A Novel A-Frame and Monopile Steel Sub-Structure, with Cast Steel Ring Node, for an Offshore Wind Turbine

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CURRENT FOUNDATION TECHNOLOGY

Offshore sited wind turbines usually have foundations which are either :-

- Very large diameter, tubular steel monopiles driven into the sea-bed to a depth of typically 30m or more.

or

- Massive concrete gravity bases which can weigh in excess of 6000 tonnes, and which sit directly on the sea-bed.

Typical monopile foundation for a 3-4 MW turbine, with a pile diameter of around 6m. An extra sleeve is grouted to the top of the pile to provide a bolted flange connection for the upper tower, and also to provide additional stiffness.

DISADVANTAGES OF MONOPILES

The main disadvantages with the monopile foundation are :-

- For 4MW turbines, pile diameters can be around 7 metres, and they are often difficult and time consuming to drive, particularly in poor soil conditions.

- The weight of such massive piles can total over 900 tonnes, and the bare cost of these can be around £1,200K each (J-tubes excluded).

- Our design calculations show that for turbines of around 5MW capacity, hydrodynamic fatigue damage becomes a limiting design criterion, with the fatigue life of the structure becoming unacceptably low. Thus the monopile substructure is limited to turbines of around 4.5MW capacity.

- When J-tubes (for the power cables) and landing stages, are welded to the monopile, this can further down-rate the fatigue life of the structure.

- Plain monopiles are becoming uneconomic for turbine capacities beyond about 4MW, particularly in water depths beyond 20 metres.

DETAILS OF A-FRAME SUPPORT

The novel system proposed is primarily aimed at offshore sited turbines of >4MW capacity and for water depths of 20 metres and beyond.

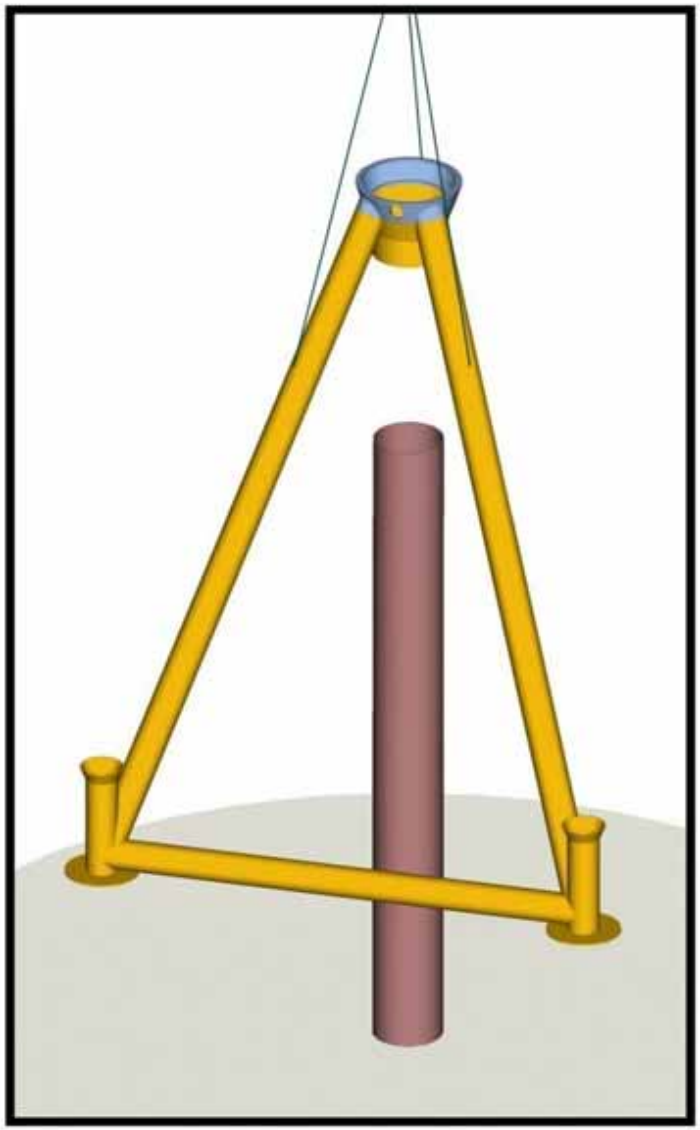
This A-Frame support system (which is design registered & patented*) assists the monopile to overcome the disadvantages listed previously.

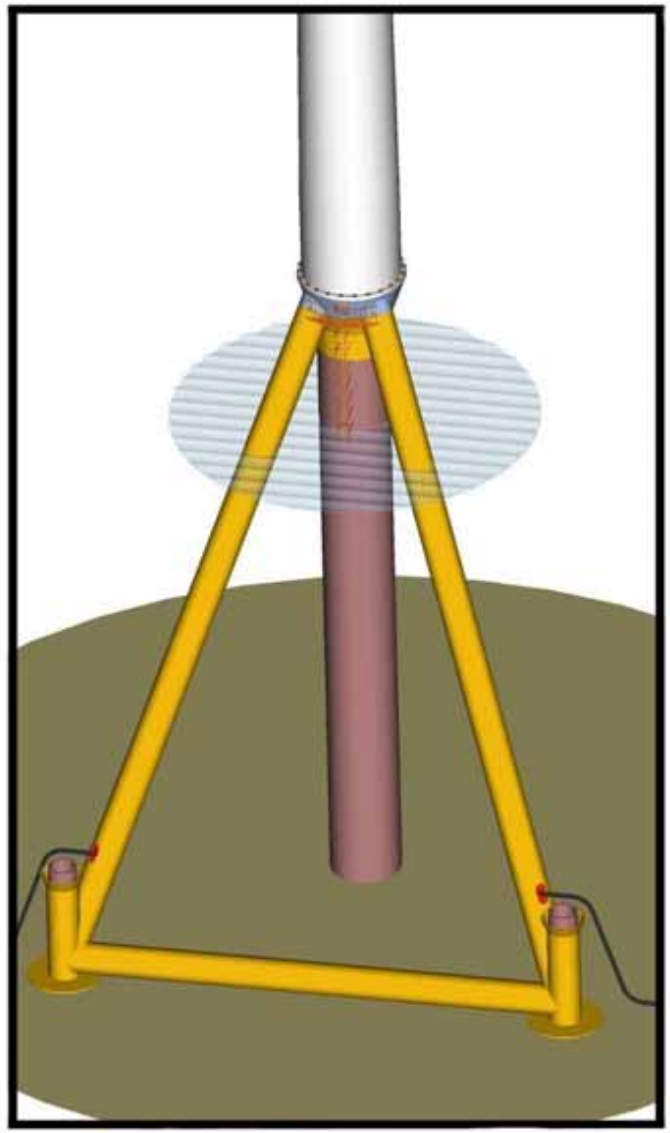
- It enables the monopile diameter to be considerably reduced (from 7 metres to around 4 metres) thus greatly reducing cost and pile driving time.

- It considerably improves fatigue lives.

- It greatly extends the capacity of the turbine which can be installed. Our calculations show that 10MW turbine capacity is easily achievable, even for 30 metre water depths.

The A-frame support has a cast steel ring at its upper apex, and this is lowered over a pre driven monopile of around 4 metres diameter. The ring is usually coned so that at its upper diameter, which incorporates a bolting flange, it can readily accept tower diameters of around 6 metres and beyond. The ring acts as a transition cone from the upper column to the smaller diameter, pre-driven pile.



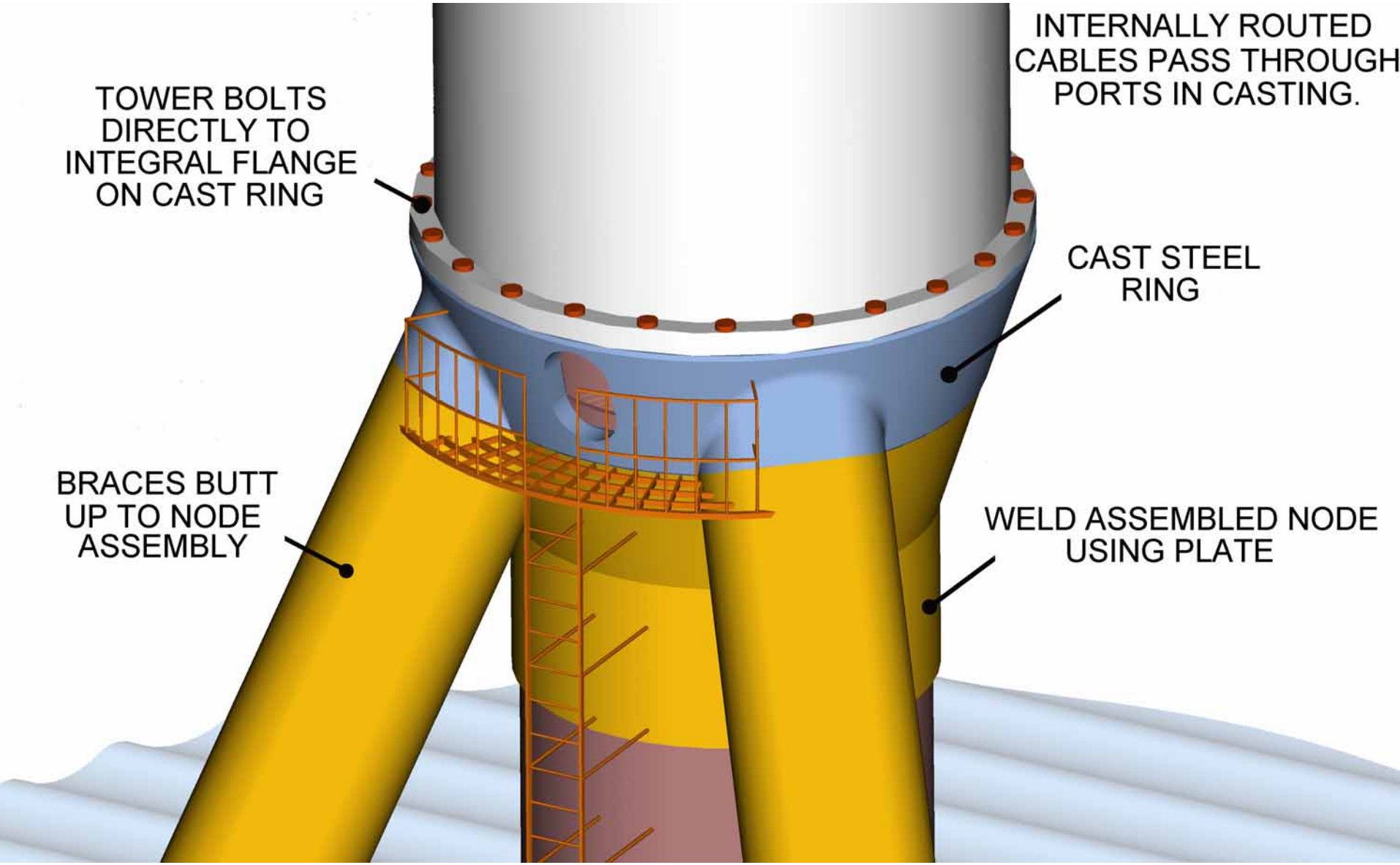


A-Frame and cast steel ring lowered over small diameter monopile

(*This complete A-Frame and monopile arrangement is design registered and protected by WA Design Ltd.)

INSTALLATION METHOD

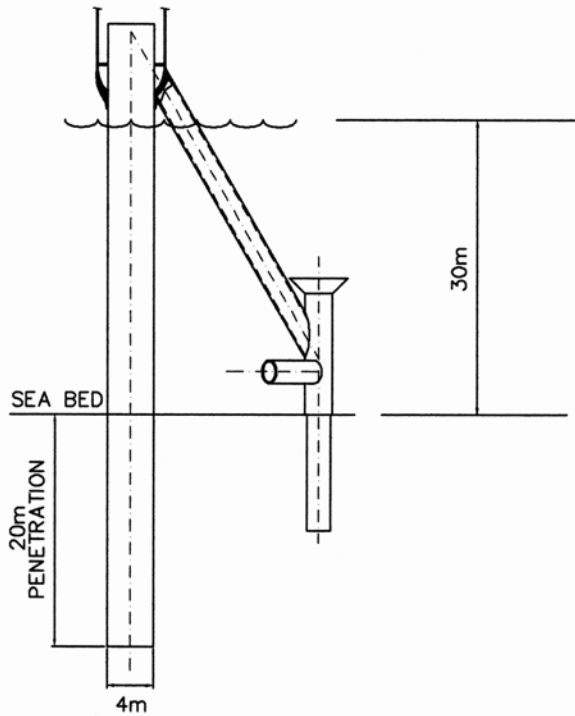
- The A-Frame is lowered over the pile in a level attitude, by means of special integrated lift points and a matched sling arrangement, and using a conventional jack-up barge.
- When the feet of the A-Frame contact the sea-bed, the ring is immediately clamped to the main pile. Then the two small secondary piles are driven and the ring is grouted to the main pile.
- The A-Frame typically weighs around 280 tonnes (for a 5MW generator) and the assembly becomes a stiff but lean, flat faced tripod. Together with the monopile, the total weight is around 640 tonnes.
- Following installation of the A-Frame, the main turbine tower is lift installed and bolted as normal to the integrated cast steel flange.
- Power cables are routed internally through the special ports provided in the casting. The cables then run down the A-Frame legs, and exit near the sea-bed. The extra costs of J-tubes, which monopiles require, is eliminated.
- Installers have confirmed that the installation time involved for the monopile and A-Frame support would be no longer than for a conventional monopile with grouted sleeve. In fact bearing in mind the smaller diameter main pile and easier soil penetration, it is likely to be a shorter installation time.
- Because of the flat form of the A-Frames they can readily be stacked onto the deck of the barge to enable efficient operation. It is also expected that all the installation can be done from a single positional setting of the jack-up crane barge.



Detail of Cast Ring Node at Apex of A-Frame

5MW TURBINES – 30M WATER DEPTH – BARE STRUCTURE COST, EXCLUDING INSTALLATION.

A–FRAME ASSISTED MONOPILE

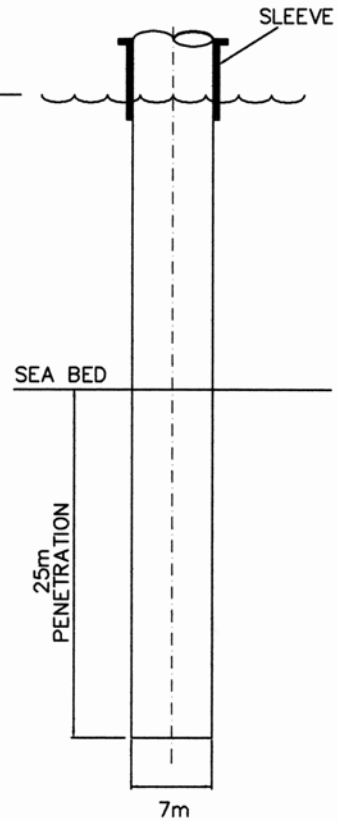


WEIGHT. = 320 TONNES (MAIN PILE)
+ 40 TONNES (FRAME PILES)
+280 TONNES (A–FRAME)
= 640 TONNES

COST £830K

(MIN. 36% SAVING OVER PLAIN MONOPILE)
(MIN 67% SAVING OVER CONCRETE GRAVITY)

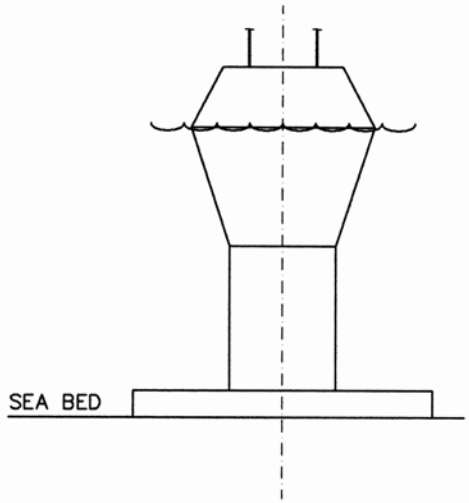
MONOPILE



WEIGHT. 950 TONNES

COST >£1,300K
(INCLUDING J–TUBES)

CONCRETE GRAVITY BASE



WT. 6000 TONNES

COST >£2500K

Weight and cost comparisons of the A-Frame concept vs. concrete gravity & monopile alternatives.

BENEFITS OF THE A-FRAME SYSTEM

- For a 5MW installation in 30m water depth, the expected weight savings over the monopile only system are over 300 tonnes and the cost savings are around £470K (36%)
- Compared to concrete gravity base systems, the weight savings will be nearly 5,500 tonnes, and the cost savings at least £1670K (67%). This does not include likely extra savings because of the very costly installation of the massive concrete gravity bases.
- For turbine capacities approaching 10MW, the above noted savings will be much greater.
- The system is also cheaper, lighter and much easier to install than conventional steel tripod substructures.
- There is much less installation time risk in driving the 4m diameter pile than with the 7m diameter pile for the monopile only system. Pile penetration can also be reduced in some circumstances.
- For turbine capacities beyond 4MW and up to 10MW this new system provides the only economic way to extend sub-structure capabilities, and particularly for water depths beyond 20m.
- The system eliminates the fatigue life limitation inherent with the monopile system. The additional support, the presence of the casting with smooth radii and also the elimination of external J-tubes considerably enhances fatigue life and guarantees longevity of the structure.
- The cast ring provides an internal route for cables through ports in the casting and down to the sea-bed via the A-Frame legs.
- The cast ring provides an integral bolting flange for connection to the tower, and also the option for an integral manway access to the tower.
- The system allows smaller and cheaper offshore installation crane barges to be employed because the heaviest individual lifts are around 300 T.

DESIGN OF A-FRAME, AND MANUFACTURE OF TRIAL RING NODE CASTING

- The DTI (via their CORLEX project) have part funded the confirmatory design study for this A-Frame concept, and also the design and manufacture of a full scale prototype cast steel ring node, which is the key part of the A-Frame.

- The programme involved conceptual design, member sizing and detailed casting design (by WA Design/Sheffield Forgemasters) and confirmatory design of the complete structure (by Atkins Aberdeen) for a typical North Sea site, and for turbines of 5MW and 10MW (scaled). The design process undertaken has included the comprehensive methodology which would be expected of an experienced analyst, for such a critical offshore structure (see summary table).

- The manufacture of the prototype (see following photo) which has now been completed, has confirmed manufacturing costs, methods and speed of manufacture.

- This means that Sheffield Forgemasters and their partners are now in a position to offer the design and supply of large numbers of A-Frames for real projects.

Cast Steel Ring Node 5.5m dia

ENGINEERING DESIGN INPUT DATA

	5MW	10MW (scaled)
Turbine mass (tonnes)	275	676
Wind speed (metres/sec 100yr storm)	50	50
Wave/Current Extreme peak		
Height (metres)	14.1	14.1
Period (sec)	11.2	11.2
Fatigue cycles/yr	5.9×10^8	5.9×10^8
Fatigue design Life (yrs) (safety factor = 2)	60	60
Applied fatigue force at Turbine (kN)	135	530

SUMMARY OF DESIGN METHOD

- Typical N sea site – 30 metres water depth.
- Non cohesive soil, with the stiffness modelled with non linear springs.
- Strength and fatigue performance considered (yield strength, stability and punching shear checked for extreme storm).
- Pile strength checks done to API to preclude local buckling.
- Lateral, axial and pull out checks done to API.
- Tower section checked using FEA
- Dynamic frequency exclusion range checks done.
- Deterministic aerodynamic and hydrodynamic loads combined to maximise base shear and overturning moment.
- SCF's computed for all critical regions.

SUMMARY

- Our design studies have shown that for offshore turbine capacities approaching 5MW, in water depths beyond 20m, the existing steel monopile system is becoming uneconomic and impractical. Fatigue lives become unacceptably low due to hydrodynamic forces and the de-rating effect of external J-tubes. The steel costs and driving times for the very large piles are becoming prohibitive.
- We have shown that this novel A-Frame concept will save around 36% over the conventional monopile system by massively reducing the main pile diameter and eliminating J-tubes. We also believe that the system will save around 67% over the basic costs of concrete gravity base systems. This latter figure excludes further benefits on installation costs over those for the massive concrete structures.
- As the power rating of turbines grows beyond 6MW our work has shown that the above stated savings will become even greater.
- The A-Frame, monopile support concept presented here represents a much more reliable method for the offshore installation of high capacity turbines because it reduces pile driving times and risks, and increases the opportunity to use smaller and cheaper offshore contractors, due to the relatively light lifts required.
- This design, together with the smoothly profiled cast ring and integral bolting flange, greatly improves fatigue life.
- This concept assists monopiles where difficult soil conditions exist.

ACKNOWLEDGEMENTS

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FURTHER INFORMATION

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