Design of support structures for offshore wind turbines – Interfaces between project owner, turbine manufacturer, authorities and designer

Entwurf von Tragstrukturen für Offshore-WEA – Schnittstellen zwischen Projekteignern, WEA-Herstellern, Behörden und Tragwerksplanern

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Zusammenfassung
Der Entwurf von Tragstrukturen für Offshore-Windenergieanlagen ist in technischer und logistischer Hinsicht eine anspruchsvolle Aufgabe. In diesem Prozess gibt es viele Beteiligte, die zahllose Schnittstelle technischer und kommerzieller Art haben. Zur effizienten Behandlung dieser Schnittstellen sind zum Teil spezielle technische Vorgehensweisen hilfreich, die in dieser Veröffentlichung dargestellt werden. Der Erfolg eines Projektes insgesamt hängt maßgeblich von der erfolgreichen Abwicklung der Schnittstellen ab.

Summary
Design of support structures for offshore wind turbines is a challenging subject both technically and logistically. Many stakeholders are involved in this process, which have many technical and commercial interfaces. Managing these interfaces can involved special technical approaches and procedures, some of which are discussed in this paper. It is of great benefit to the project if these interfaces are managed well.

1. Introduction

Offshore wind turbine installations are challenging objects for engineers of multiple disciplines, project owners and authorities. As support structures (comprising tower, substructure and foundations) are specific to every project, organizing interfaces between the various parties is important. This paper aims to provide some insight how these interfaces can be managed efficiently if all parties are willing to assume the responsibilities which are best taken care of by them. This is unfortunately not always the case, as parties try to mitigate risks to other parties.

2. Project certification and BSH approval process

2.1. General remarks

An overview of the certification process is given in Fig. 1, which is taken from the forthcoming internal standard IEC 61400-22 [5]. This paper does not include a detailed discussion about project certification; this can be found in numerous publications, mainly from the certification bodies.

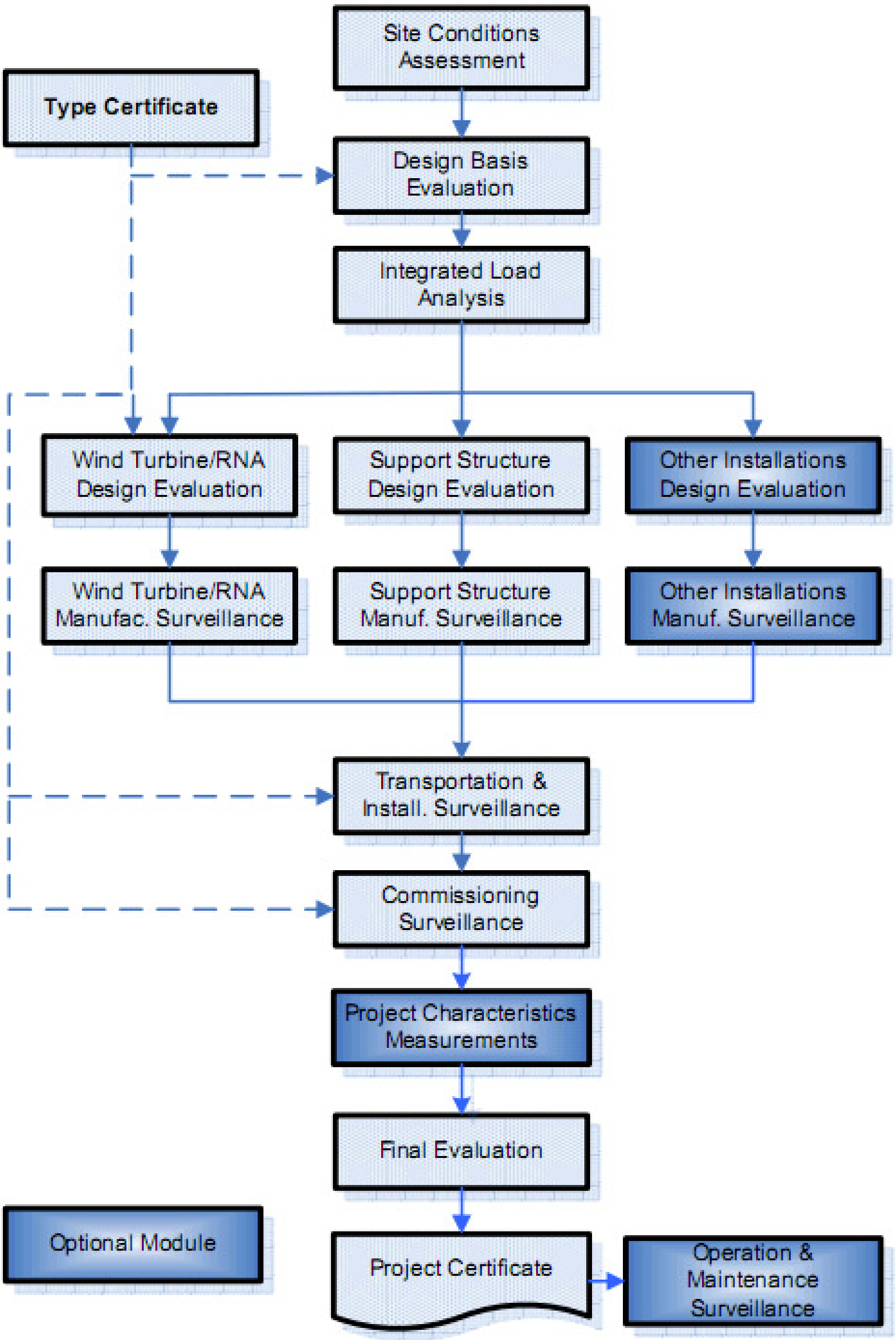

Fig. 1: Modules in Project Certification (from IEC 61400-22 [5])

Abbildung 1: Module der Projekt-Zertifizierung (aus IEC 61400-22 [5])

Some form of certification is customary for every project, although extent of certification varies. So far, the certification process and (if required) review by other authorities like BSH in Germany are rarely organized in an efficient way. This is mainly due to lack of experience from the relevant players and hence non-sufficient knowledge about optimal organization for this process.

2.2. Documentation requirements for the "Design Basis" and "Design Brief"

The following definitions follow Norsok standard N-004 (Design of steel structures, Rev. 2). They are partly adopted to suit the specific requirements for offshore wind turbine installations, but still they can be regarded as proven principles from the Oil&Gas sector. Hence, it is deemed sensible to adopt procedures which have proven to work in this area.

Generally, adequate planning shall be undertaken in the initial stages of the design process in order to obtain a workable and economic structural solution to perform the desired function. As an integral part of this planning, documentation shall be produced identifying design criteria and describing procedures to be adopted in the structural design of the support structure for the wind turbines.

Design documentation (see below) shall, as far as practicable, be concise, non-voluminous, and should include all relevant information for all phases of the lifetime of the unit.

2.2.1. Design Basis incl. site conditions

The "Design Basis" is prepared at the beginning of the design process. It is one of the most important documents in the entire process and its value and relevance should be recognized by project owners!

The **Design Basis** is a catalogue of requirements set forth by the Owner. It contains specific design requirements for the planned offshore wind farm. That implies that quantities which have inherent uncertainty (e.g. predicted wind speeds) are presented as unambiguous design values, which also reflect the Owner's desired level of safety. It is important that the Design Basis achieves a proper balance between defining the input which can only be given by the owner and leaving room to take advantage of the designer's experience by not being too specific e.g. about design methods. The Design Basis has to be certified by the project certification body.

Items to be included in the Design Basis document typically are as stated in Table 1.

Item	Comment
Applicable regulations, codes and standards (including revisions and dates)	Standards stated in the Design Basis reflect specific Owner's requirements; the list of standards shall therefore not be a comprehensive collection of standards available around the world – it should be as brief as possible and unambiguous. The **hierarchy** of codes is an important part in this respect. The owner must define which standards he wants to have primarily fulfilled and which can be used additionally if the governing standard does not contain sufficient guidance. It should be noted that for Germany, DIN standards must be used as governing standards.
General project description, main dimensions (interface level, hub height, etc.)	Interface levels (level for mechanical connection, e.g. L-flange) shall be clearly defined to set-up mechanical models and to allow contractors to precisely define their scope of work (e.g. tower length or total substructure height).

Item	Comment
Turbine locations and water depths	Wind farm layout incl. design water depths must be given. Design water depths (min. and max. values) include predicted or assumed variance of water depth during lifetime of the turbine. In areas with highly mobile seabed (e.g. on sandbanks), the difference between min. and max. design seabed level may be several meters and it is up to the designer to determine which seabed level is governing the design. High seabed levels may esp. be important when wave heights approach the breaking limit.
Environmental data (wind, waves, ice, etc.)	Comprehensive environmental data must be stated. By clearly defining the design values e.g. for extreme wind speeds, the owner of the wind farm also defines how he wants to deal with the inherent uncertainties of predictions for environmental data.
Soil data incl. design soil profiles	Design soil profiles incl. characteristic values, upper and lower bound estimates shall be provided for stiffness and strength values. Upper and lower bound values must be provided with reasonable accuracy to allow economical design.
Interface requirements (including e.g. appurtenance dimensions and routing)	If already known, details of interfaces to other contractors may be included in the Design Basis.
Coating and corrosion protection system requirements	Definition should include general requirements w.r.t. allowed systems, in-service inspection and repair philosophy and specification of corrosion allowance to be used. This is important to be defined precisely because the lifetime-cost and requirements do depend on the foreseen maintenance strategy during service life.
In-service inspection philosophy to be adopted	Client should specify the planned in-service inspection regarding structural integrity (fatigue cracks) and e.g. monitoring and potential removal of marine growth such that the design can be adopted accordingly.
Assessment methods (ULS, FLS, SLS)	Assessment methods shall only be stated in detail if they are not covered by the governing standards and if the Client wants to stipulate use of certain methods; otherwise, design methods are within the responsibility of the designer and are stated in his Design Brief.

Table 1: Contents of the Design Basis

Tabelle 1: Inhalt einer "Design Basis"

2.2.2. Design Premise

The Design Premise from contractors (e.g. the wind turbine manufacturer) summarizes input values extracted from the Design Basis (and supplementary documents, if relevant). Such document may be necessary as input from the Design Basis may need further processing before being ready for use.

2.2.3. Design Briefs

Design Briefs shall be created in the initial stages of the design process. The purpose of the Design Briefs is to document the criteria and procedures to be adopted in the design of the support structures. The Design Briefs are prepared by the parties being responsible for the component in question.

The Design Briefs shall, as far as practicable, be concise, non-voluminous, and, should include all relevant limiting design criteria for the relevant design phase. Design Briefs required are e.g. as stated in Table 2.

Design Brief	Responsibility
Design Brief for tower design evaluation	Wind Turbine Manufacturer
Design Brief for integrated load calculations	Wind Turbine Manufacturer
Design Brief(s) for substructure design evaluation	Substructure Designer

Table 2: Overview of Design Briefs in a project

Tabelle 2: Überblick über "Design Brief"-Dokumente in einem Projekt

Structural design briefs typically cover the following topics:

- ULS assessment (Extreme Event)
- FLS assessment (Fatigue)
- SLS assessment (Serviceability)
- Material selection
- Modal analysis
- Grouted Connections (if relevant)
- Corrosion & Cathodic Protection
- Scour Protection Design (if relevant)
- Ship Impact
- Geotechnical assessment
- Secondary Steel Design
- FE Analyses of Details

2.3. BSH approval process (Germany only)

In Germany, approval for offshore wind farms is granted by BSH ("Bundesamt für Seeschifffahrt und Hydrographie" = Federal Maritime and Hydrographic Agency).

The approval process for the design phase is described in [6]. A specific flow-chart is shown in Fig. 2. This flow-chart does also show the responsibilities of all parties participating in the design process.

The BSH approval process is specific to German projects, but the general process is also valid for projects outside of Germany. The BSH approval process is not yet an established procedure, hence it is expected that it will further develop with the experience gained from the first projects. The description here is based on the experience of the author and his interpretation of the BSH standard.

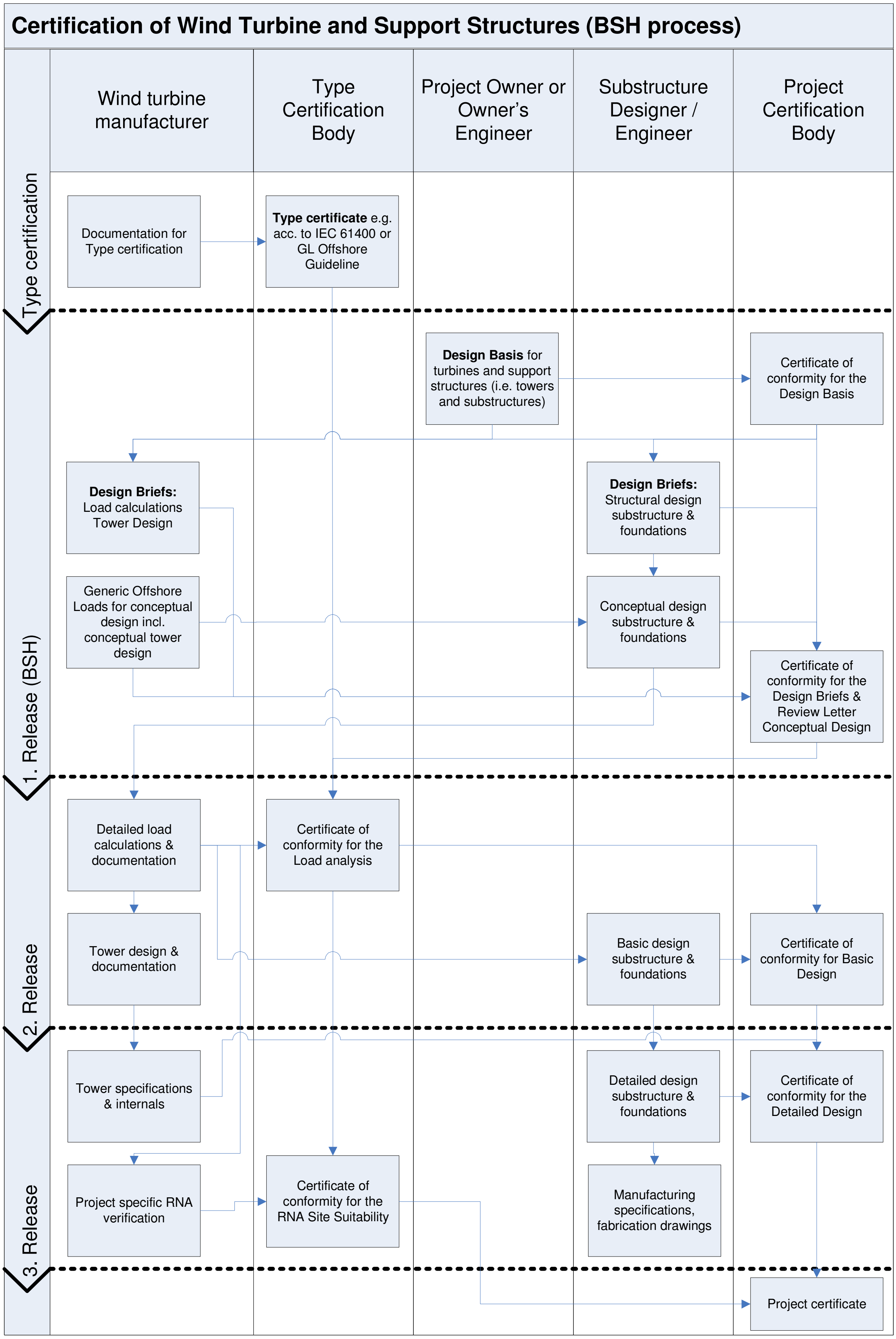

Fig. 2: Certification process (incl. BSH approval phases)

Abbildung 2: Zertifizierungs-Prozess (inkl. Ablauf für die BSH-Genehmigung)

For certification acc. to BSH standard it is important to know that BSH requires that technical rules acknowledged by German authorities are applied. A list of accepted standards ("Bauregelliste") can be found at "Deutsches Institut für Bautechnik" (DIBt):

http://www.dibt.de/en/News_Technische_Baubestimmungen.html

Use of other standards (e.g. DNV, API, etc.) is only accepted by BSH if the standards given in above list do not contain applicable rules. Such deviations must be applied for and justification for such an approach must be elaborated in detail.

If a design detail is not covered by above list, then the second-best source for potentially acceptable standards to be used are published DIN standards. These can be found at www.beuth.de. It can e.g. be noted that ISO 19902 has been published as DIN EN ISO 19902 [7].

The following shall be considered when preparing documentation for the different stages.

1st Release:

- BSH requires that design procedures are already stated in detail for the 1st Release. That implies that the Design Briefs must be supplied at this stage! This may be difficult to achieve in reality, because contractors are not yet known. This is something which must be agreed upon with BSH.
- The degree of refinement and accuracy of the conceptual design is low for the 1st release. It is important though, that possible substructures and the corresponding overall structural layout (platform height, hub height, etc.) are given. It is sufficient at this stage that masses, structural dimensions, etc. are estimated within an accuracy of about ±20%, but generally values should rather be on the conservative side.
- Upper bound estimates of structural dimensions shall be provided; special care should be paid to all aspects related to the Environmental Impact Assessment (EIA), e.g.:
  - Diameter of Gravity Base Structures (GBS), extent of soil excavation and seabed preparation and sediment management concept (e.g. reuse as ballast)
  - Scour protection concept and dimensions
  - Pile lengths and dimension (important for driving noise)

2nd Release:

- 2nd release must be achieved at least one year before installation begins. Therefore, the certified Design Basis should be finished at least 24 months before scheduled start of installation in order to allow sufficient time to prepare documentation.
- The load calculations at this stage will be site-specific, taking the actually planned substructures into account. Therefore, the resulting Basic Design will be very close to the final Detailed Design, which is documented for the 3rd release.

3. Engineering process

Engineering and certification are parallel processes. This section describes the (typical) engineering process which is required for certification of RNA (rotor-nacelle-assembly, i.e. turbine nacelle, hub and blades), tower and substructure.

The design process for the support structure is typically iterative because the structural stiffness has an impact on the loads. An overview for this iterative procedure is provided in Fig. 3. For this figure it is assumed that the wind turbine simulation is carried out with Flex 5 and the substructure design with ANSYS ASAS(NL).

During this process the components are checked as an integrated system. Adverse conditions (e.g. resonance problems leading to increase in loads due to unfavorable eigenfrequencies or excessive dynamic excitation from wave loading due to insufficient stiffness of the substructure) will be detected and appropriate changes to the system can then be made (*"interface check"* in Fig. 3). Changes may be necessary esp. to the stiffness of the support structure (tower and/or substructure) or to controller settings of the turbine (where applicable).

The number of iterations required depends on site conditions and type of substructure. Generally, the following can be assumed:

- Jackets are not sensitive to wave loading and loads are only moderately affected by changes in structural stiffness. Therefore, just one iteration is often sufficient in this case. The lower part of the jacket and the pile design itself may be an exception to this rule as they are more sensitive to soil properties, esp. lateral stiffness assumptions.
- Monopiles and some Gravity Base Structures (GBS) are much more sensitive to wave loading and also soil stiffness. In this case, two or more iterations are typically required.

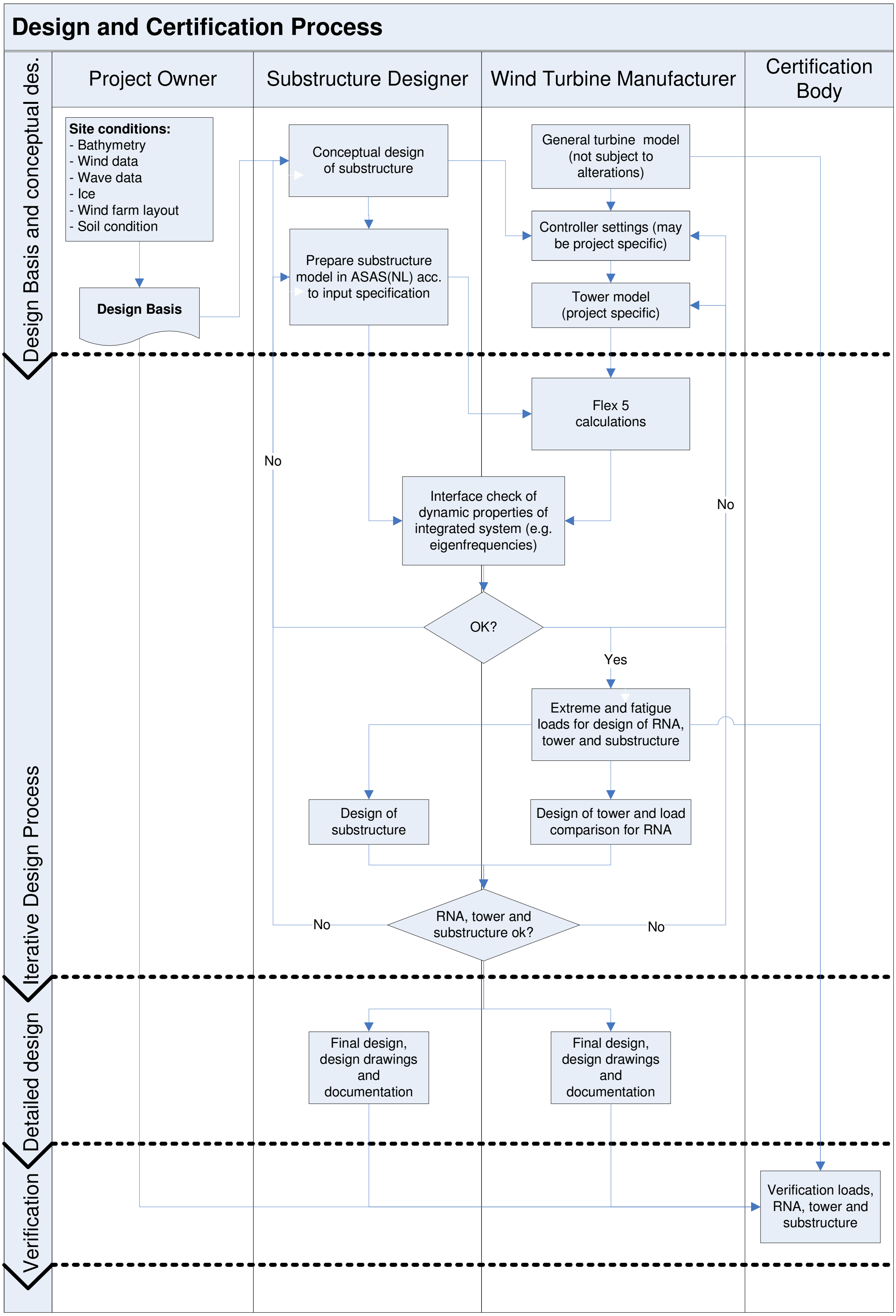

Fig. 3: Iterative design process

Abbildung 3: Iterativer Entwurfsprozess

4. Integrated load analysis

Integrated load analysis is an important part of the design process. Since 2008, the new standard IEC 61400-3 exists [4] which is regarded as the most up-to-date reference for offshore load calculations. Nevertheless, it is recognized by experts and also the IEC maintenance group that this area is still in rapid development and therefore review of first practical experience using the standard will be used to further develop its contents.

During this process, it is required that a model of the substructure, which is typically not under the responsibility of the wind turbine manufacturer, is used for the load calculations. Interface problems are minimized in this case if the model can be prepared by the substructure designer himself. This can e.g. be done by using the sequential coupling method as described in [1]. REpower has developed calculation procedures which can make effective use of externally prepared ASAS(NL) models (which must be prepared in a precisely specified way). The sequential coupling has been found to be conservative compared to more accurate models, see [2].

A visualization of such an integrated model is shown in Fig. 4.

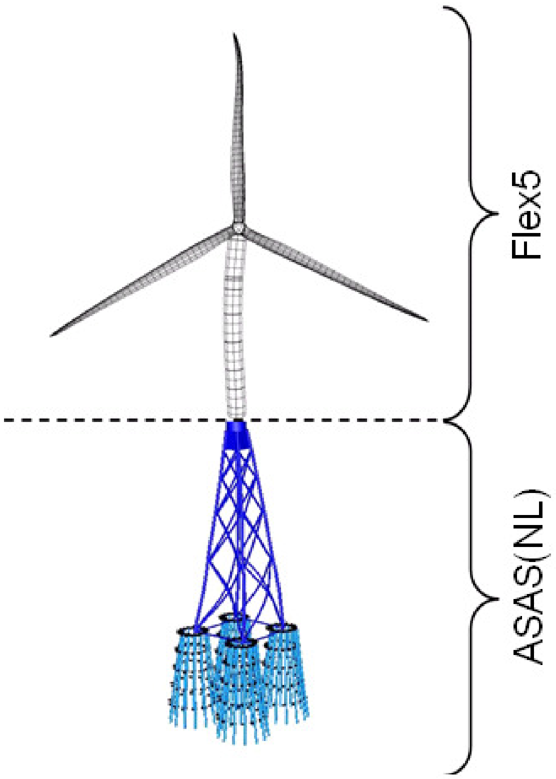

Fig. 4: Integrated model for load simulations

Abbildung 4: Integriertes Modell für Lastsimulationen

Using such an approach, the design process can be organized as follows:

1) Structural models are prepared by the substructure designer in accordance with the input specification. The substructure designer can hence model the substructure with the required accuracy under his own responsibility.

2) Said models are used in a sequential analysis by the wind turbine manufacturer, the global dynamical behaviour and impact of wave loads are then adequately covered.
3) Loads and/or displacement time series at the tower-substructure interface are transferred to the substructure designer for further processing, i.e. ULS and FLS design. This is a big advantage for the design because model consistency is ensured throughout the whole process.

This approach has been used successfully by REpower in several projects. The same approach can also be used with other codes, e.g. Poseidon (developed by Cord Böker at the Leibniz University of Hannover [3]) if the procedures are adapted to suit the input formats of such other codes.

The responsibilities should ideally be split as follows:

- Responsibility relevant for the hydrodynamic loading should rest with the substructure designer. He should provide all relevant input to the wind turbine manufacturer (e.g. regarding hydrodynamic coefficients or special items like time series of breaking wave forces). This goes along with the responsibility for the structural model itself.
- Responsibility for integrating the wave loads in the integrated load analysis rests with the turbine manufacturer, because he is essentially the only party capable to assume this responsibility.

During the integrated load analysis, it is important to understand the system's behaviour and to adopt the design approach accordingly. It is e.g. crucial to understand whether wave excitation is a significant issue for (global) fatigue loads of the structure. This is typically the case for Monopiles. In this case, great care must be exercised to take account of the following:

a) Dynamic excitation due to wave loading is strongly influenced by the **first natural frequency and the mode shape** in the wave loaded zone. Accurate determination of soil stiffness and soil-pile-interaction is therefore important.

b) Damping is small in cross-wind direction as no (or only small) aerodynamic damping exists. This means that esp. wind-wave-misalignment can be critical. It is therefore crucial to accurately define the **overall structural damping** (which is also influenced by soil damping) and **wind-wave-directionality**.

For jackets, on the other hand, wave loading is much less important. The above mentioned items can therefore be treated in a simplified manner. Only in the lower part of the jacket, member forces are influenced by pile stiffness and care when modelling soil-pile-interaction is required.

5. Installation tolerances

Tolerances are another important interface between various parties. Some cases with importance also for the design works are:

1) **Substructure inclination:** Permanent inclination of the substructure, resulting from installation tolerance and settlement during operation, causes additional loading due to the resulting eccentricities of nacelle, tower, etc. Typically, an allowable total

inclination of 0.5° is taken into account for the design which must be properly ensured during installation and potentially be monitored during service life.

2) **Positional tolerances of bolts:** Esp. for gravity based structures, where anchor cages are often used to connect substructure and tower, the positional tolerances of the bolts is important (Fig. 5), because many bolts have to fit into many holes when the tower is installed onto the substructure. This can have an impact at the design stage, because larger tolerances can be allowed if the construction is adapted accordingly (e.g. by using larger bolt holes with special washers in the tower bottom flange).

3) **Tolerances for L-flanges:** If an L-flange (inside of the tower) is used to connect tower and substructure (as e.g. done when jackets are used), then flange flatness and out-of-roundness are crucial tolerances to ensure reliability of the connection as well as ability to install the towers (which could be endangered when the out-of-roundness tolerance is exceeded).

Fig. 5: Mechanical interface for a gravity base structure (GBS)

Abbildung 5: Mechanische Schnittstelle für eine Schwergewichtsgründung

6. Summary

Interfaces between all parties in an offshore wind project are numerous during design, certification and construction. In this paper, some items regarding esp. regarding substructure design have been discussed, but there are countless other interfaces in other disciplines (e.g. cabling and windfarm management) as well. Proper management of these interfaces, esp. clearly identifying and accepting responsibilities is of big importance for the success of a project.

7. References

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