# New onshore wind turbine foundation system for poor soil

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**Abstract.** In this study, an innovative idea of using a plane circular raft surrounded by a water tank is tested numerically using finite element simulations and compared with a conventional piled foundation. In this work cost and behavior comparisons are done for two foundation solutions, namely a piled raft and a circular raft surrounded by a water tank. An observed soil profile found in Port-Said region, Egypt is used. The soil profile is implemented in the FE software Abaqus to find out the validity of using the different types of foundations on the mentioned type of soil. In terms of settlement and tilting it is shown that there is a good effect of using a water tank surrounding the ordinary circular raft for the actual soil profile in the Port-Said region. For the cost issue, the analysis was carried out to calculate the whole foundation cost for a circular raft surrounded by a water tank and also for a piled raft. It is shown that using the new foundation system decrease the foundation cost by 28% compared to using piled raft with pile length equal to 24 m. The effect of dynamic loads was also investigated and the results showed that the complete system, using circular raft surrounded by a water tank, successfully avoids resonance through the rotor excitations.

## FOUNDATION DESCRIPTION

### [1] Piled raft

A piled raft is a raft foundation that has piles to reduce the settlement. The raft foundation and the piles are designed to cooperate to ensure that the settlement does not exceed the allowable settlement value. Figure 1-a shows more details of the geometry and dimensions of the piled raft.

### [2] Circular raft surrounded by a water tank

For the new system with a circular raft surrounding by a water tank, the idea is to use water to give a stabilizing moment to resist the overturning moment. The reason for using water is the ease of moving water with wind turbine movement. The water tank is divided into four parts and only one or two parts will contain water and all parts are connected to an active system to move water between parts. To get a big resisting moment with the relatively light weight from the water, a big water volume must be used. Figure 1-b shows more details of the geometry and dimensions of the foundation with a water tank that are used in this study.

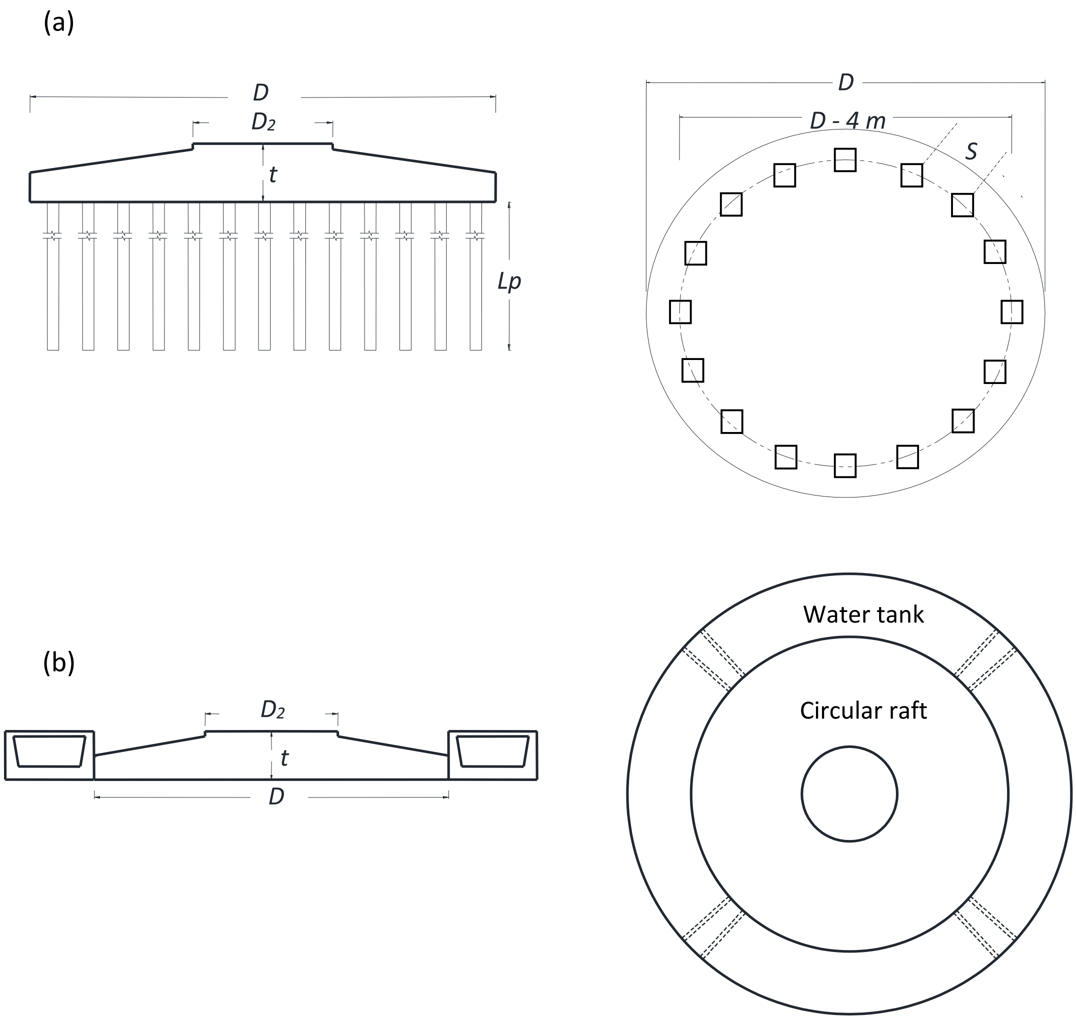


**Figure 1** *(a) Piled raft, and (b) Circular raft surrounded by a water tank.*

## Water movement system

The water system depends on motors and pipes with electric valves. Between all parts there are two pipes to move air from the part which is intended to be filled to the other part which is intended to be emptied. Water movement will depend on rotor hub position which depends on wind direction. Figure 2 shows the reference line (R.L) and angles used to move water from one part to the other parts. Table 1 presents the location of the water according to the rotor hub position. Wind turbines already have control system. Therefore, water movement control system will use wind direction and wind speed sensors that are used in the yaw system in wind turbines.

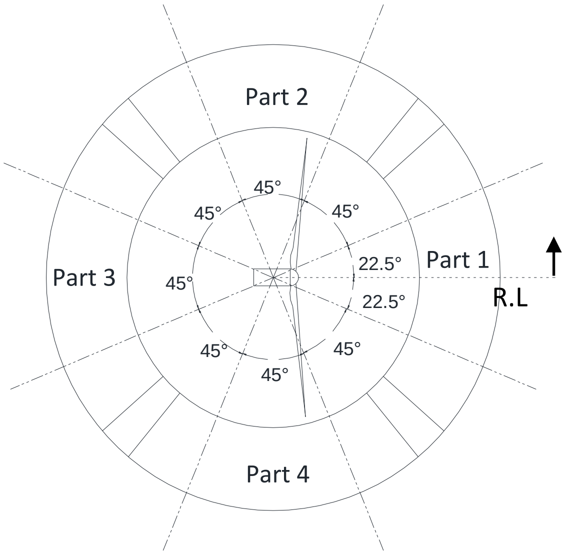


**Figure 2** Reference line and angles used to move water from one part to the other parts

**Table 1** Location of the water according to rotor hub angle with the R.L.

| Rotor hub angle with the R.L. | Water position |
|---|---|
| 0.00 to 22.5 & 337.5 to 360 | Part 1 |
| 22.5 to 67.5 | Part 1 + Part 2 |
| 67.5 to 112.5 | Part 2 |
| 112.5 to 157.5 | Part 2 + Part 3 |
| 157.5 to 202.5 | Part 3 |
| 202.5 to 247.5 | Part 3 + Part 4 |
| 247.5 to 292.5 | Part 4 |
| 292.5 to 337.5 | Part 4 + Part 1 |

## SIMULATION

An actual soil profile found in Port-Said region, Egypt was used. It is a very poor soil traditionally requiring piling, the soil profile was implemented in the finite element software Abaqus to investigate the behavior of the different types of foundations on the mentioned type of soil. A three dimensional finite element model of the foundation-soil system was created using *ABAQUS*. For the soil model, the computational region chosen is 100x100x50 m where the depth in z direction is 50 m. C3D20R element was selected using a fine grid around the raft and a coarse grid for the far field. The geotechnical material model adopted in this proposal is the Mohr-Coulomb model. Full interaction was assumed between the soil and the half of the foundation (the compression side) and surface contact interaction was used between the foundation and the soil in the other half (the tension side) to allow the foundation to elevate without any tension at the interface. This study compares the suitability of different foundation types including a novel solution, with circular raft surrounded by a water tank, for soil with poor properties. The load conditions are based on usual loads for 100m high 2 MW wind turbines.

**RESULTS**

Using a water tank surrounding the raft decreases the cost and differential settlement problems compared to using a piled raft. Considering specifically the poor ground properties near Port-Said city, the whole foundation cost for a circular raft surrounded by a water tank was compared to an ordinary piled raft. In this analysis actual costs were determined considering local Egyptian construction cost levels. The results revealed that using the new foundation system in Port-Said city region can decrease the foundation cost by 28% compared to using a piled raft with pile length of 24 m and piles diameter of 0.5 m. Differential settlement problem is one of the biggest challenges for designing wind turbine foundations for poor soils. Using a circular raft and a water tank with $B_{tank}$ = 5 m decreases the differential settlement by 40% compared to a piled raft with pile length $L_p$ = 24 m. However, the settlement increases by 35% compared to a piled raft with pile length $L_p$ = 24 m but is still lower than the allowable settlement value for a shallow foundation.

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