Joint R&D - program: Innovative Foundation Solutions, The Novel Bucket Foundation

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1. SUMMARY

The focus on cost reduction in offshore wind projects has initiated a joint R&D-project in Aalborg University and the MBD test field, using the novel bucket foundation principle. The five year project has proven the bucket foundation to be feasible in suitable soil condition in water depth up to app. 45 meters. A 12 x 6 meter prototype was installed at the test field in Frederikshavn late 2002, with a 3 MW Vestas turbine in normal operation. The project has developed design standards based on an analytic model and FEM-models for the construction and installation methodologies, which has been recognised by various authorities[1].

2. THE PROJECT

Cost reduction has been the driving force in development of a prototype foundation of a novel principle, the bucket foundation. See fig. 1.

Fig. 1. The 12 x 6 meter prototype bucket foundation before installation in Frederikshavn

The R&D-project includes an analytical model and 2/3-D FEM-models that can be regarded as universal model concerning the aspect of soil/structure interaction obtaining loads from an offshore wind turbine. The principle is today used for a Vestas V90-3.0 MW turbine as a prototype in the test field for offshore wind turbine research, which has been built in connection with a joint R&D-program between Centre for Wind Energy Systems (WEST), Aalborg University and MBD Offshore Power. See fig.2.

Fig. 2. The Vestas V90 installed at the bucket foundation December 2002.

The stability of the foundation is ensured by a combination of earth pressures on the skirt and the vertical bearing capacity of the bucket. Lowering the pressure in the cavity between the bucket and the soil surface performs the installation process.

Model tests have been performed on buckets from 50 mm to 400 mm with skirt length varying from 0 to the same as the diameter of the bucket. See fig. 3.

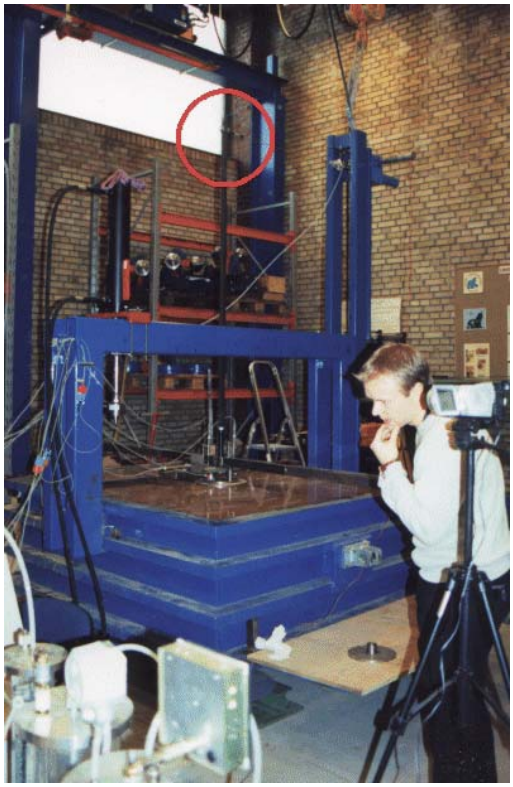

Fig. 3. Test bench for bucket 50 – 400 mm at Aalborg University.

Further test regarding load, installation method, control of the inclination and control of the penetration rate are carried out in the test field in Frederikshavn with a 2-meter bucket and a 4-meter bucket.

The 12 x 6 m prototype is on-line monitored for dynamic response and analyses. At the same time, tests with up to 500 mm buckets are carried out in the laboratory in a pressure tank with dynamic load to study the soil/structure interaction.

3. DEVELOPMENT OF THE DESIGN PROCEDURE

Since the bucket foundation is an innovative foundation, no standard design procedure is available and must be set up. This procedure complies of 3 parts:

- Design basis describes the wind turbine and the site conditions.
- Conceptual design, demonstrates that the dimensions of the foundation are suf ficient to observe the different load sceneries by means of an analytical model. Penetration investigations are carried out based on cone penetration tests (CPT).
- Detailed design, the interactions between the bucket and the soil are investigated. The investigation is carried out by means of the performed model tests and 2D or 3D FE - analysis. See fig 4.

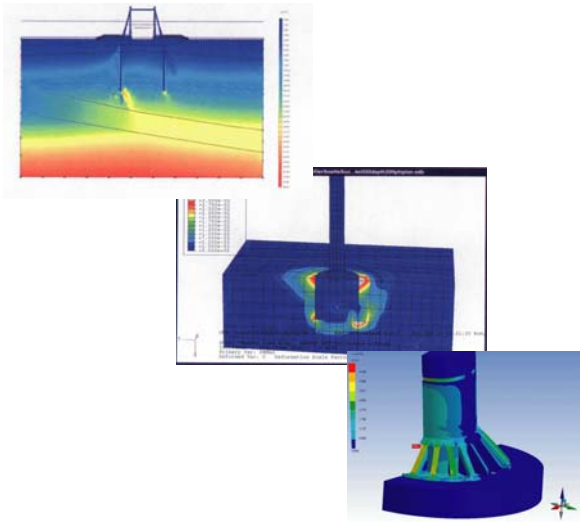

Fig. 4. 2D-FEM soil mode, 3D-FEM soil model and 3D-FEM steel structure model.

4. TEST FIELD IN FREDERIKSHAVN

The test field is place in the North part of the harbour, where ELSAM have established 4 prototype wind turbines as part of the test field.

The present set-up:

- A prototype of the bucket foundation placed under a Vestas V90 3MW turbine. The foundation and tower is equipped accelerometers and monitoring for online frequents analyses.
- A 35.000 sq. m test pit with undisturbed seabed used for scale test with 2x2 and 4x4 meter test buckets.
- A 20.000 sq. m test pit with undisturbed seabed which can be used for further test purposes.
- The near shore sea in front of the prototype wind turbines, which can be used for scale test of structures and energy systems. See fig 5.

Fig. 5. The Vestas V90 and the Nordex N80 at the test field in Frederikshavn

5. PENETRATION TESTS WITH 4X4 M BUCKET

The prediction of the penetration forces is calibrated with results from the tests. A unique guidance system is developed in orderto penetrate the bucket with a inclination of +/- 0,1 degree. See fig 6.

6. PULL TESTS WITH 2X2 M BUCKET.

The strength of the seabed is measured with a cone penetration test (CPT) and the force/displacement is predicted in a 3D FEM-model. The results from the pull test are used to calibrate the numerical and the analytic model used to design the specific bucket for the specific turbine position. See fig 7.

Fig. 6. Penetration test with the 4x4 m bucket.

Fig. 7. Pull test with the 2x2m bucket.

7. FOUNDATION ANALYSIS

Monitoring system on the Vestas V90:

- 15 Kinemetrics force balance accelerometers
- Digitexx online monitoring

- The analyses of the soil/structure are performed in three steps:
- Modal analyses determine the mode shapes.
- Fatigue analysis, estimates the stress cycle distribution
- Cyclic structure behaviour

8. THE NEXT PHASE:

The next phase is to commercialise the concept to facilitate the prospected cost saving into future offshore wind farms.

The bucket concept will be brought into commercial use by the "Offshore Foundation Group" [2]

The members of the group are:

- MarCon A/S
- Bladt Industries A/S
- MTHojgaard A/S
- MBD Offshore Power A/S

9. CONCLUSION

The R&D project has proven the bucket foundation to be feasible in suitable soil condition in water depth from "near shore" to 45 meters. The 12 x 6 m prototype was installed at the test field in Frederikshavn in late 2002, with a 3 MW wind turbine in normal operation. A design standard for the construction and installation methodologies has been recognised by various authorities.

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[1] Tove Feld, DNV Global Wind Energy:

STATE-OF-THE-ART DESIGN STANDARD SPECIFIC DEVELOPED AND APPLICABLE FOR OFFSHORE WINDTURBINE STRUCTURES, 2004, p. 6

[2] Lasse Løvgren, MT Højgaard Profil 04-05 p. 27.