

## Jacket substructures for the REpower 5M wind turbine

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### Summary

Jacket substructures are an attractive solution in water depths of about 20m to 50m for Offshore wind turbines. REpower has gained experience with two different jackets through realization of prototype projects. A welded jacket and an alternative with cast nodes are presented in this paper. The main design challenges are addressed and the peculiarities of the design process compared to jackets in the Oil&Gas sector are described. Furthermore indicative comparison to a tripod solution is made. The conclusion is that jacket substructures are at an early stage of their development for use in Offshore wind and have good potential to develop to an esteemed solution through further development of the industry and methods employed for mass fabrication and installation.

### 1. Introduction

Support structures for Offshore application, esp. in deeper waters, have been identified by many sources as a vital contribution to cost effective installations. For larger turbines like the REpower 5M demands for the support structures increase significantly compared to smaller turbines. REpower has gained experience with jacket substructures for the REpower 5M turbine in recent projects. The conclusions from this experience will be summarized in this paper.

Jacket structures are commonly used in the Oil&Gas sector, see e.g. Fig. 1 which shows a typical light-weight jacket. Many design elements and assessment procedures can be transferred to the design of jackets for Offshore Wind turbines, but some areas require new constructions or special consideration in the design process. These items will be highlighted later.



Fig. 1: Typical light-weight jacket (courtesy of Aker Kværner Verdal)

## 2. Evaluation of different jacket solutions

REpower has been involved in two projects where jacket solutions have been used together with the REpower 5M wind turbine. The first project is the Beatrice Demonstrator Windfarm (part of the DOWNVIInD research programme) where two 5M have been installed on welded jackets [1] [6] offshore in 45m water depth. A prototype for another solution with cast nodes is currently being built by Weserwind Offshore Construction GmbH in Bremerhaven on an onshore location (Fig. 2, Fig. 4). This jacket has been designed to be suitable for the “alpha ventus” project with 30m water depth as well.



Fig. 2: CAD model of turbine and jacket (Bremerhaven prototype)

Both welded and cast designs have their merits and it is not easy to determine which construction is best suited for a project. This does to a high extent depend on the fabricators involved.

Welded constructions (Fig. 3) have the following advantages:

- Fit-up is more flexible, i.e. tolerances can be accommodated easier.
- The high cost for steel castings is avoided.
- Generally the construction is more flexible, whereas equal nodes are desirable for the cast version (at least for smaller number of installations – for large numbers different castings can be justified).
- The number of welds is smaller as circumferential welds in the legs at the nodes can at least be partly avoided.



**Fig. 3: Fabrication of the Beatrice jackets and transition nodes (courtesy of Burntisland Fabrications Ltd.)**

Advantages of the construction with cast nodes (Fig. 5) are:

- Only simple circumferential welds are to be executed, these can be efficiently fabricated with automated welding processes (Fig. 6). This reduces the number of skilled welders which need to be involved.
- Quality control on the circumferential welds can be automated and is more reliable compared to complex welds at tubular nodes.
- Cast elements have a high fatigue and ultimate capacity and they can be manufactured with continuous high quality.
- Nodal angles can be varied on a broader scale, i.e. there are less constraints for the overall layout.



**Fig. 4: Assembly of the jacket with cast nodes on site in Bremerhaven (courtesy of Weserwind GmbH)**



Fig. 5: Casted KK-node



Fig. 6: Automated welding (courtesy of Weserwind GmbH)

The implication of these arguments for both variants is that different manufacturers will have different preferences depending on their capabilities. It can be assumed though that the cast version will have advantages esp. for large number of structures (serial production). In such a case the production processes can be streamlined to take full advantage of the automated welding process.

The typical weight for jacket (REpower design) in 30m water depth in the German North sea is given in Table 1. The jacket itself (legs and bracings) is only about 1/3 of the total weight per installation. Foundations (piles) do also contribute about 1/3 and the remainder is other items like the transition node or pile sleeves. These weights can differ significantly depending on the construction type chosen. Pile sleeves do e.g. become dramatically heavier when swaging is used to connect sleeves and piles. Other transition node constructions may also be significantly heavier than the solution developed by REpower which is relatively light-weight.

Jacket frame (Legs & bracings)	<u>Primary structure:</u> $\Sigma=425t$	<u>Jacket subtotal:</u> $\Sigma=510t$	<u>Total weight per installation:</u> $\Sigma=825t$
Pile sleeves			
Transition node incl. platform			
Boat landings (2 pcs.)	<u>Secondary structures:</u> $\Sigma=85t$		
Misc. (e.g. J-tubes)			
Anodes			
Piles	315t (8 piles, D=1067mm, L=50m, t=30mm)		

Table 1: Typical weight break-down for Jacket at „alpha ventus“ (Borkum West)

An estimated weight for a tripod at the same site is shown in Table 2. It can be seen that the primary structural weight is about twice the weight of the jacket structure while piles are comparable. The overall weight is significantly higher for the tripod, so this structure is only attractive if it can be fabricated at a much lower unit cost than the jacket. As steel prices tend to increase further, it is regarded as an unlikely scenario by REpower that Tripods can compete with jackets when fabricators have set up facilities for efficient serial production.

Tripod	<u>Primary structure:</u> $\Sigma=840t$	<u>Tripod subtotal:</u>  $\Sigma=925t$	<u>Total weight per installation:</u>  $\Sigma=1295t$ (+57% compared to jacket)
Pile sleeves			
Platform			
Boat landings (2 pcs.)	<u>Secondary structures:</u> $\Sigma=85t$		
Misc. (e.g. J-tubes)			
Anodes			
Piles	370t (3 piles, D=2500mm, L=50m, t=40mm)		

**Table 2: Estimated weight break-down for a Tripod at „alpha ventus“ (Borkum West)**

### 3. Transition node designs

An important element of a jacket design is the transition node between the jacket and the tubular tower. This is a critical design element which needs careful detailing esp. with respect to fatigue performance. Several authors have shown jacket design proposals in the past, but the transition structure was often only sketched and not realistically designed. This is hence a large uncertainty for such proposals as the transition node is the greatest design challenge!

Furthermore, functional requirements need to be observed regarding the following items:

- Service platform
- Access system (esp. boat landings)
- Crane requirements (if any)
- Cable routes and entry points to the interior of the structure
- Location of switchgear, emergency refuge and transformer (if present at this level)

The solution used for the Beatrice project (“OWEC Jacket Quattropod” - OJQ) is shown in Fig. 7. This solution for the transition node is relatively heavy, but enables a wide jacket top and flexible batter angles.



**Fig. 7: Beatrice WT-A jacket with transition node**

The solution developed by REpower (Fig. 8) is much lighter, but has so far only been tested for a relatively steep batter angle and a narrow jacket top. Both solutions have space in the transition area to accommodate functional elements like the switchgear. The flange connec-

tion to the tower is about 6-10m above the platform level, hence the tower is shorter by that distance.



Fig. 8: Transition node for REpower jacket (photo courtesy of Weserwind GmbH)

#### 4. Design of jacket substructures

The design of jacket substructures for Offshore Wind Turbines is in principle similar to the design procedures for fixed Offshore installations. There are some areas though where specialized knowledge from the Wind Industry is required.

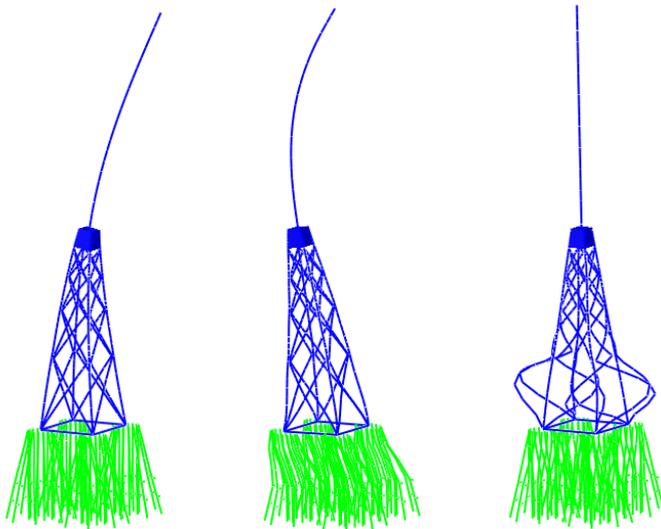
##### Load simulations:

Integrated analysis of wind turbine and support structure under the loading of wind, waves, ice and other, typically less important, environmental conditions is a crucial step in the design [4]. Load calculations will in the near future be based on the upcoming IEC 61400-3 standard [2] which has been developed in the past years by experts from both the wind and the offshore sector. Fatigue and extreme conditions are covered by the load cases definitions given there.

The advantage of jacket substructures in that area is that they are not very sensitive to wave loading as the structure attracts only small wave loads and is very stiff. Hence, wave excitation of the entire system is hardly an issue. This is also favourable for the tower loads as insignificant excitation of the first eigenmodes does also mean lower tower loads.

##### Modal analysis:

Modal analysis (Fig. 9) is also an important step for other Offshore structures as excitation due to wave loading could be an issue. It is even more important for wind turbines, though, as driving frequencies from turbine operation (like the blade-passing frequency) or coupled turbine-substructure modes can be of relevance. For jacket structures it is especially important to assess whether local vibration modes can occur. For the DOWNVIInD project this has been identified as a major contribution to overall fatigue damage in the lower parts of the jacket where long slender members have a particular probability of being excited [5].



**Fig. 9: Modal analysis results (onshore jacket with piled foundations)**

#### Fatigue assessment:

Many elements of wind turbine support structures are governed by the fatigue assessment. This is of course also the case for nodes of jackets. The presence of stress concentrations in welded joints does require special attention. Typically the parametric formulas as given e.g. in DNV-RP-C203 [3] can also be used for wind turbine installations.

It is favourable to base fatigue assessment on time histories of all relevant components. REpower has developed specialized post-processing tools which accomplish this task automatically. Typically 8 points around the circumference of a node are evaluated and it is often found that significant reserves compared to conservative superposition of component spectra can be achieved. This enables significantly lighter designs compared to other proposals which are designed with more conservative design methods.

Cast components are also assessed based on time histories. Stress distributions are determined with FE models in this case.

## **5. Foundations**

Two alternatives are being used for jacket foundation: Piles and suction buckets.

Steel piles are more common and have also been used for the Beatrice project. They are typically driven through pile sleeves and connected to the structure by grouting or swaging. Piles can be adapted to a wide range of soil conditions, so this is a very flexible solution. A significant amount of the overall steel weight is from the piles as has been shown in Table 1. This calls for good soil investigations and advanced design of the piles, also with respect to cyclic loading, to minimize the steel weight in this part of the structure. So far it is often the case that very conservative design approaches are chosen for the piles, which is partly caused by the lack of scientific progress in this area.

Suction buckets have only been used for some Oil&Gas projects and research regarding the use for Offshore wind turbines is currently conducted. So far the stability under high cyclic tensile loading could not be demonstrated sufficiently. Furthermore scour protection is an issue for suction buckets which is normally not required in case of piles. Suction buckets are,

on the other hand, very attractive in terms of installation time. They might become an alternative to piles when research regarding cyclic behaviour and scour protection design has progressed.

## 6. Outlook

Jacket substructures are a relatively light-weight and robust solution for Offshore wind turbines. Different constructions have been used together with the REpower 5M and experience in design and fabrication has been gained through realization of these prototypes. The next steps are now bigger wind farms and a focus on serial production and optimization of installation procedures. It is expected that significant cost savings compared to the current status can be achieved by such an optimization process and the experience gained from first projects with larger number of turbines.

## References

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- [2] IEC 61400-3 (CDV): Wind turbines, Part 3: Design requirements for offshore wind turbines.
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