Stiffness Formulation of Flexible Bucket Foundation

a macro model approach

Ibsen, Lars Bo; Liingaard, Morten; Larsen, Kim André

Publication date:
2009

Document Version
Publisher's PDF, also known as Version of record

181

STIFFNESS FORMULATION OF FLIXIBLE BUCKET FOUNDATION

A MACRO MODEL APPROACH

Lars B. Ibsen[1], Morten Liingaard [2] , Kim A Larsen [3]
1) Aalborg University, 2) DONG Energy, 3) COWI

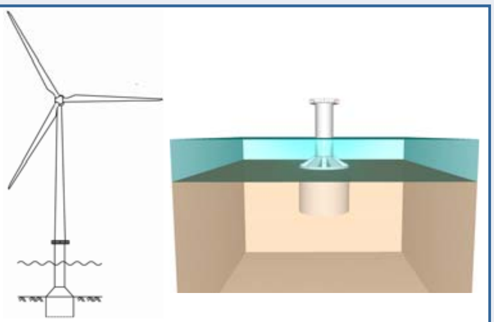
Abstracts

The response of offshore wind turbines e.g. static, eigen frequencies and eigen modes, are affected by elastic properties of the foundation and the subsoil. The Elastic Macro Model is developed to evaluate the soil-structure interaction of flexible bucket foundations for offshore wind turbines so that it can be properly included and analysed in a composite structure-foundation system. The typical approach for analysing the structure-foundation system is to use a finite-element method. Such an approach is, however, inefficient and time consuming

The Elastic Macro Model describes the foundation as a substructure with predetermined properties.

The interaction between the foundation and structure is expressed purely in terms of force and moment resultants, and their conjugate displacements and rotations. The Macro Model modelling the Bucket Foundation is suitable for implementation in an internationally recognized aero-elastic code as e.g. HAWC or FLEX.

The Bucket Foundation



The monopod bucket foundation, also called “monopod suction caisson”, is a promising foundation concept for offshore wind turbines which has the potential to be cost-effective in certain soil conditions. Depending on the skirt length and diameter, the bucket foundation can have a bearing capacity similar to that of a monopile, a gravity foundation or in between.

Prototype installed:

December 2002: Frederikshavn, Denmark.

March 2009: Horns Rev 2 Offshore Wind Farm, Denmark

Stiffness Coefficients

The stiffness coefficients can be used to describe the static elastic behaviour of both surface and bucket foundations, however there are some conditions that are worth noticing:

• The stiffness coefficients for the *surface foundation* are dependent on Poisson’s Ratio ν , shear modulus G of the soil and the flexibility of foundation.

•The stiffness coefficients for the *bucket foundation* are dependent on ν , G of the soil, the flexibility of the bucket material, the skirt thickness *t* and the embedment ratio of the bucket, *H/2R*.

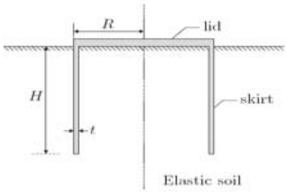
The dimensionless elastic stiffness coefficients can be determined as:

$$K^0_{VV} = \frac{V}{GRu}$$

$$K^0_{HH} = \frac{H}{GRu}$$

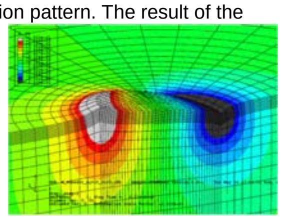
$$K^0_{MM} = \frac{M}{GR^2\theta}$$

$$K^0_{HM} = \frac{M}{GR^2u} \quad \text{or} \quad K^0_{HM} = \frac{H}{GR^2\theta}$$



Methods

The dimensionless elastic stiffness coefficients are determined by means of finite element analyses in ABAQUS. The elastic properties of the soil are given by shear modulus *G* and Poisson’s Ratio *v*. The soil is modelled by means of 3-dimensional finite and infinite second-order solid elements and the foundation is modelled by second-order elastic shell elements. An example of the numerical simulations is shown in the Figure. A surface foundation is subjected to a prescribed rotation around the horizontal axis x_2. The foundation is constrained in the horizontal direction x_2, i.e. a rocking deformation pattern. The result of the analysis is the resulting moment and horizontal force due to the prescribed rotation, which is used to determine K^0_{MM} and K^0_{HM}.

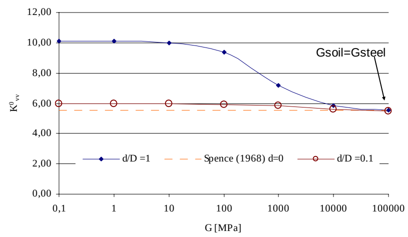


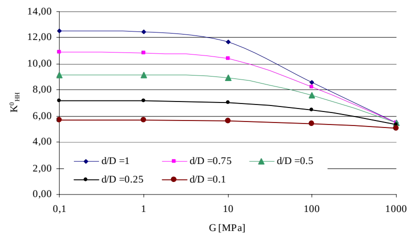
The monopod bucket foundation is installed using suction assisted penetration Frederikshavn 2002

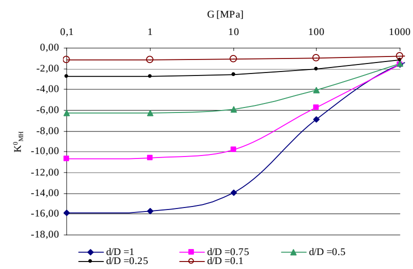
Results

Material and model data used in the evaluation of the dimensionless stiffness coefficient.

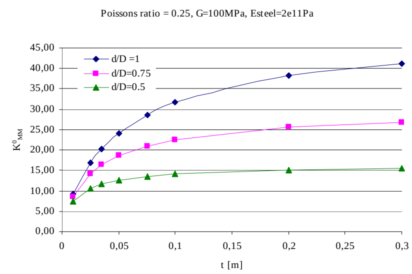
E_{soil}	ν_{soil}	D [m]	t_{skirt} [m]	$t_{top\ plate}$ [m]	ν_{steel}	E_{steel} [Pa] Skirt / Top plate
Variates	0.25	10	0.05	0.05	0.25	2.1 10^{11} / 2.1 10^{15}







Influence of the skirt thickness

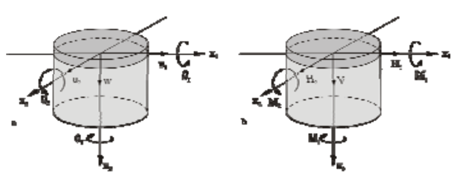


Methods

The interaction between the foundation and structure are within the macro model expressed purely in terms of force and moment resultants, and their conjugate displacements and rotations.

The elastic stiffness of the foundation can be expressed by dimensionless elastic stiffness coefficients corresponding to vertical (K^0_{VV}), horizontal (K^0_{HH}), moment (K^0_{MM}) and torsional (K^0_{TT}) degrees of freedom. Cross coupling between horizontal and moment loads exists so an additional cross coupling term (K^0_{MH}) is necessary. Under general (combined) static loading, see figure, the elastic stiffness of the foundation system can be expressed as:

$$\begin{bmatrix} V/GR^2 \\ H_1/GR^2 \\ H_2/GR^2 \\ T/GR^3 \\ M_1/GR^3 \\ M_2/GR^3 \end{bmatrix} = \begin{bmatrix} K^0_{VV} & 0 & 0 & 0 & 0 & 0 \\ 0 & K^0_{HH} & 0 & 0 & 0 & -K^0_{HM} \\ 0 & 0 & K^0_{HH} & 0 & K^0_{HM} & 0 \\ 0 & 0 & 0 & K^0_{TT} & 0 & 0 \\ 0 & 0 & K^0_{HM} & 0 & K^0_{MM} & 0 \\ 0 & -K^0_{HM} & 0 & 0 & 0 & K^0_{MM} \end{bmatrix} \begin{bmatrix} w/R \\ u_1/R \\ u_2/R \\ \theta_T \\ \theta_{M1} \\ \theta_{M2} \end{bmatrix}$$



Sign conventions full six degrees of freedom

R is the radius of the foundation, *G* is the shear modulus of the soil and K^0 is non-dimensional static stiffness components.