Three Dimensional Computer Simulation of Pile Foundation for Offshore Wind Turbine

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Abstract- Finned pile foundation is used as foundation for offshore wind turbine. The behaviour of fin piles is difficult to explain using simple pile–soil theories or two dimensional numerical analyses because of the complicated geometry of the piles. In the current study, a linear 3D analysis of monopile, finned pile and taper finned pile foundation with an elastic plastic soil model (Mohr-Coulomb), an elastic pile material (steel), cushion model (Mohr-Coulomb) and interface elements are used to model the pile–soil interaction using MIDAS GTS-NX finite element software package. A define soil model represent medium dense sand and hollow steel pile embedded within sand subjected to large lateral loading. Analysis shows that lateral resistance increase if monopile pile is replaced by finned pile and lateral resistance further increases if finned pile replaced by taper finned pile (having taper cross section of fin i.e. major thickness at top and minor at bottom) surrounded with cushion material against lateral loading.

Indexed Terms- Monopile, Finned Pile, Taper Finned Pile, Cushion, Lateral Resistance, FEM etc.

I. INTRODUCTION

Worldwide, wind energy is accepted as one of the most developed, cost-effective and proven renewable energy technologies to meet increasing electricity demands in a sustainable manner. While onshore wind energy technologies have reached to a stage of mass deployment and have become competitive with fossil fuel based electricity generation with supportive policy regimes across the world, exploitation of offshore wind energy is yet to reach a comparable scale, National Offshore Wind Energy Policy (2013).

- Global status

About 5 GW offshore wind capacity has already been installed around the world and approximately an equal capacity is under construction. There are a large number of offshore wind farms in Belgium, Denmark, Finland, Germany, Ireland, the Netherlands, Norway, Sweden, and The United Kingdom. Total turnkey investment cost for onshore 800-1100 €/KW and for offshore 1200-1850 €/KW out of that 5-10% and 15-25% cost spend on construction & maintenance of foundation respectively, Faaij and Junginger (2011).

- Developments in India

In India preliminary assessments indicate prospects along the coastline of Kerala, Karnataka and Goa. The wind resource data collected for coastline of Rameshwaram and Kanyakumari in Tamil Nadu and Gujarat Coast shows a Reasonable potential. A preliminary assessment suggests potential to establish around 1 GW capacity wind farm each along the coastline of Rameshwaram and Kanyakumari in Tamil Nadu, National Offshore Wind Energy Policy (2013).

- Types of foundation for offshore wind turbine

Different types of foundations have been proposed including monopile, gravity base, jacket of the offshore turbines currently in operation are supported on driven monopiles. The choice of monopiles results from their simplicity of installation and the proven success of driven piles in supporting offshore oil and gas infrastructures.

Piles for offshore structures are typically 60–110m long and 1.8– 2.7m diameter. By contrast, monopiles for offshore wind turbines are commonly 30–40m long and 3.5–6m diameter. Degradation in the upper soil layers resulting from cyclic loading is less severe for offshore jacket piles which are significantly restrained from pile head rotation causing lower pile head deflections, Domenico et al. (2013). This pile head deflection is more for offshore wind turbine due to higher lateral load, so there is necessity to improve lateral resistance of monopile, for that numerical analysis of finned pile and taper finned pile with surrounded cushion material is carry out.

II. METHODOLOGY

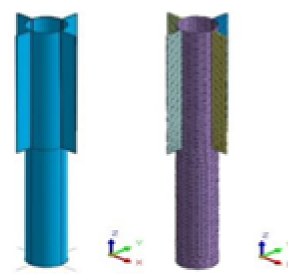
- Material properties

A three-dimensional (3D) finite element model was established in order to analyse the behaviour of monopile and finned pile. The computations were carried out using the finite element program system MIDAS GTS-NX. The sand was assumed to be a linear elastic perfectly plastic material. A non-associated Mohr–Coulomb constitutive model was assumed to govern the soil behaviour for which the material parameters are well established in geotechnical engineering practice. An elasto-plastic analysis under drained conditions was used to model piles with the yield of the sand, defined by the Mohr–Coulomb model, being the upper limit to the elastic behaviour of the sand. In the full scale analysis, the elastic soil properties, corresponding to medium dense sand, were assumed to be: Poisson's ratio υs = 0.33, and dry unit weight γs = 16.5 kN/m^3. The Mohr–Coulomb model had an effective friction angle ϕ' = 35°, Dilatancy angle Ψ = 0° and effective cohesive strength c'= 0 kPa. In order to account for the variation in soil properties with depth, Young's modulus was assumed to increase linearly according to Peng et al. (2010):

The piles and the fins, shown in Fig. 1, were assumed to be linear elastic mild steel material which has typical properties of Young's modulus, Ep = 200 GPa, Poisson's ratio, υp = 0.3, and unit weight, γp = 78 kN/m3. The yield of steel was not considered in this study.

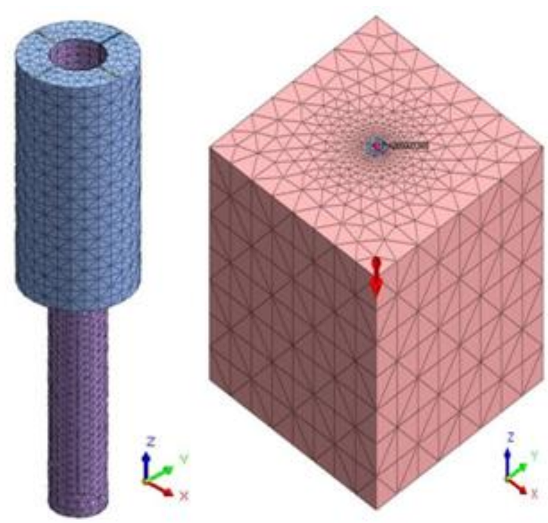
Es (Z) = Eso + Esin c (Z - Zo) (1)

Where Eso is Young's modulus at the soil at depth Zo and Esin c is the increase of Young's modulus per unit of depth. For the full scale simulations, it was assumed that Eso = 10
MPa at the surface and a rate of increase Esin c = 1 MPa/m. It was assumed that the pile was installed in a normally consolidated sand with Ko = 0.42.The Mohr-Coulomb model had been used for Cushion having modulus of elasticity E= 30MPa, angle of internal friction ϕ = 35°, cohesion c= 0 kPa and Unit weight γ = 17 kN/m^3. It should be noted that interface elements were applied between the cushion and the pile in order to model the cushion–pile interaction. Along the pile the strength reduction factor of the interface (Rinter) is set to 0.62 which is typical of cushion-steel interfaces and interface elements were applied between the sand and the pile in order to model the sand–pile interaction. Along the pile the strength reduction factor of the interface (Rinter) is set to 0.65 which is typical of sand-steel interfaces.



a) b)

Fig. 1 a) Three Dimensional View and b) Meshing of Finned pile



a) b)

Fig. 2 a) Three Dimensional View of Cushion and Finned Pile and b) Sand Block

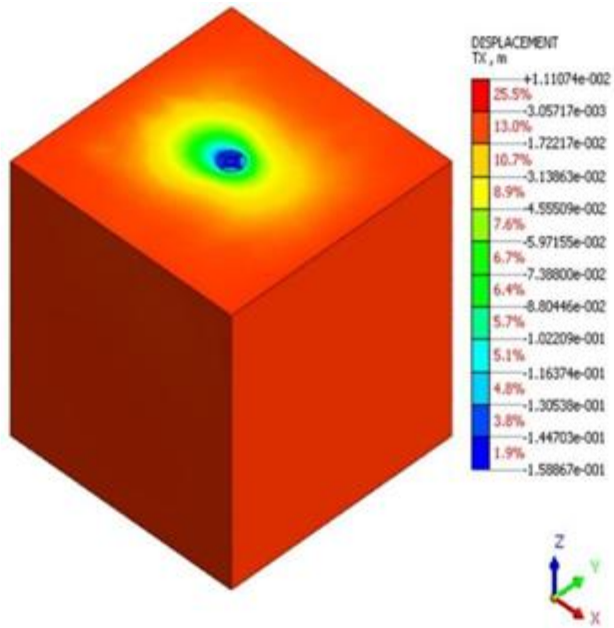


Fig.3 Displacement Contour around finned pile on sand block

III. NUMERICAL MODELLING

The three-dimensional finite element program, MIDAS GTS-NX was chosen to model the pile and the sand. The boundary is a cube with sides of 22.5 times the diameter of the pile and a depth 2.5 times the pile length. The geometry of a three-dimensional model of a pile embedded in soil is shown in Fig.2 b). The bottom boundary was fixed against movements in all directions, whereas the 'ground surface' was free to move in all directions. The vertical boundaries were fixed against movements in the direction normal to them.

Table 1 Geometrical Properties of Pile

Properties	Monopile	Finned pile	Taper fin pile
Length	40m	40m	40m
Outer diameter	4m	4m	4m
Wall thickness	0.05m	0.05m	0.05-0.04m
Fin thickness (top)	-	0.05m	0.05-0.16m
Fin thickness (bottom)	-	0.05m	0.05m
Fin width	-	2m	2m
Fin length	-	20m	20m

IV. TAPER FINNED PILE

The stresses on laterally loaded pile foundation is maximum at top and also maximum displacement also occur at pile head, Bowles (2001). In order to reduce stresses at top of pile and increase performance in terms of lateral resistance making cross-section of fin taper (having major thickness at top and lower at bottom) shown in Fig.4). Upper thickness varies from 0.05 to 0.16m to find out least pile head displacement against lateral loading by keeping lower thickness constant i.e. 0.05m.

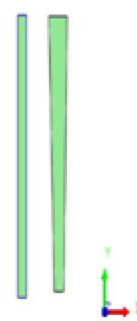


Fig. 4 Side view of Simple and taper fin

V. CUSHION MATERIAL

The surrounding cushion material having thickness 2.24m and length 20m that is equal to fin length. The modulus of elasticity, poisons ratio and unit weight of cushion material is 30 MPa, 0.3 and 17kN/m^3 respectively.

Table 2 Properties of pile, cushion and sand

Properties	Finned pile	Cushion	Sand
Modulus of Elasticity, E	200GPa	30MPa	Eso = 10 MPa, Esinc = 1 MPa/m
Poisson's Ratio	0.3	0.3	0.33

Unit weight	78kN/m^3	17kN/m^3	16.5 kN/m^3

VI. RESULTS AND DISCUSSION

Lateral load was applied in the range from 50MN to 200MN along the fin (in the direction of -ve x-axis) and result was generated in the form of p-y curve, where 'y' is the pile head displacement (% pile diameter).

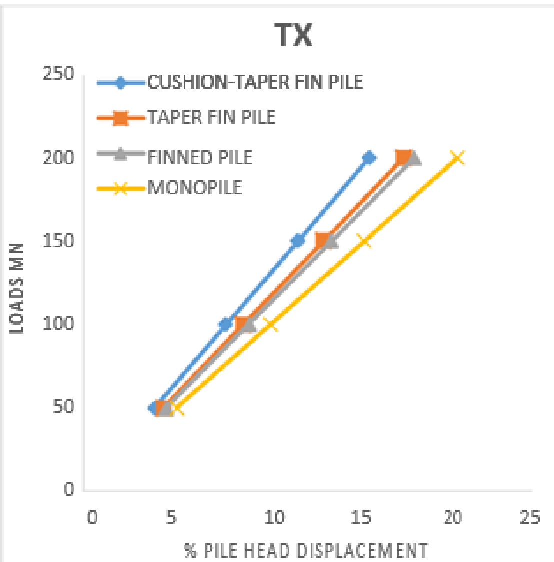


Fig. 5 p-y curve for x-axis (along loading direction)

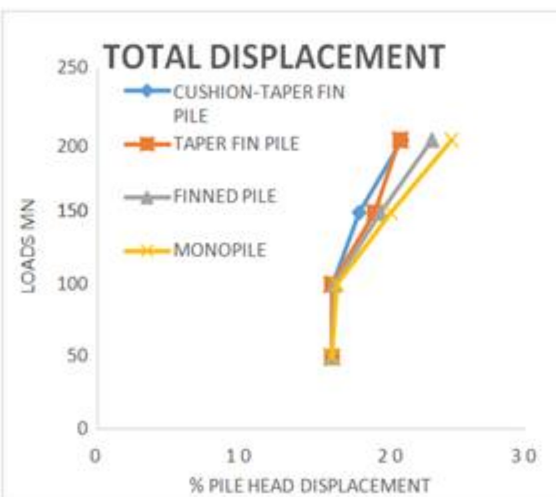


Fig. 6 p-y curve for total displacement

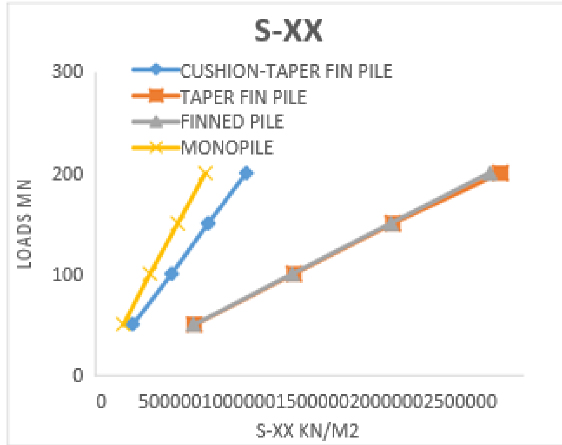


Fig. 7 p-ss curve for x-axis (along loading direction)

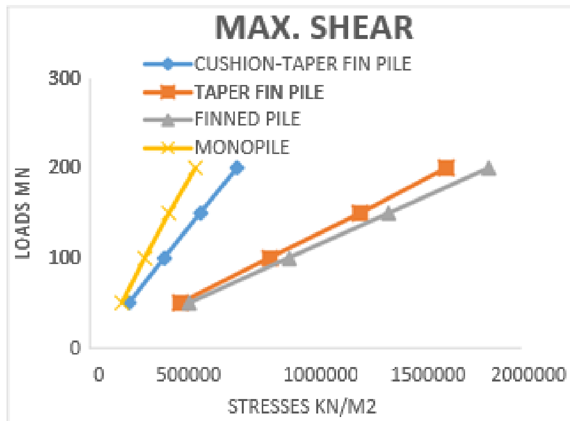


Fig.8 Load Vs Shear Stresses curve

CONCLUSION

In this paper a comparative study between monopile, finned pile, taper fin pile and cushion-taper fin pile has been carried out in order to increase lateral resistance of pile foundation for offshore wind turbine against lateral load, so from this study some conclusion were drawn.

- From Fig.5 and 6 it is concluded that lateral resistance of cushion-taper fin pile is more compared to finned pile, taper fin pile and monopile in all direction.
- From Fig.7 it is concluded that solid stresses in loading directions are minimum in monopile and cushion-taper fin pile but maximum in the finned and taper finned pile due to increase in steel quantity for making of fin.

- From Fig.8 it is concluded that shear stresses in loading directions are minimum in monopile and cushion-taper fin pile but maximum in the finned and taper finned pile due to increase in steel quantity for making of fin.

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