation is listed here again.

- Lifting and landing of tripod structure
- Foundation piles
- Turbine tower
- Nacelle
- Rotor / blades

Despite the similarities with the installation of a tripod structure, in some cases there is a significant difference regarding the installation of the foundation piles. In the oil and gas industry there are two ways of establishing the connection between piles and support structure. The piles can be driven through pile sleeves at the bottom of the structure a so-called ‘tower’ structure or the piles can be driven through the legs of the structure. In this case the connection is made at the top of the structure. Such a structure is called a ‘jacket’ structure. Although there is a difference in the way forces are directed to the foundation, in practice often no distinction is made between these two terms.
Usually the legs are inclined for a jacket structure. With respect to the installation procedure the difference lies in the fact that the piles are to be driven at an angle to the vertical in the case of a ‘jacket’ structure while they may be driven vertically for a ‘tower‘ structure.

Example: Beatrice demonstrator project
To date only one project using a jacket type support structure has been undertaken: the Beatrice Demonstrator Project. This project involved two 5 MW turbines situated in 45 m water depth. The electrical cables link the turbines to the nearby Beatrice oil field production platform. The turbines were installed as shown in Figure 23. The jacket support structure was transported to the offshore location on a barge. There, a heavy lifting vessel equipped with two cranes lifted the structure off the barge and tilted it until it was in an upright position. Subsequently, the support structure was lowered onto the seabed and levelled, after which the piles were driven. The second part of the installation procedure involved installing the entire wind turbine, including the turbine tower, in one lift. The turbine was pre-assembled onshore on top of a soft landing system and lifted off the quayside using a specially designed lifting frame. At the offshore location the turbine was mated with the support structure, where the soft landing system compensated the motion of the turbine assembly during the set down phase. Finally, the lifting frame and the soft landing system were removed to complete the installation procedure.

Figure 23: *Various stages of the installation at the Beatrice demonstrator project*

6. Design Considerations

6.1 Site Data

In the next phase for work package 4.2, preliminary designs will be made for several bottom-mounted support structure types. In order to get realistic results from the assessment of the preliminary design, realistic input data is required. In preparation for this next phase a location in the North Sea has been selected for which the environmental data has been obtained. This location coincides with the location of the Mangrove project, an earlier study project on deep water support structures in which Delft University of Technology participated. For this location three actual soil profiles are available. The approximate location for which the soil data was determined is indicated in figure 6. The water depth at this location is in the range of 35 to 40 m. Wind and wave data have been derived from the NEXTRA database. Access to this database was provided by Shell. The location for which the wave data is valid is 53°46'43" N and 3°56'28" E. These hindcast data cover the period October 1964 to September 1998. The wind measurements were taken at 53 º13'05" N 03º13'12" E, covering the period January 1979 to December 2001. Figure 24 shows the selected location. The respective locations of wind, wave and soil data are given in Figure 25.

Figure 24: *Selected location for environmental data collection*

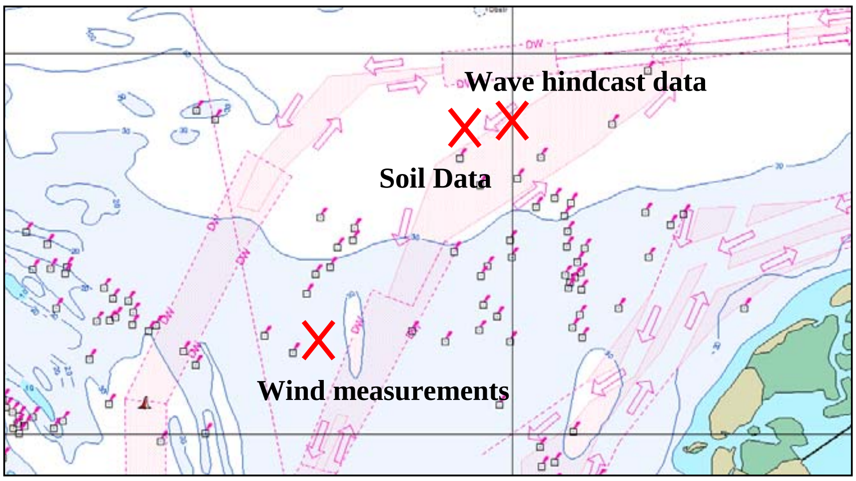


Figure 25: *Locations of origin of wind, wave and soil data*

In section 6.2 a summary of the environmental parameters is given. The local water depth is mentioned in section 6.3, whereas section 6.4 briefly describes the soil data. Tidal range and storm surge and current velocity are discussed briefly in sections 6.5 and 6.6 respectively. The determination of the extreme wave height and the directionality is treated in section 6.7, whereas section 6.8 deals with the determination of the extreme wind speed and the directionality of the wind in the same manner. The processing of raw wind and wave data to obtain 3-D scatter diagrams is explained in section 6.9. Finally, a list of critical turbine parameters is given in section 6.10.

6.2 Data description

The main parameters for the description of the soil characteristics are as follows:

- Submerged unit weight of soil γ'
- Angle of internal friction (sand) φ
- Undrained shear strength (clay) c_u

The wave data is described in terms of the following parameters:

- Dominant wave direction $\theta_{wave;dom}$
- Significant wave height H_s
- Direction spreading factor f_θ
- Zero-crossing period T_z
- Peak period T_p
- Full wave direction $\theta_{wave;full}$

The wind data is given in terms of

- Wind speed V_w
- Wind direction θ_{wind}

For both the wind and wave data there are 8 entries per 24 hours. Each entry corresponds to a 3 hour period, which is generally the maximum period for which a sea state can be assumed to be stationary. The wind measurements are taken every 3 hours after 01:00, whereas the entries for the wave data are given every 3 hours after 00:00. This leaves sufficient overlap to allow correlation of wind and wave data with respect to time. Although there is a significant spatial difference between the locations of origin of the wind and wave data – approximately 80 km - both locations are far out at sea, where conditions may be assumed to be identical.

To give a full description of environmental conditions, wind and wave data are to be combined. As the wind and wave data do not cover the same period, some of the data must be discarded. Moreover, the wave data for certain years cover only the winter months. The wind and wave data corresponding to these years is discarded as well. This leaves 10 full years of environmental data, covering 1979 and the period 1989 to 1997. Within this time span there are two periods for which no T_z is available. The wind and wave data corresponding to these periods – 07-06-1996 12:00 to 08-06-1996 09:00 and 03-05-1995 12:00 to 06-05-1995 06:00 – is also discarded. This leaves 29 184 data points which can be used for further processing.

6.3 Water depth

The water depth at the location mentioned in section 6.3 is 41m [1]. However, as the one of he main parameters in the research of work package 4.2 is the water depth and the effects of water depth variations on the suitability of various support structure concepts, a number of selected water depths will be used instead. As a starting point a water depth of 25m will be used. This depth is the upper limit for current monopile offshore wind turbines. Water depths of 35 and 45m will also be studied.

6.4 Soil Conditions

The soil conditions for the study area have been obtained from the Mangrove project. In this project, soil data was provided by Fugro, a leading company in the field of geotechnical data collection. Data is available for three locations, ranging from a relatively hard profile to a relatively soft profile. The hard soil profile consists entirely of sand layers. The soft soil profile contains several significant layers of clay. An intermediate soil profile is also available. This profile contains a few thin layers of clay. The soil profiles can be viewed in Appendix B along with the most important soil parameters.

6.5 Tidal range and storm surge

Tidal Range
The tidal range has been obtained for a location at 53º37’00”N, 4º12’00”E [1]. This is approximately 30km from the location stated in section 6.1. However, as the circumstances at this location are similar to the selected location, the tidal range found for this location can be assumed to apply to the proposed location as well. The tidal range is 1.6m.

Storm Surge
Based on experience that Delft University of Technology has gained during previous studies in the field of offshore engineering for locations on the North Sea a storm surge value of 2.0 m may be adopted for the given location.

6.6 Current velocity

From analysis of data provid
ed by Shell it was found that the maximum current velocity is 0.82 m/s. The data was obtained for a location at 53º37’14”N, 3º96’48”E. The data was gathered over a period ranging from October 1964 to May 1995.

6.7 Extreme wave height

From the wave data the extreme wave height can also be determined. The extreme wave height is determined as the maximum wave height that occurs with a certain return period. To obtain the extreme wave height, the significant wave heights are taken from the original (unbinned) data series. These values are put in ascending order and the number of occurrences for each value is noted. A cumulative frequency of occurrence is assigned to each value. This means that the highest has a frequency of occurrence of 1, the subsequent value has an occurrence of 2 – assuming this value occurs only once in the period under scrutiny and the lowest value has a frequency of occurrence of 29 184. This is because an elevation that is exceeded by a certain wave is also exceeded by all higher waves. The frequency of occurrence is expressed as a return period. Each occurrence in a 10 year period thus corresponds to a return period of $10/29184 = 3.4 \cdot 10^{-4}$. All values above a certain threshold value are subsequently plotted. For the threshold value H_s = 3.0 m is chosen. A curve is fitted to the data yielding the following expression for the maximum significant wave height as a function of the return period:

$$H_s\left(T_{return}\right) = 0.8162\ln\left[T_{return}\right] + 7.7166$$

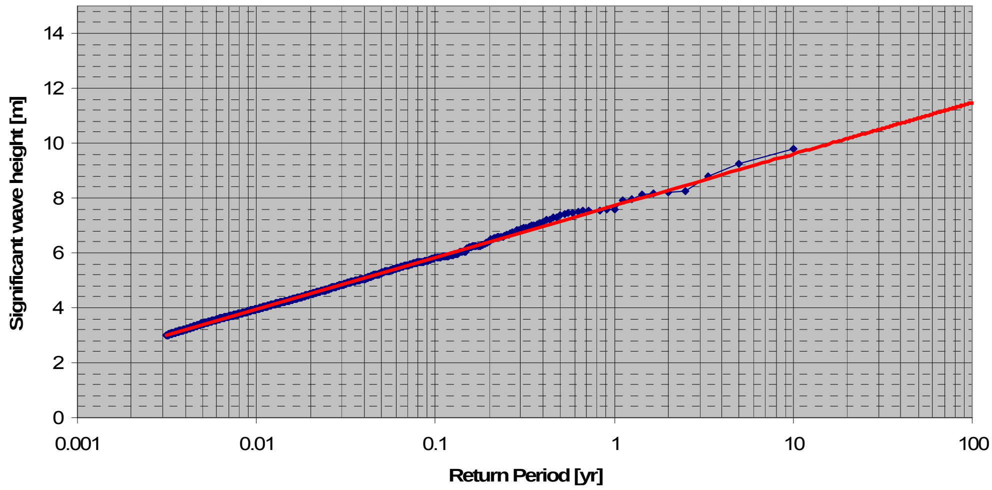


Figure 26: *Determining the maximum significant wave height*

Figure 26 shows the plotted data points along with the fitted curve. From the relationship obtained from the curve fit, values for the maximum significant wave height can be found. These values are given in Table 3. The values in the central column are significant wave heights. To obtain the maximum wave height the following relationship is used:

$$H_{\max} = 1.86 H_s$$

Table 3: *Extreme wave heights as a function of return period.*

T_{return} [yr]	H_s [m]	H_{max} [m]
1	7.72	14.35
5	9.03	16.80
10	9.60	17.85
50	10.91	20.29
100	11.48	21.34

The design wave height H_D is equal to the maximum wave height with a return period of 50 years, $H_{max,50}$. Thus the design wave height is 20.29m.

Wave roses

The 3-D scatter diagram does not take directionality into account. Therefore a different diagram is produced giving the spreading of wave directions per wave height bin. First, $\theta_{wave;full}$ is gathered in bins of 30°. Subsequently, H_s and $\theta_{wave;full}$ are sorted to obtain the number of occurrences of each wave direction per wave height bin. Figure 7 shows a wave rose for wave heights ranging from 0.0 m to 3.0 m. In this figure 0° corresponds with north. It can be seen that the dominant wave directions are south west (SW) and north to northwest (NNW). The probability of occurrence as a percentage is given on the radial axes. The full series of wave roses is given in Appendix D. A wave rose is shown in Figure 27 for various wave heights.

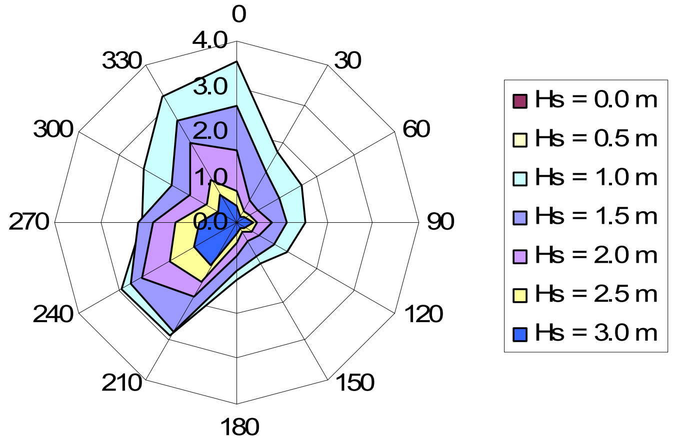


Figure 27: *Wave rose for various wave heights, directions are "coming from"*

6.8 Extreme wind speed

For determining the extreme wind speed the same approach as for the extreme wave height is employed, though it should be noted that the starting point is the unbinned wind data translated to the hub height. The threshold value that is applied is V_w = 20 m/s. The curve fit yields the following expression for the wind speed at hub height as a function of the return period:

$$V_{\max;3hr}\left(T_{return}\right) = 2.5728\ln\left(T_{return}\right) + 33.851$$

Figure 28 shows the plotted data along with the fitted curve:

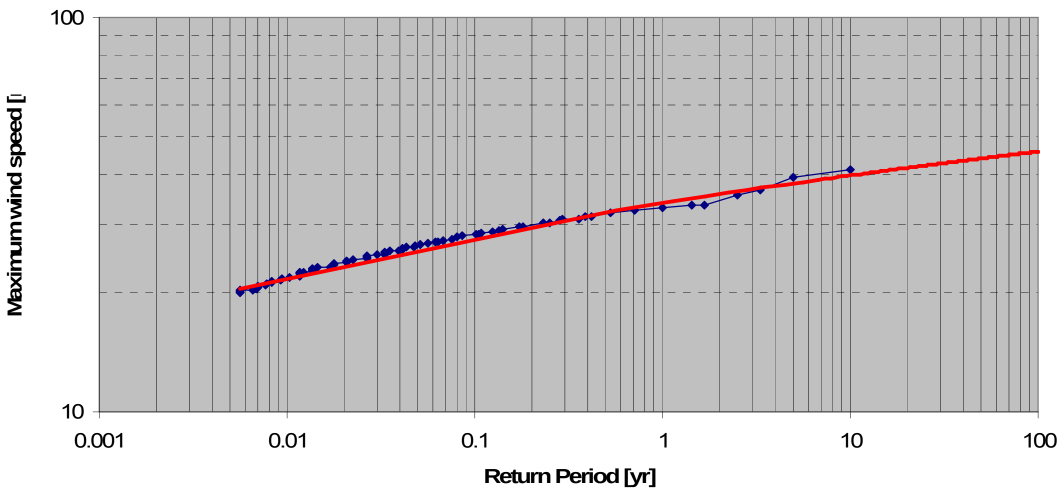


Figure 28: *Determining the maximum wind speed*

Table 4 shows the maximum wind speed at hub height as a function of the return period. The values in correspond to a 3-hour stationary situation.

Table 4: *Extreme wind speeds as a function of the return period.*

T_{return} [yr]	V_w [m/s]
1	33.85
5	37.99
10	39.78
50	43.92
100	45.70

Wind roses
The wind directionality can be treated in the same way as the directionality for the wave data. The wind roses are determined using V_w and θ_{wind}. θ_{wind} is gathered in bins of 30°. V_w and θ_{wind} are sorted to obtain the number of occurrences of each wave direction per wind speed bin. Figure 29 gives a wave rose for various wind speeds. The full range of wind roses is given in Appendix E. A wind rose is shown in Figure 29 for various wind speeds.

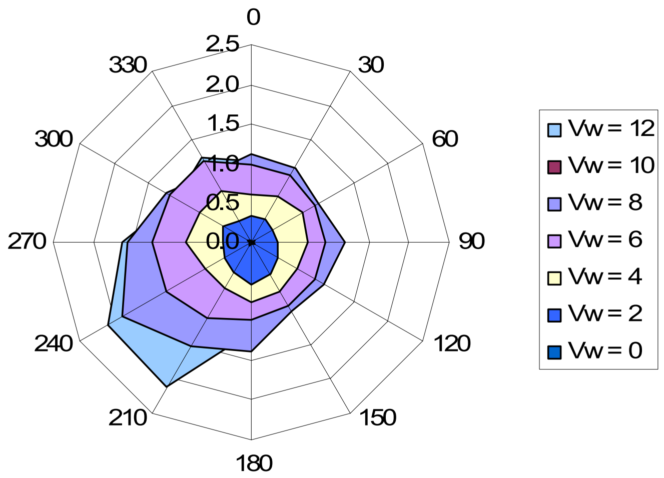


Figure 29: *Wind rose for various wind speeds, directions are "coming from"*

6.9 3-D scatter diagram

In the offshore industry wave climate data is generally expressed in a 2-dimensional scatter diagram giving the number of occurrences of each combination of H_s and T_z. For offshore wind turbine design the 2-D scatter diagram must be expanded to include V_w as a third dimension. To derive the 3-D scatter diagram, the parameters H_s and T_z and V_w will be used. First, the wind data is translated from the reference height of 10 m to the hub height. A hub height of 100 m above MSL is assumed. According to GL the wind speed at hub height can be found with

$$V_{hub} = \frac{V(z)}{\left(\frac{z}{z_{hub}}\right)^{\alpha}}$$

With:

V_{hub} = wind speed at hub height
$V(z)$ = wind speed at elevation z
z = elevation for which wind speed is given
z_{hub} = hub height
α = wind shear exponent (α = 0.14 for roughness length of 0.002 m)

The wind and wave data is subsequently gathered in bins. The V_w bins cover 2 m/s, the H_s bins cover 0.5 m and the T_z bins span 1.0 s. The binning of the V_w data is done in such a way that the wind speed bin corresponding to for example V_w = 2 m/s contains all wind speed observations ranging from 1 m/s to 3 m/s. The bin H_s = 2 m contains all wave height observations between 1.75 m and 2.25 m, while the bin T_z = 2 s includes all wave period observations from 1.5 s to 2.5 s. Subsequently, the occurrence of all combinations of V_w, H_s and T_z is counted. The data is gathered per wind speed bin and entered in a scatter diagram giving the frequency of occurrences of each combination of H_s and T_z for that wind speed bin as a percentage. This is illustrated in figure 2.1 for V_w =10 m/s.

Vw = 10		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9												0
	8.5												0
	8												0
	7.5												0
	7												0
	6.5												0
	6												0
	5.5												0
Hs	5												0
	4.5												0
	4								0.0034				0.0034
	3.5							0.0411	0.0034				0.0445
	3						0.0240	0.1302					0.1542
	2.5						0.5209	0.1576	0.0069				0.6853
	2					0.0034	2.1554	0.0617					2.2205
	1.5					1.8196	2.0046	0.0171					3.8413
	1				0.0343	3.7556	0.3392						4.1291
	0.5				0.4352	0.8738	0.0137						1.3227
	0				0.0171	0.0343							0.0514
		0	0	0	0.4866	6.4867	5.0577	0.4078	0.0137	0	0	0	12.4525

Figure 30: *Part of a 3-D scatter diagram for V_w = 10 m/s*

A diagram as shown in Figure 30 is produced for each wind speed bin. The full set of scatter diagrams make up the 3-D scatter diagram. This is given in Appendix F.

6.10 Critical turbine parameters

Table 5 contains a draft list for the integrated design procedure. It presents the interface requirements between turbine and support structure for overall design optimization. This list will be reviewed during the further detailing of the preliminary designs of the different support structure types analyzed in WP4.2. The list serves as input to WP 1A.1 integral design approach and standards.

Table 5: *Draft list of turbine parameters*

Parameter	Unit	Description
N_{blades}	[ ]	Number of blades
h_{hub}	MSL + [m]	Design (initial) hub height
D_{rotor}	[m]	Rotor diameter
P_{rated}	[W]	Rated power
P-V curve	[W/(m/s)]	Power curve
RPM range	[rpm]	Rotation speed range
Ω-V curve	[(rad/s)/(m/s)]	Rotation speed per wind speed curve
M_{top}	[kg]	Top mass (rotor, hub, nacelle)
c.o.g. of M_{top}	[m, m, m]	Top mass co-ordinates
I_{top}	[m^4]	Top mass moments of inertia
D_{tower} (h_{tower})	[m] function of h_{tower}	Tower geometry diameters
t_{tower} (h_{tower})	[m] function of h_{tower}	Tower geometry wall thickness
Additional tower masses	[kg] function of h_{tower}	Additional tower masses
$F_{tower\ top,\ operational}$	[N]	Maximum operational turbine load
$F_{tower\ top,\ extreme}$	[N]	Maximum extreme turbine load
$F_{tower\ top,\ torsion}$	[N]	Maximum torsion turbine load
$F_{tower\ top,\ shut\text{-}down}$	[N]	Maximum shut-down turbine load
β/V_w	[%/(m/s)]	Aero damping per wind speed
$F_{tower\ top}/V_w$	[N/(m/s)]	Tower top load per wind speed transfer function

It is understood that especially the loads requested in this draft list will be subject to change as the structure is optimized further. They will form a critical starting point for a very representative preliminary design.

The turbine that will be used for design and assessment purposes performed in work package WP 4.2 will be the NREL generic 5.0 MW turbine. The parameters of relevance to the preliminary design are listed in Table 6. Many additional parameters are required to determine the turbine behaviour. These are not listed here as they are implemented in the Bladed model of the NREL turbine [1].

Table 6: *Turbine parameters for the NREL 5.0MW.*

Turbine parameter	*Value*	*Unit*
Rated power	5.0	MW
Rotor diameter	126	m
Mass of rotor and nacelle	350	ton
Cut-in wind speed	3	m/s
Rated wind speed	11.4	m/s
Cut-out wind speed	25	m/s
Nominal rotor speed	12.1	rpm
Lower bound rotor speed	6.9	rpm
Upper bound rotor speed	12.1	rpm

7. Contemplations and Outlook

7.1 Contemplations

In this report a number of support structures are proposed for consideration. An analysis was done on the basis of an evaluation matrix for these support structure types. While this analysis proved to be valuable in gaining familiarity with the advantages and disadvantages of the various support structures types, it does not serve as a basis for disregarding certain support structure types for further study. In the next phase a different evaluation matrix may be set up on the experiences of the one presented in this report with exactly that aim.
This report also gave a review of different installation methods for various existing bottom founded support structure types. Finally, environmental data requirements have been described and site specific data has been generated for use in the next phase of this project.

7.2 Outlook for the next phase

The next phase of this project will focus on the design of bottom founded support structure types for various water depths. In the first stage a preliminary design will be made for these support structure types. The results of these designs in terms of material required, reliability and cost will form a basis for selection of a reduced number of concepts that will be studied in greater detail. In a later stage the soft-stiff bottom-mounted support structures of the monopile and braced/truss types will be investigated in detail. The entire design process will be reported in detail and an assessment will be made of these concepts on the basis of this detailed analysis.

References

[1] **DNV** (2004) *Design of offshore wind turbine structures* Det Norske Veritas, DNV-OS-J101

[2] **Germanischer Lloyd** (2004) *Rules and Guidelines for the Design of Offshore Wind turbines*, Hamburg, Germany

[3] **van der Tempel, J** (2006) *Design of support structures for offshore wind turbines* Delft University wind energy research institute

[4] **C-Map Norway** (1997) *C-Map world for windows*

[5] **Jonkman, J** (2006) *NREL Offshore Baseline 5 MW Manuscript* NREL/NWTC

Appendix A: Description of Assessment Parameters

Site	Description	How to Score
Varying soil conditions	How well can a concept cope with varying soil properties for different parts of a wind farm?	Very well / almost no effort = 10 Very badly / very much effort =1
Poor soil conditions / scour	How well can a concept cope if for instance the top 20 m of soil is of very poor quality or if a (deep) scour hole develops?	Very well = 10 Very badly = 1
Bedrock	How suitable is a concept if shallow bedrock is encountered? (For instance: bedrock underneath a thin layer of sand)	Very suitable / almost no effort = 10 Unsuitable / very much effort =1
Ice	How much effort is required to make a concept suitable for ice-infested waters?	Very well / almost no effort = 10 Very badly / very much effort =1

Design	Description	How to Score
Mass	What magnitude is the mass expected to be compared to other concepts?	Very small = 10 Very large = 1
Tower head motion	Will the expected tower motion for a concept affect the design and operation adversely and if so how much?	Not at all = 10 Beyond practical limits = 1
Turbine mass	How much effort and/or additional material is required to accommodate a heavier turbine?	Very little = 10 Very much = 1

Fabrication	Description	How to Score
Number of welds	How much time is required to fabricate the welds of the support structure components?	Very little time =10 A lot of time = 1
Complexity of the joints	How complex is a joint? Can the joint be welded automatically? Are the weld locations easily accessible?	Very simple / Yes / Yes = 10 Very Complex / No / No = 1

Installation	Description	How to Score
Transportation inshore	How much effort is required to transport the components from the fabrication yard to the port?	Very little = 10 Very much = 1
Transportation offshore	How much effort is required to transport the components from the port to the offshore location?	Very little = 10 Very much = 1
Lifting	How much time and effort is required to lift the components in place?	Very little = 10 Very much = 1
Foundation	How much time and effort is required to install the foundation and how difficult is it to acquire the equipment needed for installation of the foundation?	Very little / Very easy = 10 Very much / Very difficult = 1
Connections:	How many connections are to be made offshore and how much effort will be required to make the connections?	None / very little = 10 Many / very much = 1
Cable Installation	How much time and effort is required to hook up the infield electrical cable(s) to the turbine?	Very little = 10 Very much = 1

Maintenance	Description	How to Score
Scour	How much effort is required to keep scour within originally intended range?	Very little = 10 Very much = 1
Corrosion	How much effort is required to keep corrosion within originally intended range?	Very little = 10 Very much = 1
Access	How easily can a concept be accessed in moderate environmental conditions?	Very easy = 10 Very difficult = 1

Appendix B: Support Structure Evaluation Matrices

Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar	Weight
Site										
Varying soil conditions	6	8	8	5	3	6	6	6	6	8
Poor soil conditions	4	8	8	4	1	4	4	4	4	7
Bedrock	7	7	7	8	1	7	7	7	7	5
Ice	7	5	6	8	5	2	5	4	5	4
										24
Design										
Mass	4	6	8	7	7	6	7	6	6	10
Tower head motion	7	8	8	8	7	5	4	5	4	7
Turbine mass	7	7	7	7	7	6	6	6	6	8
										25
Fabrication										
Number of welds	7	6	5	7	7	7	6	6	6	6
Complexity of the joints	8	4	4	8	5	8	7	7	7	8
										14
Installation										
Transportation inshore	9	4	2	4	9	9	3	3	3	1
Transportation offshore	8	4	3	4	8	8	9	7	9	6
Lifting	6	4	2	3	6	6	4	4	4	7
Foundation	7	8	8	6	9	7	7	7	7	9
Connections	7	7	7	7	7	7	4	3	4	9
Cable Installation	7	7	7	7	7	7	4	4	4	6
										38
Maintenance										
Scour (protection)	4	7	7	4	3	4	8	6	8	4
Corrosion (protection)	6	5	5	8	6	6	6	6	6	5
Access	6	5	7	8	6	6	5	6	5	7
										16
Decommissioning										
Disconnecting	7	7	7	7	7	7	8	8	8	4
Removal of foundation	5	6	6	9	8	5	9	9	9	5
Environmental impact of remains	5	6	6	9	8	5	7	7	7	3
										12
Overall										
Reliability (proven technology)	9	6	7	9	3	2	2	2	2	6
										6

Weighted Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar
Site									
Varying soil conditions	48	64	64	40	24	48	48	48	48
Poor soil conditions	28	56	56	28	7	28	28	28	28
Bedrock	35	35	35	40	5	35	35	35	35
Ice	28	20	24	32	20	8	20	16	20
	0.5792	0.7292	0.7458	0.5833	0.2333	0.4958	0.5458	0.5292	0.5458
Design									
Mass	40	60	80	70	70	60	70	60	60
Tower head motion	49	56	56	56	49	35	28	35	28
Turbine mass	56	56	56	56	56	48	48	48	48
	0.58	0.688	0.768	0.728	0.7	0.572	0.584	0.572	0.544
Fabrication									
Number of welds	42	36	30	42	42	42	36	36	36
Complexity of the joints	64	32	32	64	40	64	56	56	56
	0.7571	0.4857	0.4429	0.7571	0.5857	0.7571	0.6571	0.6571	0.6571
Installation									
Transportation inshore	9	4	2	4	9	9	3	3	3
Transportation offshore	48	24	18	24	48	48	54	42	54
Lifting	42	28	14	21	42	42	28	28	28
Foundation	63	72	72	54	81	63	63	63	63
Connections	63	63	63	63	63	63	36	27	36
Cable Installation	42	42	42	42	42	42	24	24	24
	0.7026	0.6132	0.5553	0.5474	0.75	0.7026	0.5474	0.4921	0.5474
Maintenance									
Scour (protection)	16	28	28	16	12	16	32	24	32
Corrosion (protection)	30	25	25	40	30	30	30	30	30
Access	42	35	49	56	42	42	35	42	35
	0.55	0.55	0.6375	0.7	0.525	0.55	0.6063	0.6	0.6063
Decommissioning									
Disconnecting	28	28	28	28	28	28	32	32	32
Removal of foundation	25	30	30	45	40	25	45	45	45
Environmental impact of remains	15	18	18	27	24	15	21	21	21
	0.5667	0.6333	0.6333	0.8333	0.7667	0.5667	0.8167	0.8167	0.8167
Overall									
Reliability (proven technology)	54	36	42	54	18	12	12	12	12
	0.9	0.6	0.7	0.9	0.3	0.2	0.2	0.2	0.2
Total	867	848	864	902	792	803	784	755	774
Total	4.6356	4.2994	4.4828	5.0492	3.8607	3.8443	3.9573	3.8671	3.9173

Figure 31: *Support structure evaluation matrix for 30 m water depth by Jan van der Tempel*

Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar	Weight
Site										
Varying soil conditions	4	8	8	5	3	6	6	6	6	8
Poor soil conditions	2	8	8	4	1	4	4	4	4	7
Bedrock	5	7	7	8	1	7	7	7	7	5
Ice	5	5	6	8	5	2	5	4	5	4
										24
Design										
Mass	4	6	8	6	7	6	7	6	6	10
Tower head motion	7	8	8	8	7	5	4	5	4	7
Turbine mass	7	7	7	7	7	6	6	6	6	8
										25
Fabrication										
Number of welds	7	6	5	7	7	7	6	6	6	6
Complexity of the joints	8	4	4	8	5	8	7	7	7	8
										14
Installation										
Transportation inshore	8	4	2	4	9	9	3	3	3	1
Transportation offshore	7	4	3	4	8	8	9	7	9	6
Lifting	5	4	2	3	6	6	4	4	4	7
Foundation	6	8	8	6	9	7	7	7	7	9
Connections	6	7	7	7	7	7	4	3	4	9
Cable Installation	6	7	7	7	7	7	4	4	4	6
										38
Maintenance										
Scour (protection)	4	7	7	4	3	4	8	6	8	4
Corrosion (protection)	6	5	5	8	6	6	6	6	6	5
Access	6	5	7	8	6	6	5	6	5	7
										16
Decommissioning										
Disconnecting	7	7	7	7	7	7	8	8	8	4
Removal of foundation	5	6	6	9	8	5	9	9	9	5
Environmental impact of remains	5	6	6	9	8	5	7	7	7	3
										12
Overall										
Reliability (proven technology)	5	5	8	5	1	2	4	4	4	6
										6

Weighted Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar
Site									
Varying soil conditions	32	64	64	40	24	48	48	48	48
Poor soil conditions	14	56	56	28	7	28	28	28	28
Bedrock	25	35	35	40	5	35	35	35	35
Ice	20	20	24	32	20	8	20	16	20
	0.3792	0.7292	0.7458	0.5833	0.2333	0.4958	0.5458	0.5292	0.5458
Design									
Mass	40	60	80	60	70	60	70	60	60
Tower head motion	49	56	56	56	49	35	28	35	28
Turbine mass	56	56	56	56	56	48	48	48	48
	0.58	0.688	0.768	0.688	0.7	0.572	0.584	0.572	0.544
Fabrication									
Number of welds	42	36	30	42	42	42	36	36	36
Complexity of the joints	64	32	32	64	40	64	56	56	56
	0.7571	0.4857	0.4429	0.7571	0.5857	0.7571	0.6571	0.6571	0.6571
Installation									
Transportation inshore	8	4	2	4	9	9	3	3	3
Transportation offshore	42	24	18	24	48	48	54	42	54
Lifting	35	28	14	21	42	42	28	28	28
Foundation	54	72	72	54	81	63	63	63	63
Connections	54	63	63	63	63	63	36	27	36
Cable Installation	36	42	42	42	42	42	24	24	24
	0.6026	0.6132	0.5553	0.5474	0.75	0.7026	0.5474	0.4921	0.5474
Maintenance									
Scour (protection)	16	28	28	16	12	16	32	24	32
Corrosion (protection)	30	25	25	40	30	30	30	30	30
Access	42	35	49	56	42	42	35	42	35
	0.55	0.55	0.6375	0.7	0.525	0.55	0.6063	0.6	0.6063
Decommissioning									
Disconnecting	28	28	28	28	28	28	32	32	32
Removal of foundation	25	30	30	45	40	25	45	45	45
Environmental impact of remains	15	18	18	27	24	15	21	21	21
	0.5667	0.6333	0.6333	0.8333	0.7667	0.5667	0.8167	0.8167	0.8167
Overall									
Reliability (proven technology)	30	30	48	30	6	12	24	24	24
	0.5	0.5	0.8	0.5	0.1	0.2	0.4	0.4	0.4
Total	757	842	870	868	780	803	796	767	786
Total	3.9356	4.1994	4.5828	4.6092	3.6607	3.8443	4.1573	4.0671	4.1173

Figure 32: *Support structure evaluation matrix for 45 m water depth by Jan van der Tempel*

	Score										Weighted Score								
	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar	Weight	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar
Site																			
Varying soil conditions	3	8	8	5	3	4	6	6	6	**8**	24	64	64	40	24	32	48	48	48
Poor soil conditions	2	8	8	4	1	3	4	4	4	**7**	14	56	56	28	7	21	28	28	28
Bedrock	4	7	7	8	1	7	7	7	7	**5**	20	35	35	40	5	35	35	35	35
Ice	5	5	6	8	5	2	5	4	5	**4**	20	20	24	32	20	8	20	16	20
										24	**0.325**	**0.7292**	**0.7458**	**0.5833**	**0.2333**	**0.4**	**0.5458**	**0.5292**	**0.5458**
Design																			
Mass	2	5	8	5	7	6	7	6	6	**10**	20	50	80	50	70	60	70	60	60
Tower head motion	3	6	8	8	7	5	4	5	4	**7**	21	42	56	56	49	35	28	35	28
Turbine mass	7	7	7	7	7	6	6	6	6	**8**	56	56	56	56	56	48	48	48	48
										25	**0.388**	**0.592**	**0.768**	**0.648**	**0.7**	**0.572**	**0.584**	**0.572**	**0.544**
Fabrication																			
Number of welds	7	6	5	7	7	7	6	6	6	**6**	42	36	30	42	42	42	36	36	36
Complexity of the joints	8	4	4	8	5	8	7	7	7	**8**	64	32	32	64	40	64	56	56	56
										14	**0.7571**	**0.4857**	**0.4429**	**0.7571**	**0.5857**	**0.7571**	**0.6571**	**0.6571**	**0.6571**
Installation																			
Transportation inshore	7	4	2	4	9	9	3	3	3	**1**	7	4	2	4	9	9	3	3	3
Transportation offshore	6	4	3	4	8	8	9	7	9	**6**	36	24	18	24	48	48	54	42	54
Lifting	4	4	2	3	6	6	4	4	4	**7**	28	28	14	21	42	42	28	28	28
Foundation	5	8	8	6	9	7	7	7	7	**9**	45	72	72	54	81	63	63	63	63
Connections	7	7	7	7	7	7	4	3	4	**9**	63	63	63	63	63	63	36	27	36
Cable Installation	7	7	7	7	7	7	4	4	4	**6**	42	42	42	42	42	42	24	24	24
										38	**0.5816**	**0.6132**	**0.5553**	**0.5474**	**0.75**	**0.7026**	**0.5474**	**0.4921**	**0.5474**
Maintenance																			
Scour (protection)	4	7	7	4	3	4	8	6	8	**4**	16	28	28	16	12	16	32	24	32
Corrosion (protection)	6	5	5	8	6	6	6	6	6	**5**	30	25	25	40	30	30	30	30	30
Access	6	5	7	8	6	6	5	6	5	**7**	42	35	49	56	42	42	35	42	35
										16	**0.55**	**0.55**	**0.6375**	**0.7**	**0.525**	**0.55**	**0.6063**	**0.6**	**0.6063**
Decommissioning																			
Disconnecting	7	7	7	7	7	7	8	8	8	**4**	28	28	28	28	28	28	32	32	32
Removal of foundation	5	6	6	9	8	5	9	9	9	**5**	25	30	30	45	40	25	45	45	45
Environmental impact of remains	5	6	6	9	8	5	7	7	7	**3**	15	18	18	27	24	15	21	21	21
										12	**0.5667**	**0.6333**	**0.6333**	**0.8333**	**0.7667**	**0.5667**	**0.8167**	**0.8167**	**0.8167**
Overall																			
Reliability (proven technology)	1	4	8	5	1	1	4	4	4	**6**	6	24	48	30	6	6	24	24	24
										6	**0.1**	**0.4**	**0.8**	**0.5**	**0.1**	**0.1**	**0.4**	**0.4**	**0.4**
										Total	664	812	870	858	780	774	796	767	786
										Total	**3.2684**	**4.0034**	**4.5828**	**4.5692**	**3.6607**	**3.6484**	**4.1573**	**4.0671**	**4.1173**

Figure 33: *Support structure evaluation matrix for 80 m water depth by Jan van der Tempel*

	Score										Weighted Score								
	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar	Weight	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar
Site																			
Varying soil conditions	1	5	8	5	3	6	6	6	6	**8**	8	40	64	40	24	48	48	48	48
Poor soil conditions	1	3	8	4	1	4	4	4	4	**7**	7	21	56	28	7	28	28	28	28
Bedrock	1	6	7	8	1	7	7	7	7	**5**	5	30	35	40	5	35	35	35	35
Ice	1	4	6	8	5	2	5	4	5	**4**	4	16	24	32	20	8	20	16	20
										24	**0.1**	**0.4458**	**0.7458**	**0.5833**	**0.2333**	**0.4958**	**0.5458**	**0.5292**	**0.5458**
Design																			
Mass	1	4	6	4	4	6	7	6	6	**10**	10	40	60	40	40	60	70	60	60
Tower head motion	1	5	8	8	6	5	4	5	4	**7**	7	35	56	56	42	35	28	35	28
Turbine mass	7	7	7	7	7	6	6	6	6	**8**	56	56	56	56	56	48	48	48	48
										25	**0.292**	**0.524**	**0.688**	**0.608**	**0.552**	**0.572**	**0.584**	**0.572**	**0.544**
Fabrication																			
Number of welds	7	6	5	7	7	7	6	6	6	**6**	42	36	30	42	42	42	36	36	36
Complexity of the joints	8	4	4	8	5	8	7	7	7	**8**	64	32	32	64	40	64	56	56	56
										14	**0.7571**	**0.4857**	**0.4429**	**0.7571**	**0.5857**	**0.7571**	**0.6571**	**0.6571**	**0.6571**
Installation																			
Transportation inshore	1	3	2	2	3	3	3	3	3	**1**	1	3	2	2	3	3	3	3	3
Transportation offshore	1	4	6	4	6	6	9	7	9	**6**	6	24	36	24	36	36	54	42	54
Lifting	1	2	2	3	6	6	4	4	4	**7**	7	14	14	21	42	42	28	28	28
Foundation	1	6	8	6	9	7	7	7	7	**9**	9	54	72	54	81	63	63	63	63
Connections	1	5	7	7	7	7	4	3	4	**9**	9	45	63	63	63	63	36	27	36
Cable Installation	1	5	7	7	7	7	4	4	4	**6**	6	30	42	42	42	42	24	24	24
										38	**0.1**	**0.4474**	**0.6026**	**0.5421**	**0.7026**	**0.6553**	**0.5474**	**0.4921**	**0.5474**
Maintenance																			
Scour (protection)	4	7	7	4	3	4	8	6	8	**4**	16	28	28	16	12	16	32	24	32
Corrosion (protection)	6	5	5	8	6	6	6	6	6	**5**	30	25	25	40	30	30	30	30	30
Access	6	5	7	8	6	6	5	6	5	**7**	42	35	49	56	42	42	35	42	35
										16	**0.55**	**0.55**	**0.6375**	**0.7**	**0.525**	**0.55**	**0.6063**	**0.6**	**0.6063**
Decommissioning																			
Disconnecting	7	7	7	7	7	7	8	8	8	**4**	28	28	28	28	28	28	32	32	32
Removal of foundation	5	6	6	9	8	5	9	9	9	**5**	25	30	30	45	40	25	45	45	45
Environmental impact of remains	5	6	6	9	8	5	7	7	7	**3**	15	18	18	27	24	15	21	21	21
										12	**0.5667**	**0.6333**	**0.6333**	**0.8333**	**0.7667**	**0.5667**	**0.8167**	**0.8167**	**0.8167**
Overall																			
Reliability (proven technology)	1	4	8	5	1	1	4	4	4	**6**	6	24	48	30	6	6	24	24	24
										6	**0.1**	**0.4**	**0.8**	**0.5**	**0.1**	**0.1**	**0.4**	**0.4**	**0.4**
										Total	403	664	868	846	725	779	796	767	786
										Total	**2.4658**	**3.4862**	**4.5502**	**4.5239**	**3.4653**	**3.6969**	**4.1573**	**4.0671**	**4.1173**

Figure 34: *Support structure evaluation matrix for 120 m water depth by Jan van der Tempel*

Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar	Weight
Site										
Varying soil conditions	8	8	8	5	3	4	10	7	10	**8**
Poor soil conditions	5	7	7	1	2	6	10	6	10	**7**
Bedrock	4	6	6	3	1	6	10	6	10	**5**
Ice	5	5	5	10	6	1	2	1	1	**4**
										24
Design										
Mass	7	9	10	1	8	9	2	2	1	**10**
Tower head motion	8	10	10	10	8	1	1	4	1	**7**
Turbine mass	7	8	9	10	9	4	2	1	1	**8**
										25
Fabrication										
Number of welds	8	3	1	10	6	5	1	4	5	**6**
Complexity of the joints	9	1	3	10	8	5	4	1	8	**8**
										14
Installation										
Transportation inshore	4	7	10	1	4	4	1	3	2	**1**
Transportation offshore	8	3	3	1	5	5	10	5	7	**6**
Lifting	7	9	9	1	6	2	7	4	3	**7**
Foundation	10	7	7	2	4	6	10	1	7	**9**
Connections	9	7	6	10	8	3	5	1	2	**9**
Cable Installation	9	8	10	9	8	5	2	1	2	**6**
										38
Maintenance										
Scour (protection)	5	3	4	1	2	5	10	2	10	**4**
Corrosion (protection)	8	4	4	9	8	7	3	4	5	**5**
Access	10	8	8	10	10	2	1	7	3	**7**
										16
Decommissioning										
Disconnecting	7	7	7	7	7	3	10	1	3	**4**
Removal of foundation	9	6	6	1	7	7	10	5	8	**5**
Environmental impact of remains	4	5	5	1	10	4	8	4	8	**3**
										12
Overall										
Reliability (proven technology)	10	7	8	10	3	1	8	2	3	**6**
										6

Weighted Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar
Site									
Varying soil conditions	64	64	64	40	24	32	80	56	80
Poor soil conditions	35	49	49	7	14	42	70	42	70
Bedrock	20	30	30	15	5	30	50	30	50
Ice	20	20	20	40	24	4	8	4	4
	0.5792	**0.6792**	**0.6792**	**0.425**	**0.2792**	**0.45**	**0.8667**	**0.55**	**0.85**
Design									
Mass	70	90	100	10	80	90	20	20	10
Tower head motion	56	70	70	70	56	7	7	28	7
Turbine mass	56	64	72	80	72	32	16	8	8
	0.728	**0.896**	**0.968**	**0.64**	**0.832**	**0.516**	**0.172**	**0.224**	**0.1**
Fabrication									
Number of welds	48	18	6	60	36	30	6	24	30
Complexity of the joints	72	8	24	80	64	40	32	8	64
	0.8571	**0.1857**	**0.2143**	**1**	**0.7143**	**0.5**	**0.2714**	**0.2286**	**0.6714**
Installation									
Transportation inshore	4	7	10	1	4	4	1	3	2
Transportation offshore	48	18	18	6	30	30	60	30	42
Lifting	49	63	63	7	42	14	49	28	21
Foundation	90	63	63	18	36	54	90	9	63
Connections	81	63	54	90	72	27	45	9	18
Cable Installation	54	48	60	54	48	30	12	6	12
	0.8579	**0.6895**	**0.7053**	**0.4632**	**0.6105**	**0.4184**	**0.6763**	**0.2237**	**0.4158**
Maintenance									
Scour (protection)	20	12	16	4	8	20	40	8	40
Corrosion (protection)	40	20	20	45	40	35	15	20	25
Access	70	56	56	70	70	14	7	49	21
	0.8125	**0.55**	**0.575**	**0.7438**	**0.7375**	**0.4313**	**0.3875**	**0.4813**	**0.5375**
Decommissioning									
Disconnecting	28	28	28	28	28	12	40	4	12
Removal of foundation	45	30	30	5	35	35	50	25	40
Environmental impact of remains	12	15	15	3	30	12	24	12	24
	0.7083	**0.6083**	**0.6083**	**0.3**	**0.775**	**0.4917**	**0.95**	**0.3417**	**0.6333**
Overall									
Reliability (proven technology)	60	42	48	60	18	6	48	12	18
	1	**0.7**	**0.8**	**1**	**0.3**	**0.1**	**0.8**	**0.2**	**0.3**
Total	1042	878	916	793	836	600	770	435	661
Total	**5.543**	**4.3087**	**4.55**	**4.5719**	**4.2485**	**2.9073**	**4.1239**	**2.2492**	**3.5081**

Figure 35: *Support structure evaluation matrix for 30 m water depth by Kimon Argyriadis*

Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar	Weight
Site										
Varying soil conditions	**7**	**8**	**8**	**4**	**2**	**4**	**10**	**7**	**10**	**8**
Poor soil conditions	**4**	**7**	**7**	**1**	**2**	**5**	**10**	**7**	**10**	**7**
Bedrock	**3**	**6**	**6**	**9**	**1**	**6**	**10**	**6**	**10**	**5**
Ice	**5**	**5**	**5**	**10**	**6**	**1**	**2**	**1**	**1**	**4**
										24
Design										
Mass	4	9	10	1	4	5	2	2	2	**10**
Tower head motion	5	9	10	9	5	1	1	5	2	**7**
Turbine mass	4	9	9	10	5	5	3	1	2	**8**
										25
Fabrication										
Number of welds	6	3	1	10	5	5	2	4	5	**6**
Complexity of the joints	9	1	3	10	6	5	5	1	8	**8**
										14
Installation										
Transportation inshore	1	7	10	1	2	1	1	3	2	**1**
Transportation offshore	8	4	5	2	3	5	10	3	8	**6**
Lifting	5	4	5	1	4	3	7	4	2	**7**
Foundation	5	8	8	2	5	5	10	2	7	**9**
Connections	9	7	6	10	8	3	5	1	3	**9**
Cable Installation	8	8	10	9	8	5	2	1	2	**6**
										38
Maintenance										
Scour (protection)	3	3	4	1	2	4	10	2	10	**4**
Corrosion (protection)	7	4	4	9	7	7	3	4	5	**5**
Access	10	8	8	10	10	2	1	7	3	**7**
										16
Decommissioning										
Disconnecting	7	7	7	7	7	3	10	1	7	**4**
Removal of foundation	7	6	6	1	4	2	10	5	9	**5**
Environmental impact of remains	4	5	5	1	10	4	8	4	8	**3**
										12
Overall										
Reliability (proven technology)	8	8	9	10	3	1	6	2	3	**6**
										6

Weighted Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar
Site									
Varying soil conditions	56	64	64	32	16	32	80	56	80
Poor soil conditions	28	49	49	7	14	35	70	49	70
Bedrock	15	30	30	45	5	30	50	30	50
Ice	20	20	20	40	24	4	8	4	4
	0.4958	**0.6792**	**0.6792**	**0.5167**	**0.2458**	**0.4208**	**0.8667**	**0.5792**	**0.85**
Design									
Mass	40	90	100	10	40	50	20	20	20
Tower head motion	35	63	70	63	35	7	7	35	14
Turbine mass	32	72	72	80	40	40	24	8	16
	0.428	**0.9**	**0.968**	**0.612**	**0.46**	**0.388**	**0.204**	**0.252**	**0.2**
Fabrication									
Number of welds	36	18	6	60	30	30	12	24	30
Complexity of the joints	72	8	24	80	48	40	40	8	64
	0.7714	**0.1857**	**0.2143**	**1**	**0.5571**	**0.5**	**0.3714**	**0.2286**	**0.6714**
Installation									
Transportation inshore	1	7	10	1	2	1	1	3	2
Transportation offshore	48	24	30	12	18	30	60	18	48
Lifting	35	28	35	7	28	21	49	28	14
Foundation	45	72	72	18	45	45	90	18	63
Connections	81	63	54	90	72	27	45	9	27
Cable Installation	48	48	60	54	48	30	12	6	12
	0.6789	**0.6368**	**0.6868**	**0.4789**	**0.5605**	**0.4053**	**0.6763**	**0.2158**	**0.4368**
Maintenance									
Scour (protection)	12	12	16	4	8	16	40	8	40
Corrosion (protection)	35	20	20	45	35	35	15	20	25
Access	70	56	56	70	70	14	7	49	21
	0.7313	**0.55**	**0.575**	**0.7438**	**0.7063**	**0.4063**	**0.3875**	**0.4813**	**0.5375**
Decommissioning									
Disconnecting	28	28	28	28	28	12	40	4	28
Removal of foundation	35	30	30	5	20	10	50	25	45
Environmental impact of remains	12	15	15	3	30	12	24	12	24
	0.625	**0.6083**	**0.6083**	**0.3**	**0.65**	**0.2833**	**0.95**	**0.3417**	**0.8083**
Overall									
Reliability (proven technology)	48	48	54	60	18	6	36	12	18
	0.8	**0.8**	**0.9**	**1**	**0.3**	**0.1**	**0.6**	**0.2**	**0.3**
Total	832	865	915	814	674	527	780	446	715
Total	**4.5305**	**4.3601**	**4.6316**	**4.6514**	**3.4798**	**2.5037**	**4.0559**	**2.2984**	**3.8041**

Figure 36: *Support structure evaluation matrix for 45 m water depth by Kimon Argyriadis*

Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar	Weight
Site										
Varying soil conditions	**4**	**7**	**7**	**3**	**2**	**4**	**10**	**8**	**10**	**8**
Poor soil conditions	**4**	**6**	**6**	**1**	**2**	**5**	**10**	**7**	**10**	**7**
Bedrock	**2**	**5**	**5**	**8**	**1**	**6**	**10**	**6**	**10**	**5**
Ice	**4**	**4**	**5**	**9**	**6**	**1**	**4**	**3**	**3**	**4**
										24
Design										
Mass	2	7	10	1	2	6	5	8	3	**10**
Tower head motion	4	8	10	9	4	1	2	5	2	**7**
Turbine mass	4	7	9	10	5	5	4	1	3	**8**
										25
Fabrication										
Number of welds	5	3	1	10	4	4	3	5	6	**6**
Complexity of the joints	7	1	3	9	6	7	5	1	8	**8**
										14
Installation										
Transportation inshore	2	5	8	1	2	3	1	3	2	**1**
Transportation offshore	5	3	4	1	3	4	10	3	8	**6**
Lifting	2	3	3	1	2	3	10	6	9	**7**
Foundation	1	6	7	1	1	3	10	3	10	**9**
Connections	5	6	7	10	5	1	5	2	8	**9**
Cable Installation	4	8	10	4	5	4	8	5	8	**6**
										38
Maintenance										
Scour (protection)	4	3	4	1	2	3	10	3	10	**4**
Corrosion (protection)	6	3	3	9	6	4	4	4	5	**5**
Access	10	8	8	10	10	2	1	7	3	**7**
										16
Decommissioning										
Disconnecting	7	7	7	7	7	3	7	1	7	**4**
Removal of foundation	5	6	7	1	1	2	9	5	9	**5**
Environmental impact of remains	4	5	5	1	10	4	8	4	8	**3**
										12
Overall										
Reliability (proven technology)	6	7	8	10	3	1	8	2	3	**6**
										6

Weighted Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar
Site									
Varying soil conditions	32	56	56	24	16	32	80	64	80
Poor soil conditions	28	42	42	7	14	35	70	49	70
Bedrock	10	25	25	40	5	30	50	30	50
Ice	16	16	20	36	24	4	16	12	12
	0.3583	**0.5792**	**0.5958**	**0.4458**	**0.2458**	**0.4208**	**0.9**	**0.6458**	**0.8833**
Design									
Mass	20	70	100	10	20	60	50	80	30
Tower head motion	28	56	70	63	28	7	14	35	14
Turbine mass	32	56	72	80	40	40	32	8	24
	0.32	**0.728**	**0.968**	**0.612**	**0.352**	**0.428**	**0.384**	**0.492**	**0.272**
Fabrication									
Number of welds	30	18	6	60	24	24	18	30	36
Complexity of the joints	56	8	24	72	48	56	40	8	64
	0.6143	**0.1857**	**0.2143**	**0.9429**	**0.5143**	**0.5714**	**0.4143**	**0.2714**	**0.7143**
Installation									
Transportation inshore	2	5	8	1	2	3	1	3	2
Transportation offshore	30	18	24	6	18	24	60	18	48
Lifting	14	21	21	7	14	21	70	42	63
Foundation	9	54	63	9	9	27	90	27	90
Connections	45	54	63	90	45	9	45	18	72
Cable Installation	24	48	60	24	30	24	48	30	48
	0.3263	**0.5263**	**0.6289**	**0.3605**	**0.3105**	**0.2842**	**0.8263**	**0.3632**	**0.85**
Maintenance									
Scour (protection)	16	12	16	4	8	12	40	12	40
Corrosion (protection)	30	15	15	45	30	20	20	20	25
Access	70	56	56	70	70	14	7	49	21
	0.725	**0.5188**	**0.5438**	**0.7438**	**0.675**	**0.2875**	**0.4188**	**0.5063**	**0.5375**
Decommissioning									
Disconnecting	28	28	28	28	28	12	28	4	28
Removal of foundation	25	30	35	5	5	10	45	25	45
Environmental impact of remains	12	15	15	3	30	12	24	12	24
	0.5417	**0.6083**	**0.65**	**0.3**	**0.525**	**0.2833**	**0.8083**	**0.3417**	**0.8083**
Overall									
Reliability (proven technology)	36	42	48	60	18	6	48	12	18
	0.6	**0.7**	**0.8**	**1**	**0.3**	**0.1**	**0.8**	**0.2**	**0.3**
Total	593	745	867	744	526	482	896	588	904
Total	**3.4856**	**3.8463**	**4.4008**	**4.405**	**2.9226**	**2.3753**	**4.5517**	**2.8203**	**4.3655**

Figure 37: *Support structure evaluation matrix for 80 m water depth by Kimon Argyriadis*

Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar	Weight
Site										
Varying soil conditions	**1**	**6**	**7**	**2**	**1**	**4**	**10**	**9**	**10**	**8**
Poor soil conditions	**4**	**6**	**6**	**1**	**2**	**5**	**10**	**8**	**10**	**7**
Bedrock	**1**	**3**	**3**	**7**	**1**	**6**	**10**	**6**	**10**	**5**
Ice	**3**	**3**	**4**	**9**	**6**	**1**	**4**	**4**	**3**	**4**
										24
Design										
Mass	2	4	6	1	2	7	6	10	6	**10**
Tower head motion	2	5	7	8	2	1	4	10	3	**7**
Turbine mass	3	4	5	10	3	5	7	1	5	**8**
										25
Fabrication										
Number of welds	4	3	1	10	2	4	4	6	7	**6**
Complexity of the joints	6	1	3	9	5	7	5	1	8	**8**
										14
Installation										
Transportation inshore	1	2	8	1	1	2	1	3	1	**1**
Transportation offshore	4	1	3	5	1	3	10	3	9	**6**
Lifting	1	2	4	2	1	2	8	6	10	**7**
Foundation	1	4	5	3	1	3	10	5	10	**9**
Connections	3	2	3	10	2	4	7	2	9	**9**
Cable Installation	2	4	5	2	4	1	10	8	10	**6**
										38
Maintenance										
Scour (protection)	5	3	3	2	4	4	10	3	10	**4**
Corrosion (protection)	6	3	3	9	6	3	5	4	5	**5**
Access	10	8	8	10	10	2	1	7	3	**7**
										16
Decommissioning										
Disconnecting	7	7	7	7	7	2	7	1	7	**4**
Removal of foundation	2	3	6	1	1	2	9	5	9	**5**
Environmental impact of remains	4	5	5	1	10	4	8	4	8	**3**
										12
Overall										
Reliability (proven technology)	4	6	10	10	3	1	8	3	5	**6**
										6

Weighted Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar
Site									
Varying soil conditions	8	48	56	16	8	32	80	72	80
Poor soil conditions	28	42	42	7	14	35	70	56	70
Bedrock	5	15	15	35	5	30	50	30	50
Ice	12	12	16	36	24	4	16	16	12
	0.2208	**0.4875**	**0.5375**	**0.3917**	**0.2125**	**0.4208**	**0.9**	**0.725**	**0.8833**
Design									
Mass	20	40	60	10	20	70	60	100	60
Tower head motion	14	35	49	56	14	7	28	70	21
Turbine mass	24	32	40	80	24	40	56	8	40
	0.232	**0.428**	**0.596**	**0.584**	**0.232**	**0.468**	**0.576**	**0.712**	**0.484**
Fabrication									
Number of welds	24	18	6	60	12	24	24	36	42
Complexity of the joints	48	8	24	72	40	56	40	8	64
	0.5143	**0.1857**	**0.2143**	**0.9429**	**0.3714**	**0.5714**	**0.4571**	**0.3143**	**0.7571**
Installation									
Transportation inshore	1	2	8	1	1	2	1	3	1
Transportation offshore	24	6	18	30	6	18	60	18	54
Lifting	7	14	28	14	7	14	56	42	70
Foundation	9	36	45	27	9	27	90	45	90
Connections	27	18	27	90	18	36	63	18	81
Cable Installation	12	24	30	12	24	6	60	48	60
	0.2105	**0.2632**	**0.4105**	**0.4579**	**0.1711**	**0.2711**	**0.8684**	**0.4579**	**0.9368**
Maintenance									
Scour (protection)	20	12	12	8	16	16	40	12	40
Corrosion (protection)	30	15	15	45	30	15	25	20	25
Access	70	56	56	70	70	14	7	49	21
	0.75	**0.5188**	**0.5188**	**0.7688**	**0.725**	**0.2813**	**0.45**	**0.5063**	**0.5375**
Decommissioning									
Disconnecting	28	28	28	28	28	8	28	4	28
Removal of foundation	10	15	30	5	5	10	45	25	45
Environmental impact of remains	12	15	15	3	30	12	24	12	24
	0.4167	**0.4833**	**0.6083**	**0.3**	**0.525**	**0.25**	**0.8083**	**0.3417**	**0.8083**
Overall									
Reliability (proven technology)	24	36	60	60	18	6	48	18	30
	0.4	**0.6**	**1**	**1**	**0.3**	**0.1**	**0.8**	**0.3**	**0.5**
Total	457	527	680	765	423	482	971	710	1008
Total	**2.7443**	**2.9665**	**3.8854**	**4.4452**	**2.537**	**2.3626**	**4.8599**	**3.3571**	**4.9072**

Figure 38: *Support structure evaluation matrix for 120 m water depth by Kimon Argyriadis*

Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar	Weight
Site										
Varying soil conditions	7	8	9	5	3	7	8	8	10	**8**
Poor soil conditions	7	9	9	3	6	7	8	8	10	**7**
Bedrock	7	5	5	9	5	4	4	4	10	**5**
Ice	8	8	4	8	8	4	7	7	7	**4**
										24
Design										
Mass	7	8	8	5	6	6	7	7	7	**10**
Tower head motion	9	9	9	9	9	5	4	5	5	**7**
Turbine mass	5	6	7	9	5	5	7	6	6	**8**
										25
Fabrication										
Number of welds	9	7	5	7	7	7	5	5	5	**6**
Complexity of the joints	9	5	5	7	4	5	7	7	7	**8**
										14
Installation										
Transportation inshore	3	2	2	2	2	2	2	2	2	**1**
Transportation offshore	7	5	5	5	5	6	8	8	8	**6**
Lifting	7	5	5	3	5	7	10	10	10	**7**
Foundation	9	8	7	7	6	6	5	5	10	**9**
Connections	8	7	6	8	10	5	8	8	8	**9**
Cable Installation	7	8	8	8	8	8	5	5	5	**6**
										38
Maintenance										
Scour (protection)	5	7	7	6	6	7	9	9	9	**4**
Corrosion (protection)	7	7	7	10	7	7	8	8	8	**5**
Access	7	7	7	7	7	6	8	8	8	**7**
										16
Decommissioning										
Disconnecting	7	6	5	4	9	7	8	8	8	**4**
Removal of foundation	7	6	6	3	7	7	8	8	8	**5**
Environmental impact of remains	8	8	8	8	8	8	8	8	8	**3**
										12
Overall										
Reliability (proven technology)	9	9	9	9	6	5	5	5	5	**6**
										6

Weighted Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar
Site									
Varying soil conditions	56	64	72	40	24	56	64	64	80
Poor soil conditions	49	63	63	21	42	49	56	56	70
Bedrock	35	25	25	45	25	20	20	20	50
Ice	32	32	16	32	32	16	28	28	28
	0.7167	**0.7667**	**0.7333**	**0.575**	**0.5125**	**0.5875**	**0.7**	**0.7**	**0.95**
Design									
Mass	70	80	80	50	60	60	70	70	70
Tower head motion	63	63	63	63	63	35	28	35	35
Turbine mass	40	48	56	72	40	40	56	48	48
	0.692	**0.764**	**0.796**	**0.74**	**0.652**	**0.54**	**0.616**	**0.612**	**0.612**
Fabrication									
Number of welds	54	42	30	42	42	42	30	30	30
Complexity of the joints	72	40	40	56	32	40	56	56	56
	0.9	**0.5857**	**0.5**	**0.7**	**0.5286**	**0.5857**	**0.6143**	**0.6143**	**0.6143**
Installation									
Transportation inshore	3	2	2	2	2	2	2	2	2
Transportation offshore	42	30	30	30	30	36	48	48	48
Lifting	49	35	35	21	35	49	70	70	70
Foundation	81	72	63	63	54	54	45	45	90
Connections	72	63	54	72	90	45	72	72	72
Cable Installation	42	48	48	48	48	48	30	30	30
	0.7605	**0.6579**	**0.6105**	**0.6211**	**0.6816**	**0.6158**	**0.7026**	**0.7026**	**0.8211**
Maintenance									
Scour (protection)	20	28	28	24	24	28	36	36	36
Corrosion (protection)	35	35	35	50	35	35	40	40	40
Access	49	49	49	49	49	42	56	56	56
	0.65	**0.7**	**0.7**	**0.7688**	**0.675**	**0.6563**	**0.825**	**0.825**	**0.825**
Decommissioning									
Disconnecting	28	24	20	16	36	28	32	32	32
Removal of foundation	35	30	30	15	35	35	40	40	40
Environmental impact of remains	24	24	24	24	24	24	24	24	24
	0.725	**0.65**	**0.6167**	**0.4583**	**0.7917**	**0.725**	**0.8**	**0.8**	**0.8**
Overall									
Reliability (proven technology)	54	54	54	54	36	30	30	30	30
	0.9	**0.9**	**0.9**	**0.9**	**0.6**	**0.5**	**0.5**	**0.5**	**0.5**
Total	1005	951	917	889	858	814	933	932	1037
Total	**5.3442**	**5.0243**	**4.8565**	**4.7631**	**4.4413**	**4.2103**	**4.7579**	**4.7539**	**5.1223**

Figure 39: *Support structure evaluation matrix for 30 m water depth by Henrik Carstens*

Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar	Weight
Site										
Varying soil conditions	7	8	9	5	3	7	8	8	10	**8**
Poor soil conditions	7	9	9	3	6	7	8	8	10	**7**
Bedrock	7	5	5	9	5	4	4	4	10	**5**
Ice	8	8	4	8	8	4	7	7	7	**4**
										24
Design										
Mass	5	8	8	3	5	6	7	7	7	**10**
Tower head motion	7	9	9	9	9	5	4	5	5	**7**
Turbine mass	3	6	7	9	5	5	7	6	6	**8**
										25
Fabrication										
Number of welds	9	7	5	7	7	7	5	5	5	**6**
Complexity of the joints	9	5	5	7	4	5	7	7	7	**8**
										14
Installation										
Transportation inshore	3	2	2	2	2	2	2	2	2	**1**
Transportation offshore	7	5	5	5	5	6	8	8	8	**6**
Lifting	6	5	5	3	5	7	10	10	10	**7**
Foundation	9	8	7	7	6	6	5	5	10	**9**
Connections	8	7	6	8	10	5	8	8	8	**9**
Cable Installation	7	8	8	8	8	8	5	5	5	**6**
										38
Maintenance										
Scour (protection)	5	7	7	6	6	7	9	9	9	**4**
Corrosion (protection)	7	7	7	10	7	7	8	8	8	**5**
Access	7	7	7	7	7	6	8	8	8	**7**
										16
Decommissioning										
Disconnecting	7	6	5	4	9	7	8	8	8	**4**
Removal of foundation	7	6	6	3	7	7	8	8	8	**5**
Environmental impact of remains	8	8	8	8	8	8	8	8	8	**3**
										12
Overall										
Reliability (proven technology)	7	9	9	7	7	5	5	5	5	**6**
										6

Weighted Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar
Site									
Varying soil conditions	56	64	72	40	24	56	64	64	80
Poor soil conditions	49	63	63	21	42	49	56	56	70
Bedrock	35	25	25	45	25	20	20	20	50
Ice	32	32	16	32	32	16	28	28	28
	0.7167	**0.7667**	**0.7333**	**0.575**	**0.5125**	**0.5875**	**0.7**	**0.7**	**0.95**
Design									
Mass	50	80	80	30	50	60	70	70	70
Tower head motion	49	63	63	63	63	35	28	35	35
Turbine mass	24	48	56	72	40	40	56	48	48
	0.492	**0.764**	**0.796**	**0.66**	**0.612**	**0.54**	**0.616**	**0.612**	**0.612**
Fabrication									
Number of welds	54	42	30	42	42	42	30	30	30
Complexity of the joints	72	40	40	56	32	40	56	56	56
	0.9	**0.5857**	**0.5**	**0.7**	**0.5286**	**0.5857**	**0.6143**	**0.6143**	**0.6143**
Installation									
Transportation inshore	3	2	2	2	2	2	2	2	2
Transportation offshore	42	30	30	30	30	36	48	48	48
Lifting	42	35	35	21	35	49	70	70	70
Foundation	81	72	63	63	54	54	45	45	90
Connections	72	63	54	72	90	45	72	72	72
Cable Installation	42	48	48	48	48	48	30	30	30
	0.7421	**0.6579**	**0.6105**	**0.6211**	**0.6816**	**0.6158**	**0.7026**	**0.7026**	**0.8211**
Maintenance									
Scour (protection)	20	28	28	24	24	28	36	36	36
Corrosion (protection)	35	35	35	50	35	35	40	40	40
Access	49	49	49	49	49	42	56	56	56
	0.65	**0.7**	**0.7**	**0.7688**	**0.675**	**0.6563**	**0.825**	**0.825**	**0.825**
Decommissioning									
Disconnecting	28	24	20	16	36	28	32	32	32
Removal of foundation	35	30	30	15	35	35	40	40	40
Environmental impact of remains	24	24	24	24	24	24	24	24	24
	0.725	**0.65**	**0.6167**	**0.4583**	**0.7917**	**0.725**	**0.8**	**0.8**	**0.8**
Overall									
Reliability (proven technology)	42	54	54	42	42	30	30	30	30
	0.7	**0.9**	**0.9**	**0.7**	**0.7**	**0.5**	**0.5**	**0.5**	**0.5**
Total	936	951	917	857	854	814	933	932	1037
Total	**4.9258**	**5.0243**	**4.8565**	**4.4831**	**4.5013**	**4.2103**	**4.7579**	**4.7539**	**5.1223**

Figure 40: *Support structure evaluation matrix for 45 m water depth by Henrik Carstens*

Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar	Weight
Site										
Varying soil conditions	7	8	9	5	3	7	8	8	10	**8**
Poor soil conditions	7	9	9	3	6	7	8	8	10	**7**
Bedrock	7	5	5	9	5	4	4	4	10	**5**
Ice	8	8	4	8	8	4	7	7	7	**4**
										24
Design										
Mass	1	8	8	1	1	6	7	7	7	**10**
Tower head motion	1	9	9	9	1	5	4	5	5	**7**
Turbine mass	1	6	7	1	1	5	7	6	6	**8**
										25
Fabrication										
Number of welds	4	7	5	4	4	7	5	5	5	**6**
Complexity of the joints	4	5	5	4	4	5	7	7	7	**8**
										14
Installation										
Transportation inshore	3	2	2	2	2	2	2	2	2	**1**
Transportation offshore	7	5	5	5	5	6	8	8	8	**6**
Lifting	3	5	5	1	1	7	10	10	10	**7**
Foundation	9	8	7	7	6	6	5	5	10	**9**
Connections	5	7	6	8	5	5	8	8	8	**9**
Cable Installation	7	8	8	8	8	8	5	5	5	**6**
										38
Maintenance										
Scour (protection)	5	7	7	6	6	7	9	9	9	**4**
Corrosion (protection)	7	7	7	10	7	7	8	8	8	**5**
Access	7	7	7	7	7	6	8	8	8	**7**
										16
Decommissioning										
Disconnecting	7	6	5	4	9	7	8	8	8	**4**
Removal of foundation	7	6	6	3	7	7	8	8	8	**5**
Environmental impact of remains	8	8	8	8	8	8	8	8	8	**3**
										12
Overall										
Reliability (proven technology)	9	9	9	9	6	5	5	5	5	**6**
										6

Weighted Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar
Site									
Varying soil conditions	56	64	72	40	24	56	64	64	80
Poor soil conditions	49	63	63	21	42	49	56	56	70
Bedrock	35	25	25	45	25	20	20	20	50
Ice	32	32	16	32	32	16	28	28	28
	0.7167	**0.7667**	**0.7333**	**0.575**	**0.5125**	**0.5875**	**0.7**	**0.7**	**0.95**
Design									
Mass	10	80	80	10	10	60	70	70	70
Tower head motion	7	63	63	63	7	35	28	35	35
Turbine mass	8	48	56	8	8	40	56	48	48
	0.1	**0.764**	**0.796**	**0.324**	**0.1**	**0.54**	**0.616**	**0.612**	**0.612**
Fabrication									
Number of welds	24	42	30	24	24	42	30	30	30
Complexity of the joints	32	40	40	32	32	40	56	56	56
	0.4	**0.5857**	**0.5**	**0.4**	**0.4**	**0.5857**	**0.6143**	**0.6143**	**0.6143**
Installation									
Transportation inshore	3	2	2	2	2	2	2	2	2
Transportation offshore	42	30	30	30	30	36	48	48	48
Lifting	21	35	35	7	7	49	70	70	70
Foundation	81	72	63	63	54	54	45	45	90
Connections	45	63	54	72	45	45	72	72	72
Cable Installation	42	48	48	48	48	48	30	30	30
	0.6158	**0.6579**	**0.6105**	**0.5842**	**0.4895**	**0.6158**	**0.7026**	**0.7026**	**0.8211**
Maintenance									
Scour (protection)	20	28	28	24	24	28	36	36	36
Corrosion (protection)	35	35	35	50	35	35	40	40	40
Access	49	49	49	49	49	42	56	56	56
	0.65	**0.7**	**0.7**	**0.7688**	**0.675**	**0.6563**	**0.825**	**0.825**	**0.825**
Decommissioning									
Disconnecting	28	24	20	16	36	28	32	32	32
Removal of foundation	35	30	30	15	35	35	40	40	40
Environmental impact of remains	24	24	24	24	24	24	24	24	24
	0.725	**0.65**	**0.6167**	**0.4583**	**0.7917**	**0.725**	**0.8**	**0.8**	**0.8**
Overall									
Reliability (proven technology)	54	54	54	54	36	30	30	30	30
	0.9	**0.9**	**0.9**	**0.9**	**0.6**	**0.5**	**0.5**	**0.5**	**0.5**
Total	732	951	917	729	629	814	933	932	1037
Total	**4.1075**	**5.0243**	**4.8565**	**4.0103**	**3.5686**	**4.2103**	**4.7579**	**4.7539**	**5.1223**

Figure 41: *Support structure evaluation matrix for 80 m water depth by Henrik Carstens*

Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar	Weight
Site										
Varying soil conditions	7	8	9	5	3	7	8	8	10	**8**
Poor soil conditions	7	9	9	3	6	7	8	8	10	**7**
Bedrock	7	5	5	9	5	4	4	4	10	**5**
Ice	8	8	4	8	8	4	7	7	7	**4**
										24
Design										
Mass	1	8	8	1	1	6	7	7	7	**10**
Tower head motion	1	9	9	1	1	5	4	5	5	**7**
Turbine mass	1	6	7	1	1	5	7	6	6	**8**
										25
Fabrication										
Number of welds	1	7	5	1	1	7	5	5	5	**6**
Complexity of the joints	1	5	5	1	1	5	7	7	7	**8**
										14
Installation										
Transportation inshore	3	2	2	2	2	2	2	2	2	**1**
Transportation offshore	7	5	5	5	5	6	8	8	8	**6**
Lifting	7	5	5	3	5	7	10	10	10	**7**
Foundation	9	8	7	7	6	6	5	5	10	**9**
Connections	8	7	6	8	10	5	8	8	8	**9**
Cable Installation	7	8	8	8	8	8	5	5	5	**6**
										38
Maintenance										
Scour (protection)	5	7	7	6	6	7	9	9	9	**4**
Corrosion (protection)	7	7	7	10	7	7	8	8	8	**5**
Access	7	7	7	7	7	6	8	8	8	**7**
										16
Decommissioning										
Disconnecting	7	6	5	4	9	7	8	8	8	**4**
Removal of foundation	7	6	6	3	7	7	8	8	8	**5**
Environmental impact of remains	8	8	8	8	8	8	8	8	8	**3**
										12
Overall										
Reliability (proven technology)	1	9	9	1	1	5	5	5	5	**6**
										6

Weighted Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar
Site									
Varying soil conditions	56	64	72	40	24	56	64	64	80
Poor soil conditions	49	63	63	21	42	49	56	56	70
Bedrock	35	25	25	45	25	20	20	20	50
Ice	32	32	16	32	32	16	28	28	28
	0.7167	**0.7667**	**0.7333**	**0.575**	**0.5125**	**0.5875**	**0.7**	**0.7**	**0.95**
Design									
Mass	10	80	80	10	10	60	70	70	70
Tower head motion	7	63	63	7	7	35	28	35	35
Turbine mass	8	48	56	8	8	40	56	48	48
	0.1	**0.764**	**0.796**	**0.1**	**0.1**	**0.54**	**0.616**	**0.612**	**0.612**
Fabrication									
Number of welds	6	42	30	6	6	42	30	30	30
Complexity of the joints	8	40	40	8	8	40	56	56	56
	0.1	**0.5857**	**0.5**	**0.1**	**0.1**	**0.5857**	**0.6143**	**0.6143**	**0.6143**
Installation									
Transportation inshore	3	2	2	2	2	2	2	2	2
Transportation offshore	42	30	30	30	30	36	48	48	48
Lifting	49	35	35	21	35	49	70	70	70
Foundation	81	72	63	63	54	54	45	45	90
Connections	72	63	54	72	90	45	72	72	72
Cable Installation	42	48	48	48	48	48	30	30	30
	0.7605	**0.6579**	**0.6105**	**0.6211**	**0.6816**	**0.6158**	**0.7026**	**0.7026**	**0.8211**
Maintenance									
Scour (protection)	20	28	28	24	24	28	36	36	36
Corrosion (protection)	35	35	35	50	35	35	40	40	40
Access	49	49	49	49	49	42	56	56	56
	0.65	**0.7**	**0.7**	**0.7688**	**0.675**	**0.6563**	**0.825**	**0.825**	**0.825**
Decommissioning									
Disconnecting	28	24	20	16	36	28	32	32	32
Removal of foundation	35	30	30	15	35	35	40	40	40
Environmental impact of remains	24	24	24	24	24	24	24	24	24
	0.725	**0.65**	**0.6167**	**0.4583**	**0.7917**	**0.725**	**0.8**	**0.8**	**0.8**
Overall									
Reliability (proven technology)	6	54	54	6	6	30	30	30	30
	0.1	**0.9**	**0.9**	**0.1**	**0.1**	**0.5**	**0.5**	**0.5**	**0.5**
Total	697	951	917	597	630	814	933	932	1037
Total	**3.1522**	**5.0243**	**4.8565**	**2.7231**	**2.9607**	**4.2103**	**4.7579**	**4.7539**	**5.1223**

Figure 42: *Support structure evaluation matrix for 120 m water depth by Henrik Carstens*

Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar	Weight
Site										
Varying soil conditions	6	8	8	4	5	4	4	2	0	**8**
Poor soil conditions	3	6	6	1	2	3	3	1	0	**7**
Bedrock	5	3	3	8	1	4	4	4	0	**5**
Ice	4	4	2	6	4	3	2	4	0	**4**
										24
Design										
Mass	3	4	6	1	4	4	3	3	0	**10**
Tower head motion	5	6	7	5	5	4	1	6	0	**7**
Turbine mass	4	7	8	6	4	5	2	2	0	**8**
										25
Fabrication										
Number of welds	7	5	3	7	8	7	6	6	0	**6**
Complexity of the joints	8	5	4	6	6	8	4	4	4	**8**
										14
Installation										
Transportation inshore	4	6	8	4	3	7	3	3	0	**1**
Transportation offshore	7	5	6	7	7	7	7	7	0	**6**
Lifting	7	6	6	5	5	7	5	6	0	**7**
Foundation	4	6	6	5	5	8	2	4	0	**9**
Connections	7	5	5	6	6	7	2	3	0	**9**
Cable Installation	8	6	4	7	8	8	1	1	0	**6**
										38
Maintenance										
Scour (protection)	6	5	5	4	4	6	8	8	0	**4**
Corrosion (protection)	7	6	5	7	7	7	7	7	0	**5**
Access	7	7	5	7	7	7	3	4	0	**7**
										16
Decommissioning										
Disconnecting	6	6	5	4	4	6	6	5	0	**4**
Removal of foundation	5	6	6	8	7	6	8	8	0	**5**
Environmental impact of remains	5	6	6	10	10	5	7	7	0	**3**
										12
Overall										
Reliability (proven technology)	7	6	6	4	4	1	1	1	0	**6**
										6

Weighted Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar
Site									
Varying soil conditions	48	64	64	32	40	32	32	16	
Poor soil conditions	21	42	42	7	14	21	21	7	
Bedrock	25	15	15	40	5	20	20	20	
Ice	16	16	8	24	16	12	8	16	
	0.4583	**0.5708**	**0.5375**	**0.4292**	**0.3125**	**0.3542**	**0.3375**	**0.2458**	**0**
Design									
Mass	30	40	60	10	40	40	30	30	
Tower head motion	35	42	49	35	35	28	7	42	
Turbine mass	32	56	64	48	32	40	16	16	
	0.388	**0.552**	**0.692**	**0.372**	**0.428**	**0.432**	**0.212**	**0.352**	**0**
Fabrication									
Number of welds	42	30	18	42	48	42	36	36	
Complexity of the joints	64	40	32	48	48	64	32	32	32
	0.7571	**0.5**	**0.3571**	**0.6429**	**0.6857**	**0.7571**	**0.4857**	**0.4857**	**0.2286**
Installation									
Transportation inshore	4	6	8	4	3	7	3	3	
Transportation offshore	42	30	36	42	42	42	42	42	
Lifting	49	42	42	35	35	49	35	42	
Foundation	36	54	54	45	45	72	18	36	
Connections	63	45	45	54	54	63	18	27	
Cable Installation	48	36	24	42	48	48	6	6	
	0.6368	**0.5605**	**0.55**	**0.5842**	**0.5974**	**0.7395**	**0.3211**	**0.4105**	**0**
Maintenance									
Scour (protection)	24	20	20	16	16	24	32	32	
Corrosion (protection)	35	30	25	35	35	35	35	35	
Access	49	49	35	49	49	49	21	28	
	0.675	**0.6188**	**0.5**	**0.625**	**0.625**	**0.675**	**0.55**	**0.5938**	**0**
Decommissioning									
Disconnecting	24	24	20	16	16	24	24	20	
Removal of foundation	25	30	30	40	35	30	40	40	
Environmental impact of remains	15	18	18	30	30	15	21	21	
	0.5333	**0.6**	**0.5667**	**0.7167**	**0.675**	**0.575**	**0.7083**	**0.675**	**0**
Overall									
Reliability (proven technology)	42	36	36	24	24	6	6	6	
	0.7	**0.6**	**0.6**	**0.4**	**0.4**	**0.1**	**0.1**	**0.1**	**0**
Total	769	765	745	718	710	763	503	553	32
Total	**4.1487**	**4.0021**	**3.8033**	**3.7699**	**3.7236**	**3.6328**	**2.7146**	**2.8628**	**0.2286**

Figure 43: *Support structure evaluation matrix for 30 m water depth by Patrik Passon*

Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar	Weight
Site										
Varying soil conditions	4	7	7	2	2	3	4	2	4	**8**
Poor soil conditions	2	4	5	1	1	2	3	1	3	**7**
Bedrock	5	3	3	8	1	5	4	4	4	**5**
Ice	3	4	2	3	3	2	2	4	3	**4**
										24
Design										
Mass	2	4	6	1	2	2	2	2	3	**10**
Tower head motion	4	6	7	5	4	3	2	6	2	**7**
Turbine mass	2	5	7	3	2	1	2	2	2	**8**
										25
Fabrication										
Number of welds	6	4	3	6	6	6	6	6	4	**6**
Complexity of the joints	7	5	4	6	6	7	4	4	4	**8**
										14
Installation										
Transportation inshore	3	5	8	3	2	6	1	1	2	**1**
Transportation offshore	6	4	5	6	6	6	7	7	6	**6**
Lifting	7	6	6	5	5	7	5	6	4	**7**
Foundation	2	6	6	4	3	7	2	4	2	**9**
Connections	7	5	5	4	4	7	3	4	3	**9**
Cable Installation	8	6	4	7	8	8	1	1	1	**6**
										38
Maintenance										
Scour (protection)	6	5	5	4	4	6	8	8	8	**4**
Corrosion (protection)	7	6	5	7	7	7	7	7	7	**5**
Access	7	7	5	7	7	7	4	5	4	**7**
										16
Decommissioning										
Disconnecting	6	6	5	4	4	6	6	5	6	**4**
Removal of foundation	5	6	6	8	7	6	8	8	8	**5**
Environmental impact of remains	4	6	6	10	10	5	7	7	7	**3**
										12
Overall										
Reliability (proven technology)	4	6	6	4	4	1	1	1	1	**6**
										6

Weighted Score

	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar
Site									
Varying soil conditions	32	56	56	16	16	24	32	16	32
Poor soil conditions	14	28	35	7	7	14	21	7	21
Bedrock	25	15	15	40	5	25	20	20	20
Ice	12	16	8	12	12	8	8	16	12
	0.3458	**0.4792**	**0.475**	**0.3125**	**0.1667**	**0.2958**	**0.3375**	**0.2458**	**0.3542**
Design									
Mass	20	40	60	10	20	20	20	20	30
Tower head motion	28	42	49	35	28	21	14	42	14
Turbine mass	16	40	56	24	16	8	16	16	16
	0.256	**0.488**	**0.66**	**0.276**	**0.256**	**0.196**	**0.2**	**0.312**	**0.24**
Fabrication									
Number of welds	36	24	18	36	36	36	36	36	24
Complexity of the joints	56	40	32	48	48	56	32	32	32
	0.6571	**0.4571**	**0.3571**	**0.6**	**0.6**	**0.6571**	**0.4857**	**0.4857**	**0.4**
Installation									
Transportation inshore	3	5	8	3	2	6	1	1	2
Transportation offshore	36	24	30	36	36	36	42	42	36
Lifting	49	42	42	35	35	49	35	42	28
Foundation	18	54	54	36	27	63	18	36	18
Connections	63	45	45	36	36	63	27	36	27
Cable Installation	48	36	24	42	48	48	6	6	6
	0.5711	**0.5421**	**0.5342**	**0.4947**	**0.4842**	**0.6974**	**0.3395**	**0.4289**	**0.3079**
Maintenance									
Scour (protection)	24	20	20	16	16	24	32	32	32
Corrosion (protection)	35	30	25	35	35	35	35	35	35
Access	49	49	35	49	49	49	28	35	28
	0.675	**0.6188**	**0.5**	**0.625**	**0.625**	**0.675**	**0.5938**	**0.6375**	**0.5938**
Decommissioning									
Disconnecting	24	24	20	16	16	24	24	20	24
Removal of foundation	25	30	30	40	35	30	40	40	40
Environmental impact of remains	12	18	18	30	30	15	21	21	21
	0.5083	**0.6**	**0.5667**	**0.7167**	**0.675**	**0.575**	**0.7083**	**0.675**	**0.7083**
Overall									
Reliability (proven technology)	24	36	36	24	24	6	6	6	6
	0.4	**0.6**	**0.6**	**0.4**	**0.4**	**0.1**	**0.1**	**0.1**	**0.1**
Total	649	714	716	626	577	660	514	557	504
Total	**3.4134**	**3.7852**	**3.693**	**3.4249**	**3.2069**	**3.1963**	**2.7648**	**2.885**	**2.7041**

Figure 44: *Support structure evaluation matrix for 45 m water depth by Patrik Passon*

Score

Criterion	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar	Weight
Site										
Varying soil conditions	2	5	6	1	1	2	4	2	4	**8**
Poor soil conditions	1	3	4	1	1	1	3	1	3	**7**
Bedrock	5	3	3	8	1	5	4	4	4	**5**
Ice	2	2	1	2	2	2	2	4	3	**4**
										24
Design										
Mass	1	3	5	1	1	1	2	2	3	**10**
Tower head motion	3	4	6	3	3	2	2	6	2	**7**
Turbine mass	2	5	7	3	2	1	2	2	2	**8**
										25
Fabrication										
Number of welds	5	4	3	5	5	5	6	6	4	**6**
Complexity of the joints	6	5	4	6	6	7	4	4	4	**8**
										14
Installation										
Transportation inshore	1	2	7	1	1	3	1	1	2	**1**
Transportation offshore	3	2	4	3	3	3	7	7	6	**6**
Lifting	5	4	4	3	3	6	5	6	4	**7**
Foundation	1	5	5	4	3	5	2	4	2	**9**
Connections	7	4	4	3	3	7	3	4	3	**9**
Cable Installation	8	6	4	7	8	8	1	1	1	**6**
										38
Maintenance										
Scour (protection)	5	4	4	4	4	5	8	8	8	**4**
Corrosion (protection)	7	6	5	7	7	7	7	7	7	**5**
Access	7	7	5	7	7	7	4	5	4	**7**
										16
Decommissioning										
Disconnecting	6	6	5	3	3	6	6	5	6	**4**
Removal of foundation	4	5	5	8	7	5	8	8	8	**5**
Environmental impact of remains	3	4	4	10	10	4	7	7	7	**3**
										12
Overall										
Reliability (proven technology)	2	3	4	2	1	1	1	1	1	**6**
										6

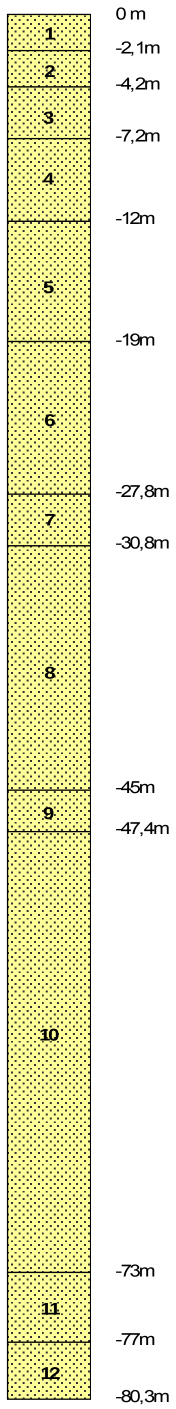
Weighted Score

Criterion	Monopile	Tripod	Jacket	Gravity base	Suction bucket	Compliant tower	Floating: Barge	Floating: TLP	Floating: Spar
Site									
Varying soil conditions	16	40	48	8	8	16	32	16	32
Poor soil conditions	7	21	28	7	7	7	21	7	21
Bedrock	25	15	15	40	5	25	20	20	20
Ice	8	8	4	8	8	8	8	16	12
	0.2333	**0.35**	**0.3958**	**0.2625**	**0.1167**	**0.2333**	**0.3375**	**0.2458**	**0.3542**
Design									
Mass	10	30	50	10	10	10	20	20	30
Tower head motion	21	28	42	21	21	14	14	42	14
Turbine mass	16	40	56	24	16	8	16	16	16
	0.188	**0.392**	**0.592**	**0.22**	**0.188**	**0.128**	**0.2**	**0.312**	**0.24**
Fabrication									
Number of welds	30	24	18	30	30	30	36	36	24
Complexity of the joints	48	40	32	48	48	56	32	32	32
	0.5571	**0.4571**	**0.3571**	**0.5571**	**0.5571**	**0.6143**	**0.4857**	**0.4857**	**0.4**
Installation									
Transportation inshore	1	2	7	1	1	3	1	1	2
Transportation offshore	18	12	24	18	18	18	42	42	36
Lifting	35	28	28	21	21	42	35	42	28
Foundation	9	45	45	36	27	45	18	36	18
Connections	63	36	36	27	27	63	27	36	27
Cable Installation	48	36	24	42	48	48	6	6	6
	0.4579	**0.4184**	**0.4316**	**0.3816**	**0.3737**	**0.5763**	**0.3395**	**0.4289**	**0.3079**
Maintenance									
Scour (protection)	20	16	16	16	16	20	32	32	32
Corrosion (protection)	35	30	25	35	35	35	35	35	35
Access	49	49	35	49	49	49	28	35	28
	0.65	**0.5938**	**0.475**	**0.625**	**0.625**	**0.65**	**0.5938**	**0.6375**	**0.5938**
Decommissioning									
Disconnecting	24	24	20	12	12	24	24	20	24
Removal of foundation	20	25	25	40	35	25	40	40	40
Environmental impact of remains	9	12	12	30	30	12	21	21	21
	0.4417	**0.5083**	**0.475**	**0.6833**	**0.6417**	**0.5083**	**0.7083**	**0.675**	**0.7083**
Overall									
Reliability (proven technology)	12	18	24	12	6	6	6	6	6
	0.2	**0.3**	**0.4**	**0.2**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Total	524	579	614	535	478	564	514	557	504
Total	**2.728**	**3.0196**	**3.1266**	**2.9296**	**2.6022**	**2.8103**	**2.7648**	**2.885**	**2.7041**

Figure 45: *Support structure evaluation matrix for 80 m water depth by Patrik Passon*

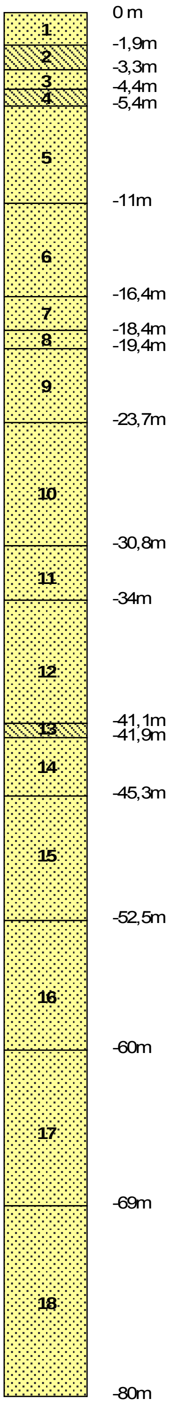
Appendix C: Soil Profiles and Characteristics

<u>Hard soil:</u>



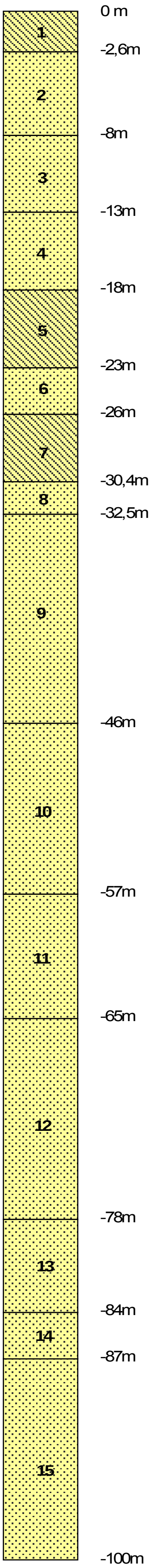
Layer Number	Soil Type	γ' [kN/m^3]	δ [º]	$c_{u,top}$ [kPa]	$c_{u,bottom}$ [kPa]
1	Sand	8.5	20	-	-
2	Sand	9.0	25	-	-
3	Sand	9.0	32	-	-
4	Sand	10.0	30	-	-
5	Sand	10.0	34	-	-
6	Sand	10.0	35	-	-
7	Sand	9.0	30	-	-
8	Sand	10.0	35	-	-
9	Sand	9.0	30	-	-
10	Sand	10.0	35	-	-
11	Sand	10.0	33	-	-
12	Sand	10.0	35	-	-

Intermediate soil:



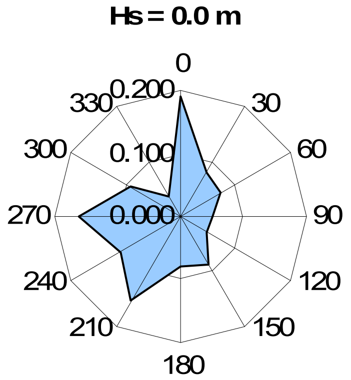
Layer Number	Soil Type	γ' [kN/m^3]	δ [º]	$c_{u,top}$ [kPa]	$c_{u,bottom}$ [kPa]
1	Sand	8.5	15	-	-
2	Clay	8.0	-	20	20
3	Sand	9.0	20	-	-
4	Clay	8.0	-	30	30
5	Sand	11.0	35	-	-
6	Sand	9.5	25	-	-
7	Sand	11.5	35	-	-
8	Silt	9.5	15	-	-
9	Sand	10.5	25	-	-
10	Sand	11.0	30	-	-
11	Silt	9.5	20	-	-
12	Sand	10.5	25	-	-
13	Clay	9.5	-	250	250
14	Sand	10.5	25	-	-
15	Sand	11.0	30	-	-
16	Sand	11.0	30	-	-
17	Sand	10.5	25	-	-
18	Sand	11.5	35	-	-

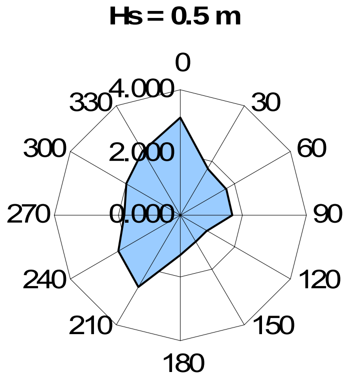
Soft soil:

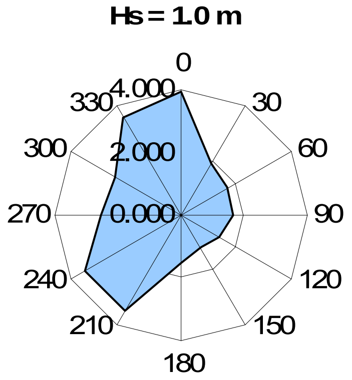


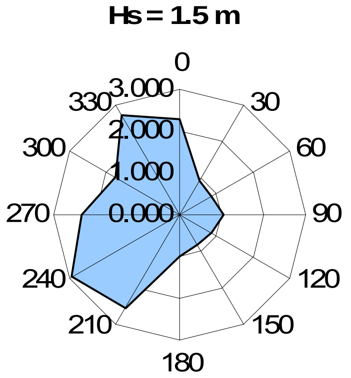
Layer Number	Soil Type	γ' [kN/m^3]	δ [º]	$c_{u,top}$ [kPa]	$c_{u,bottom}$ [kPa]
1	Clay	8.0	-	5	7
2	Sand	10.0	30	-	-
3	Sand	9.0	25	-	-
4	Silt	8.5	15	-	-
5	Clay	8.0	-	60	40
6	Sand	8.5	20	-	-
7	Clay	10.0	-	75	85
8	Sand	10.0	30	-	-
9	Sand	10.0	35	-	-
10	Sand	10.0	35	-	-
11	Sand	10.0	35	-	-
12	Sand	10.0	35	-	-
13	Sand	10.0	35	-	-
14	Sand	10.0	30	-	-
15	Sand	10.0	35	-	-

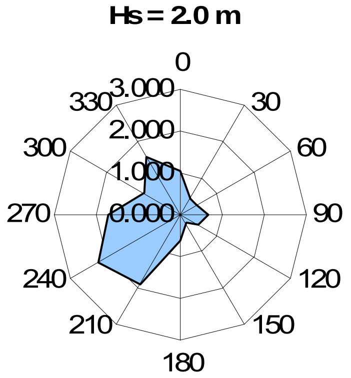
Appendix D: Wave Roses

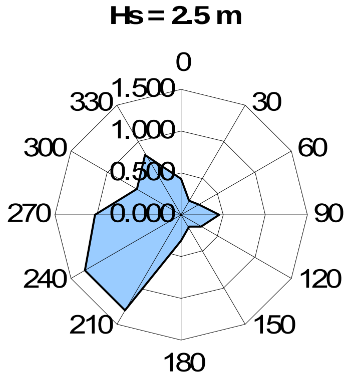


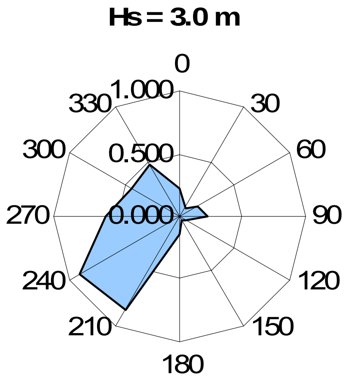


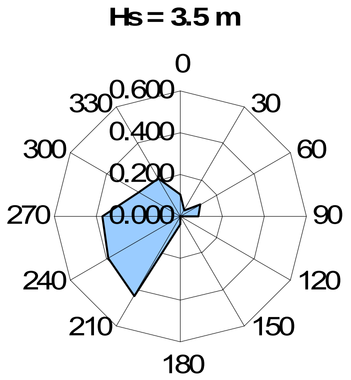


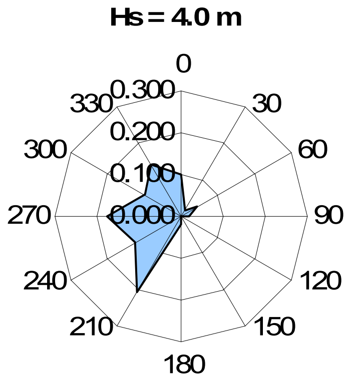




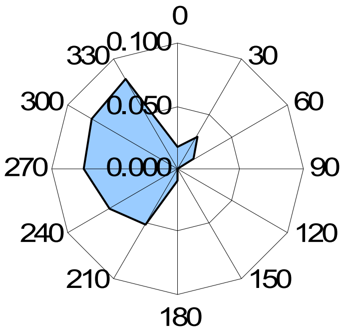




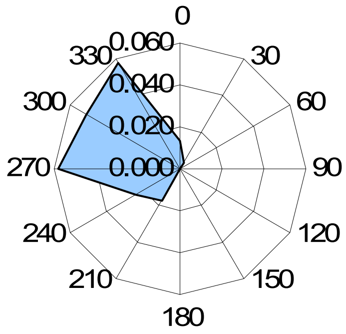




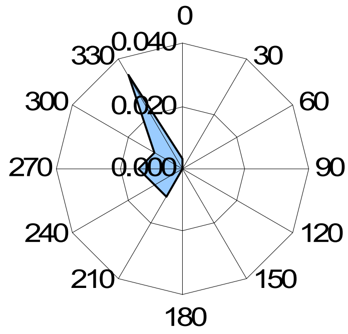
Hs = 4.5 m



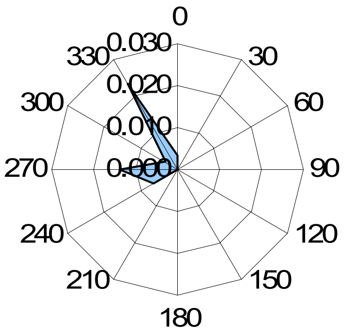
Hs = 5.0 m



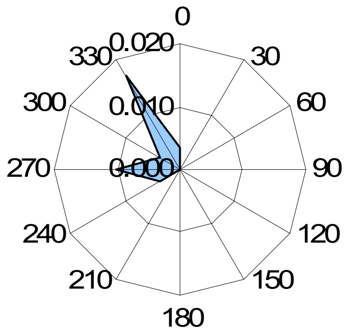
Hs = 5.5 m



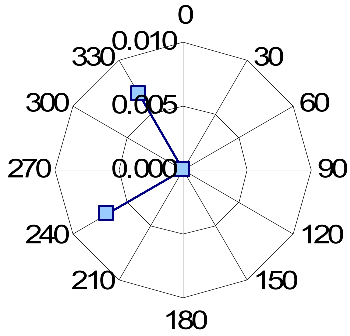
Hs = 6.0 m



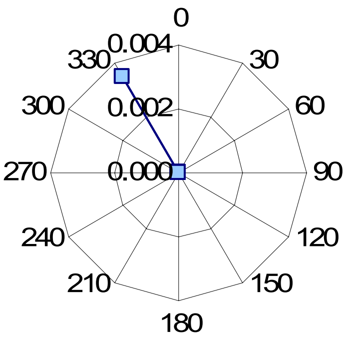
Hs = 6.5 m



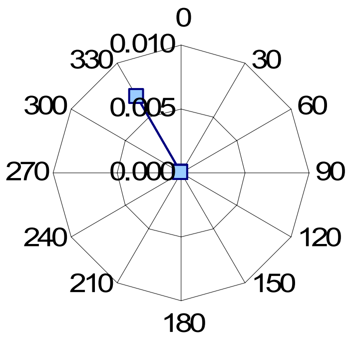
Hs = 7.0 m



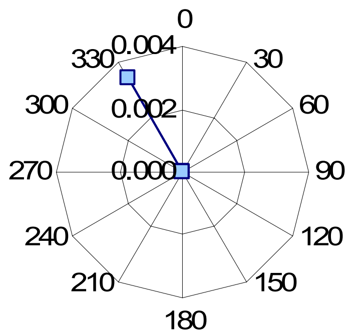
Hs = 7.5 m



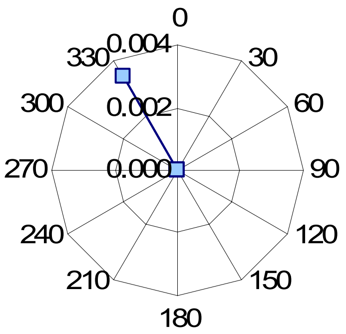
Hs = 8.0 m



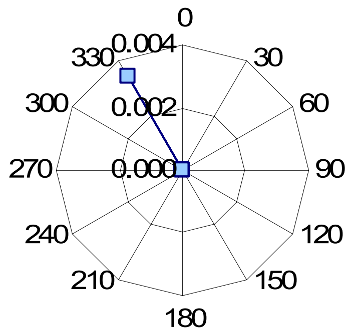
Hs = 8.5 m



Hs = 9.0 m

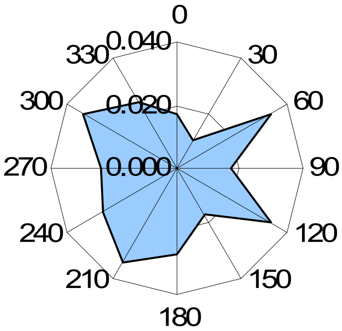


Hs = 9.5 m

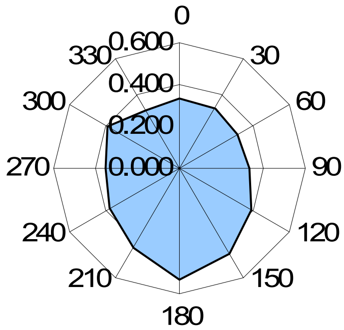


Appendix E: Wind Roses

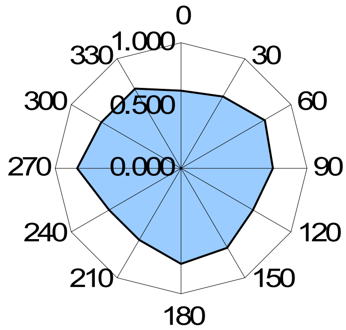
Vw = 0



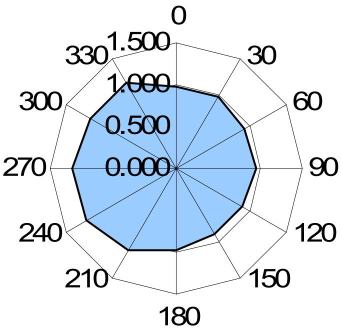
Vw = 2



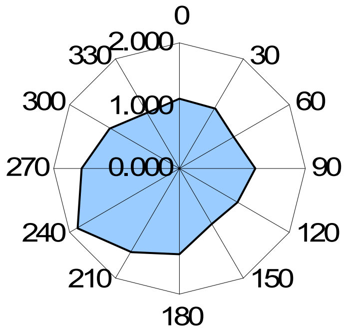
Vw = 4



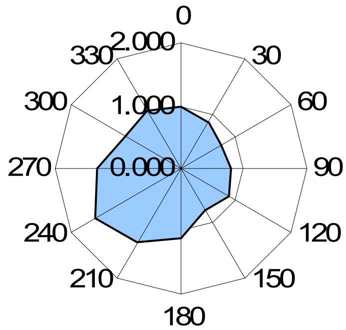
Vw = 6



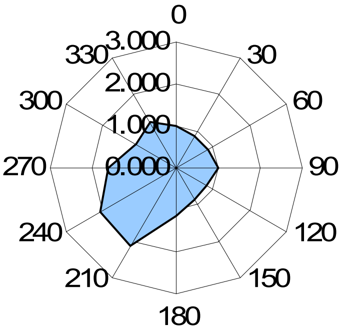
Vw = 8



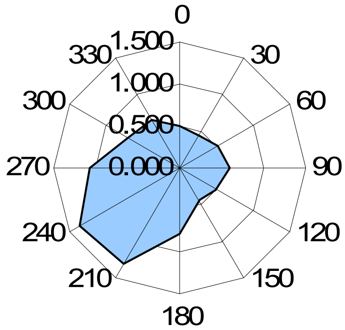
Vw = 10



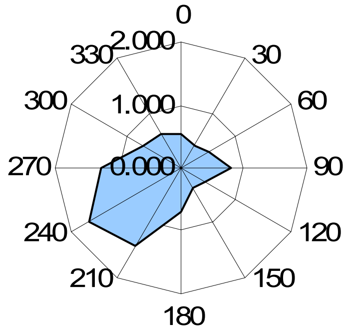
Vw = 12

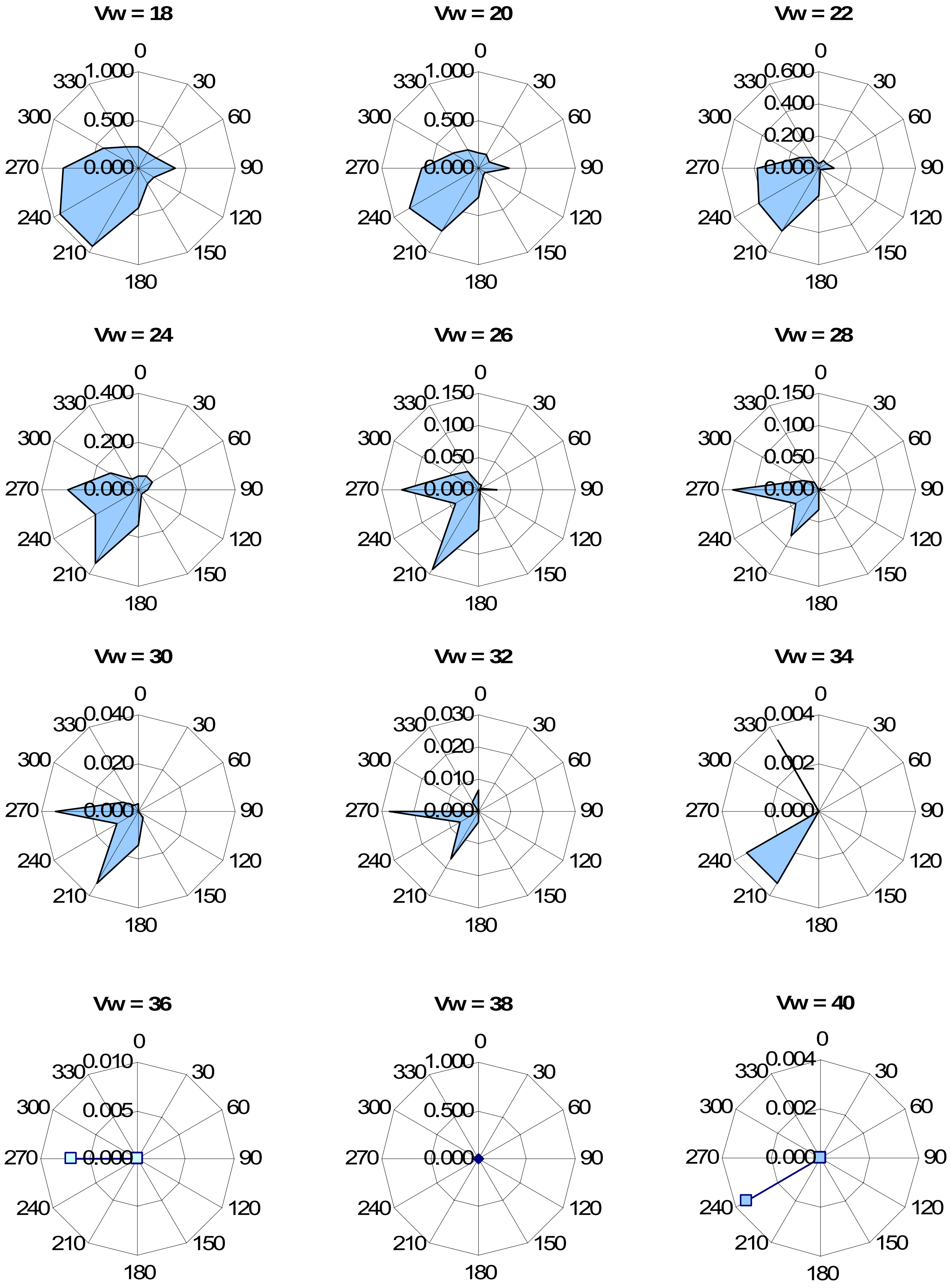


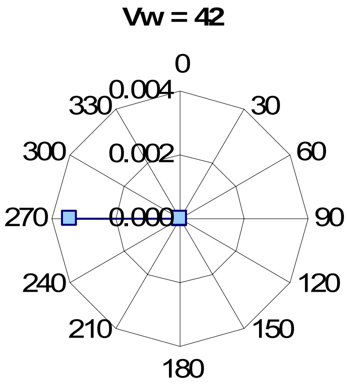
Vw = 14



Vw = 16




Vw = 18
Vw = 20
Vw = 22
Vw = 24
Vw = 26
Vw = 28
Vw = 30
Vw = 32
Vw = 34
Vw = 36
Vw = 38
Vw = 40


Vw = 42
0
30
60
90
120
150
180
210
240
270
300
330
0.004
0.002
0.000

Appendix F: Full 3-D Scatter Diagram

Entries are probability of occurrence of environmental state in %.

Vw = 0		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9												0
	8.5												0
	8												0
	7.5												0
	7												0
	6.5												0
	6												0
	5.5												0
Hs	5												0
	4.5												0
	4												0
	3.5												0
	3												0
	2.5												0
	2						0.0034	0.0069					0.0103
	1.5						0.0137	0.0103					0.0240
	1					0.0411	0.0788	0.0034					0.1234
	0.5				0.0069	0.1165	0.0206						0.1439
	0												0
		0	0	0	0.0069	0.1576	0.1165	0.0206	0	0	0	0	0.3015

Vw = 2		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9												0
	8.5												0
	8												0
	7.5												0
	7												0
	6.5												0
	6												0
	5.5												0
Hs	5												0
	4.5												0
	4												0
	3.5												0
	3							0.0034					0.0034
	2.5						0.0103	0.0034					0.0137
	2						0.0720	0.0583					0.1302
	1.5					0.0377	0.3255	0.1302					0.4934
	1				0.0034	0.7607	0.8943	0.0925					1.7510
	0.5				0.3015	1.6824	0.1645						2.1484
	0				0.0308	0.0411							0.0720
		0	0	0	0.3358	2.5219	1.4666	0.2878	0	0	0	0	4.6121

Vw = 4		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9												0
	8.5												0
	8												0
	7.5												0
	7												0
	6.5												0
	6												0
	5.5												0
Hs	5												0
	4.5												0
	4												0
	3.5							0.0034					0.0034
	3							0.0103					0.0103
	2.5						0.0240	0.0137	0.0069				0.0445
	2						0.1610	0.0720	0.0034				0.2364
	1.5					0.1713	0.8875	0.1645					1.2233
	1					1.9600	1.3603	0.0788					3.3991
	0.5				0.4934	2.7686	0.2056	0.0103					3.4779
	0	0.0069			0.1062	0.0445							0.1576
		0.0069	0	0	0.5996	4.9445	2.6384	0.3529	0.0103	0	0	0	8.5526

Vw = 6		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9												0
	8.5												0
	8												0
	7.5												0
	7												0
	6.5												0
	6												0
	5.5												0
Hs	5												0
	4.5												0
	4												0
	3.5												0
	3						0.0034	0.0137					0.0171
	2.5						0.0788	0.0480					0.1268
	2						0.5174	0.1199					0.6373
	1.5					0.5037	1.6859	0.1028					2.2924
	1				0.0137	3.8206	1.3226	0.0308					5.1878
	0.5				0.7470	3.2381	0.1234	0.0137					4.1221
	0	0.0206			0.1131	0.0685		0.0034					0.2056
		0.0206	0	0	0.8738	7.6309	3.7315	0.3324	0	0	0	0	12.5891

Vw = 8		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9												0
	8.5												0
	8												0
	7.5												0
	7												0
	6.5												0
	6												0
	5.5												0
Hs	5												0
	4.5												0
	4												0
	3.5							0.0240					0.0240
	3						0.0103	0.0720					0.0822
	2.5						0.2227	0.1542					0.3769
	2					0.0034	1.3124	0.1782					1.4940
	1.5					1.4254	2.4089	0.0857					3.9200
	1				0.0206	5.1021	0.9354	0.0069					6.0650
	0.5				0.6442	2.2341	0.0720	0.0137					2.9640
	0	0.0069			0.0754	0.0480							0.1302
		0.0069	0	0	0.7401	8.8130	4.9616	0.5345	0	0	0	0	15.0562

Vw = 10		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9												0
	8.5												0
	8												0
	7.5												0
	7												0
	6.5												0
	6												0
	5.5												0
Hs	5												0
	4.5												0
	4								0.0034				0.0034
	3.5							0.0411	0.0034				0.0445
	3						0.0240	0.1302					0.1542
	2.5						0.5208	0.1576	0.0069				0.6853
	2					0.0034	2.1553	0.0617					2.2204
	1.5					1.8195	2.0045	0.0171					3.8411
	1				0.0343	3.7555	0.3392						4.1290
	0.5				0.4352	0.8738	0.0137						1.3226
	0				0.0171	0.0343							0.0514
		0	0	0	0.4866	6.4864	5.0576	0.4078	0.0137	0	0	0	12.4520

Vw = 12		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9												0
	8.5												0
	8												0
	7.5												0
	7												0
	6.5												0
	6												0
	5.5												0
Hs	5												0
	4.5								0.0034				0.0034
	4							0.0171	0.0034				0.0206
	3.5							0.1508					0.1508
	3						0.1542	0.5517	0.0034				0.7093
	2.5						1.2952	0.2433					1.5385
	2					0.0171	3.6047	0.0274					3.6493
	1.5					2.7172	2.0285	0.0034					4.7492
	1				0.0308	2.8886	0.1028						3.0222
	0.5				0.3118	0.5106	0.0034						0.8258
	0	0.0034			0.0137	0.0206							0.0377
		0.0034	0	0	0.3564	6.1541	7.1889	0.9937	0.0103	0	0	0	14.7067

Vw = 14		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9												0
	8.5												0
	8												0
	7.5												0
	7												0
	6.5												0
	6												0
	5.5								0.0034				0.0034
Hs	5								0.0034				0.0034
	4.5								0.0137				0.0137
	4							0.0548	0.0377				0.0925
	3.5							0.2981	0.0034				0.3015
	3						0.1302	0.6031					0.7333
	2.5						1.5556	0.1268					1.6824
	2					0.0137	2.5288						2.5425
	1.5					1.3603	0.8635	0.0069					2.2307
	1				0.0103	1.0999	0.0206						1.1308
	0.5				0.1131	0.1165							0.2296
	0				0.0034								0.0034
		0	0	0	0.1268	2.5905	5.0987	1.0896	0.0617	0	0	0	8.9672

Vw = 16		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9												0
	8.5												0
	8												0
	7.5												0
	7												0
	6.5												0
	6									0.0034			0.0034
	5.5								0.0034				0.0034
Hs	5								0.0343				0.0343
	4.5							0.0034	0.0583				0.0617
	4							0.1850	0.0788				0.2638
	3.5							0.7299	0.0034				0.7333
	3						0.3118	1.0896					1.4015
	2.5						2.3300	0.1165					2.4465
	2					0.0137	2.3986	0.0103					2.4226
	1.5					0.9149	0.5311						1.4460
	1				0.0069	0.4934	0.0137						0.5140
	0.5				0.0274	0.0480							0.0754
	0												0
		0	0	0	0.0343	1.4700	5.5853	2.1347	0.1782	0.0034	0	0	9.4058

Vw = 18		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9												0
	8.5												0
	8												0
	7.5												0
	7												0
	6.5												0
	6									0.0137			0.0137
	5.5								0.0206	0.0103			0.0308
Hs	5								0.0308				0.0308
	4.5							0.0171	0.1131				0.1302
	4							0.2570	0.0514				0.3084
	3.5							0.6750					0.6750
	3						0.2844	0.9663					1.2507
	2.5						1.2850	0.0274					1.3124
	2					0.0103	0.8087	0.0034					0.8224
	1.5					0.2159	0.1439						0.3598
	1				0.0034	0.1165	0.0069						0.1268
	0.5					0.0034							0.0034
	0												0
		0	0	0	0.0034	0.3461	2.5288	1.9463	0.2159	0.0240	0	0	5.0644

Vw = 20		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9												0
	8.5												0
	8												0
	7.5									0.0069			0.0069
	7									0.0034			0.0034
	6.5									0.0069			0.0069
	6									0.0069			0.0069
	5.5								0.0240	0.0103			0.0343
Hs	5								0.0857				0.0857
	4.5							0.0514	0.1748				0.2262
	4							0.4626	0.0480				0.5106
	3.5							0.9492					0.9492
	3						0.2638	0.6442					0.9080
	2.5						0.6819	0.0103					0.6922
	2					0.0103	0.3187						0.3289
	1.5					0.0925	0.0206						0.1131
	1					0.0206							0.0206
	0.5												0
	0												0
		0	0	0	0	0.1234	1.2850	2.1176	0.3324	0.0343	0	0	3.8925

Vw = 22		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9												0
	8.5												0
	8												0
	7.5									0.0034			0.0034
	7									0.0069			0.0069
	6.5									0.0034			0.0034
	6									0.0137			0.0137
	5.5								0.0445	0.0069			0.0514
Hs	5								0.0857				0.0857
	4.5							0.0514	0.1234				0.1748
	4							0.4283	0.0171				0.4454
	3.5							0.5071					0.5071
	3						0.0685	0.2913					0.3598
	2.5						0.1782	0.0206					0.1987
	2						0.0514						0.0514
	1.5					0.0034							0.0034
	1					0.0034							0.0034
	0.5												0
	0												0
		0	0	0	0	0.0069	0.2981	1.2987	0.2707	0.0343	0	0	1.9086

Vw = 24		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9												0
	8.5										0.0034		0.0034
	8										0.0034		0.0034
	7.5									0.0069			0.0069
	7									0.0103			0.0103
	6.5									0.0069			0.0069
	6								0.0034	0.0240			0.0274
	5.5								0.0480	0.0206			0.0685
Hs	5								0.1610				0.1610
	4.5							0.1131	0.1542				0.2673
	4							0.3529					0.3529
	3.5							0.2673					0.2673
	3						0.0480	0.1028					0.1508
	2.5						0.0925	0.0069					0.0994
	2						0.0206						0.0206
	1.5					0.0034	0.0034						0.0069
	1												0
	0.5												0
	0												0
		0	0	0	0	0.0034	0.1645	0.8429	0.3666	0.0685	0.0069	0	1.4529

Vw = 26		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9												0
	8.5												0
	8												0
	7.5										0.0034		0.0034
	7									0.0069	0.0069		0.0137
	6.5									0.0137			0.0137
	6								0.0103	0.0206			0.0308
	5.5								0.0480	0.0034			0.0514
Hs	5								0.0583				0.0583
	4.5							0.0343	0.0583				0.0925
	4							0.1131					0.1131
	3.5							0.0617					0.0617
	3						0.0137	0.0206					0.0343
	2.5						0.0171						0.0171
	2						0.0034						0.0034
	1.5						0.0034						0.0034
	1												0
	0.5												0
	0												0
		0	0	0	0	0	0.0377	0.2296	0.1748	0.0445	0.0103	0	0.4968

Vw = 28		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9										0.0034		0.0034
	8.5												0
	8									0.0069			0.0069
	7.5									0.0171	0.0034		0.0206
	7									0.0034			0.0034
	6.5									0.0274			0.0274
	6								0.0171	0.0206			0.0377
	5.5								0.0548	0.0034			0.0583
Hs	5								0.0617				0.0617
	4.5							0.0274	0.0240				0.0514
	4							0.0308					0.0308
	3.5							0.0274					0.0274
	3							0.0137					0.0137
	2.5												0
	2												0
	1.5												0
	1												0
	0.5												0
	0												0
		0	0	0	0	0	0	0.0994	0.1576	0.0788	0.0069	0	0.3427

Vw = 30		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5										0.0034		0.0034
	9												0
	8.5												0
	8												0
	7.5												0
	7									0.0034			0.0034
	6.5									0.0069			0.0069
	6								0.0137	0.0069			0.0206
	5.5								0.0137				0.0137
Hs	5								0.0343				0.0343
	4.5							0.0103	0.0034				0.0137
	4							0.0103					0.0103
	3.5												0
	3						0.0034						0.0034
	2.5												0
	2												0
	1.5												0
	1												0
	0.5												0
	0												0
		0	0	0	0	0	0.0034	0.0206	0.0651	0.0171	0.0034	0	0.1096

Vw = 32		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10										0.0034		0.0034
	9.5												0
	9												0
	8.5												0
	8									0.0034			0.0034
	7.5												0
	7									0.0034			0.0034
	6.5									0.0034			0.0034
	6								0.0137	0.0034			0.0171
	5.5								0.0069				0.0069
Hs	5								0.0137				0.0137
	4.5							0.0069					0.0069
	4												0
	3.5												0
	3							0.0034					0.0034
	2.5						0.0034						0.0034
	2												0
	1.5												0
	1												0
	0.5												0
	0												0
		0	0	0	0	0	0.0034	0.0103	0.0343	0.0137	0.0034	0	0.0651

Vw = 34		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9												0
	8.5												0
	8												0
	7.5												0
	7									0.0034			0.0034
	6.5									0.0034			0.0034
	6												0
	5.5												0
Hs	5												0
	4.5							0.0034					0.0034
	4												0
	3.5												0
	3												0
	2.5												0
	2												0
	1.5												0
	1												0
	0.5												0
	0												0
		0	0	0	0	0	0	0.0034	0	0.0069	0	0	0.0103

Vw = 36		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9												0
	8.5												0
	8												0
	7.5									0.0034			0.0034
	7												0
	6.5												0
	6												0
	5.5								0.0034				0.0034
Hs	5												0
	4.5												0
	4												0
	3.5												0
	3												0
	2.5												0
	2												0
	1.5												0
	1												0
	0.5												0
	0												0
		0	0	0	0	0	0	0	0.0034	0.0034	0	0	0.0069

Vw = 38		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9												0
	8.5												0
	8												0
	7.5												0
	7												0
	6.5												0
	6												0
	5.5												0
Hs	5												0
	4.5												0
	4												0
	3.5												0
	3												0
	2.5												0
	2												0
	1.5												0
	1												0
	0.5												0
	0												0
		0	0	0	0	0	0	0	0	0	0	0	0

Vw = 40		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9												0
	8.5												0
	8									0.0034			0.0034
	7.5												0
	7												0
	6.5												0
	6												0
	5.5												0
Hs	5												0
	4.5												0
	4												0
	3.5												0
	3												0
	2.5												0
	2												0
	1.5												0
	1												0
	0.5												0
	0												0
		0	0	0	0	0	0	0	0	0.0034	0	0	0.0034

Vw = 42		Tz											
		0	1	2	3	4	5	6	7	8	9	10	
	10												0
	9.5												0
	9												0
	8.5												0
	8												0
	7.5												0
	7												0
	6.5												0
	6												0
	5.5								0.0034				0.0034
Hs	5												0
	4.5												0
	4												0
	3.5												0
	3												0
	2.5												0
	2												0
	1.5												0
	1												0
	0.5												0
	0												0
		0	0	0	0	0	0	0	0.0034	0	0	0	0.0034