



Laval (Greater Montreal)

June 12 - 15, 2019

SOIL-STRUCTURE INTERACTION IN OFFSHORE CAISSONS SUBJECT TO LATERAL LOADS

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Abstract: This paper describes development and application of a numerical model to investigate interaction between large-diameter submerged caissons with the soil around. The structure is essentially treated as flexible piles. The model uses a matrix formulation of the beam-on-elastic foundation theory as applicable to the problem. A historical analytical procedure for estimating load-reflection curve considering the mobilized angle of friction is examined for comparison. Both the old and the proposed model are applied in design of a group of tower foundations at river-crossing part a power transmission grid. Each tower supported by a single caisson of great founding depth, subjected to scour, hydraulic drag, wind and earthquake forces as well as vertical load from the tower. Results from the two analyses are found to be in reasonable agreement for most of the parameters, including the distribution of bending moments along the lengths of the caissons and deflections at the top.

1 INTRODUCTION

Response of offshore caissons under lateral loads can be calculated with analytical methods developed over the decades or with modern matrix-based numerical models utilizing the beam on elastic foundation concept. These two different approaches are implemented here for a practical structure. The results are plotted to get understanding of the behavior predicted by the schemes.

2 LOAD-DEFLECTION BEHAVIOUR OF SINGLE PILE

Behavior of a laterally-loaded caisson is essentially the same as that of a single pile subjected to lateral load. One of the earliest methods of calculating that was proposed in the mid-1950s (Rowe 1955), which was developed as a case of sheet pile wall response estimated based on stress-strain theory of cohesionless soil under earth pressure (Rowe 1954, 1995). The concept utilizes the modified coefficient of horizontal subgrade reaction established earlier (Terzaghi 1943) with consideration of flexural characteristics and geometry of the pile. The relationship between the modulus for a pile with finite width and that for continuous walls was determined using Φ_m -mobilization theory (Rowe 1955) and verified by test data. A design procedure was presented which significantly reduced complexity of the calculation procedure while producing load-deflection curves with reasonable accuracy, considering the uncertainties in the soil parameters.

Table 1: Caisson properties and loads

Dimensions and Loads on Caisson	Value
Height of caisson above river, z (m)	1.5
General scour depth below the river, S (m)	45.7
Local scour depth, d (m)	25.3
Caisson Length, H (m)	72.5+D
Chosen length of caisson penetration, D (m)	30.5
Wind load per unit width T_1 , (kN/m)	292
Height of action of T_1 above top of caisson, h_1 (m)	55.8
Wave load per unit width T_2 , (kN/m)	211
Height of action of T_2 below top of caisson h_2 , (m)	10.4
Sand Wave per unit width T_3 , (m)	167
Height of action of T_3 below caisson top h_3 , (kN/m)	45.3
Hydraulic drag per unit width, T_4 , (m)	351
Height of action of T_4 below caisson top h_4 , (kN/m)	23.5
Weight of Tower, WT (kN)	3929
Height of point of action of WT above top of caisson, h' (m)	45.7
Submerged weight of caisson, W' (kN)	65518

3 CASE STUDY

The structure studied is one of a group of caissons in a big river for river crossing part of a power transmission grid in Bangladesh (Rowe et al. 1984). Details of the structure are given in Table 1. The loads acting on the caisson are schematically shown in Figure 1.

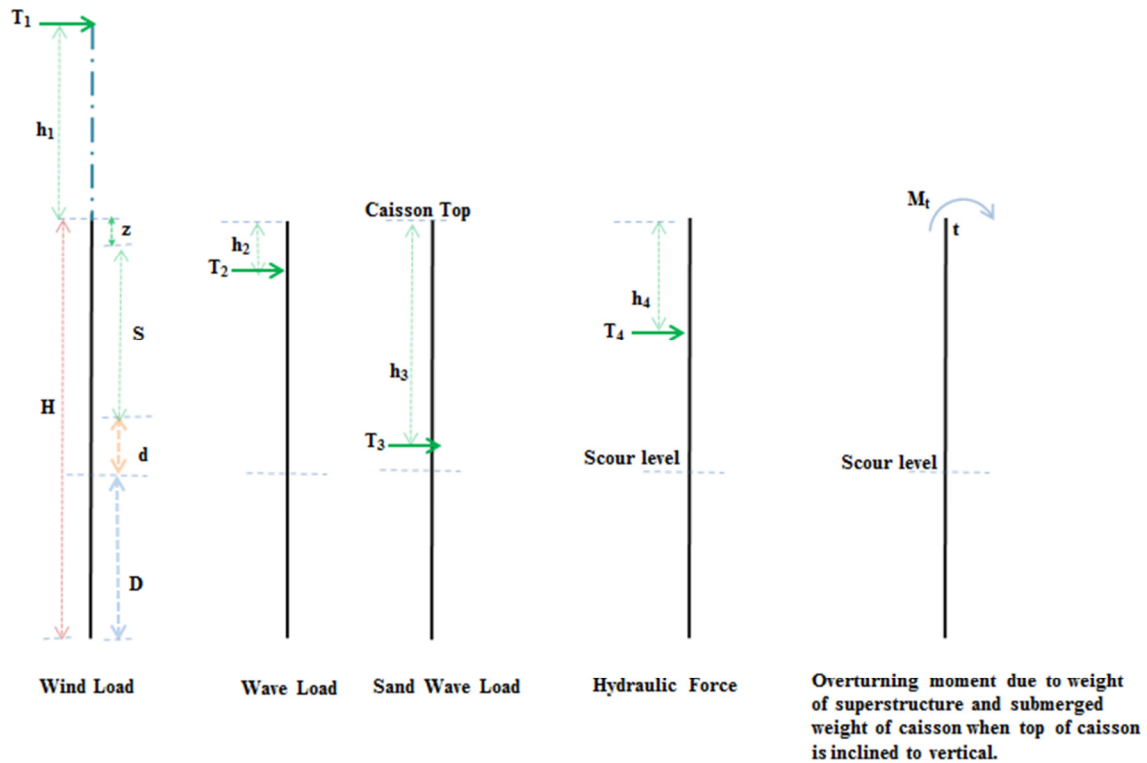


Figure 1: Loads applied to the caisson

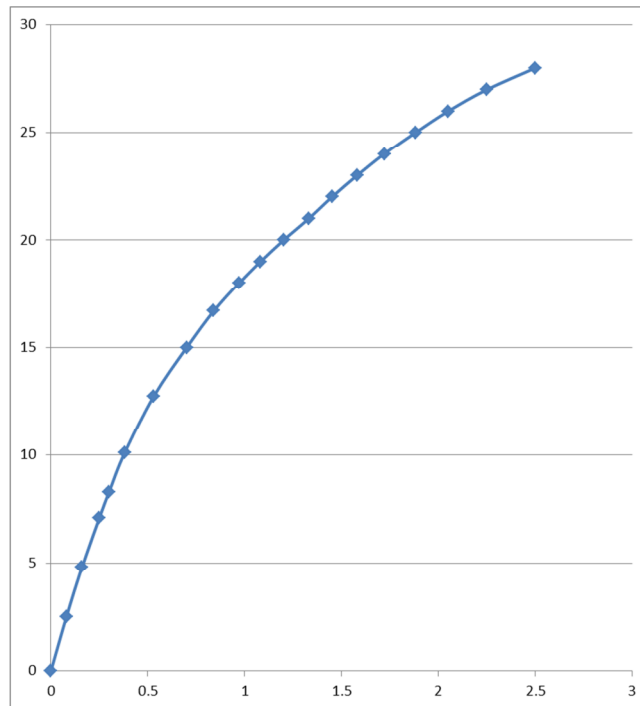


Figure 2: Moment-deflection response of single caisson

Response of the caisson in terms of moment due to the loads and deflection at the tip as calculated following the scheme by Rowe (1955) is presented in Figure 2.

4 BNWF MODEL

The response of laterally loaded caisson is modeled in this study as an elastic isotropic beam on a nonlinear Winkler foundation (BNWF), utilizing a series of elastic beam elements for the caisson and a series of nonlinear spring elements which represent the vertical and lateral load-deformation of the surrounding soil.

The caisson nodes are created with three dimensions (x , y and z directions) and six degrees-of-freedom (3 translational degrees-of-freedom, 3 rotational degrees-of-freedom). The caisson nodes are fixed against translation in the y -direction and have no rotational fixity about the x and z axes. The caisson nodes are free to translate in the vertical and horizontal directions. The caisson nodes over the penetration length of the caissons are linked with the spring nodes.

The soil springs are modeled as zero-length elements and assigned separate uniaxial material objects which can account for load-deformation response of the surrounding soil in the lateral and vertical directions. The spring nodes are only generated over the embedded length of the caisson. They are generated with three translational degrees of freedoms. Translation at the soil-ends of the spring elements are fixed in x , y and z directions while the caisson-ends of the spring elements can translate with the caisson nodes in the vertical and horizontal directions.

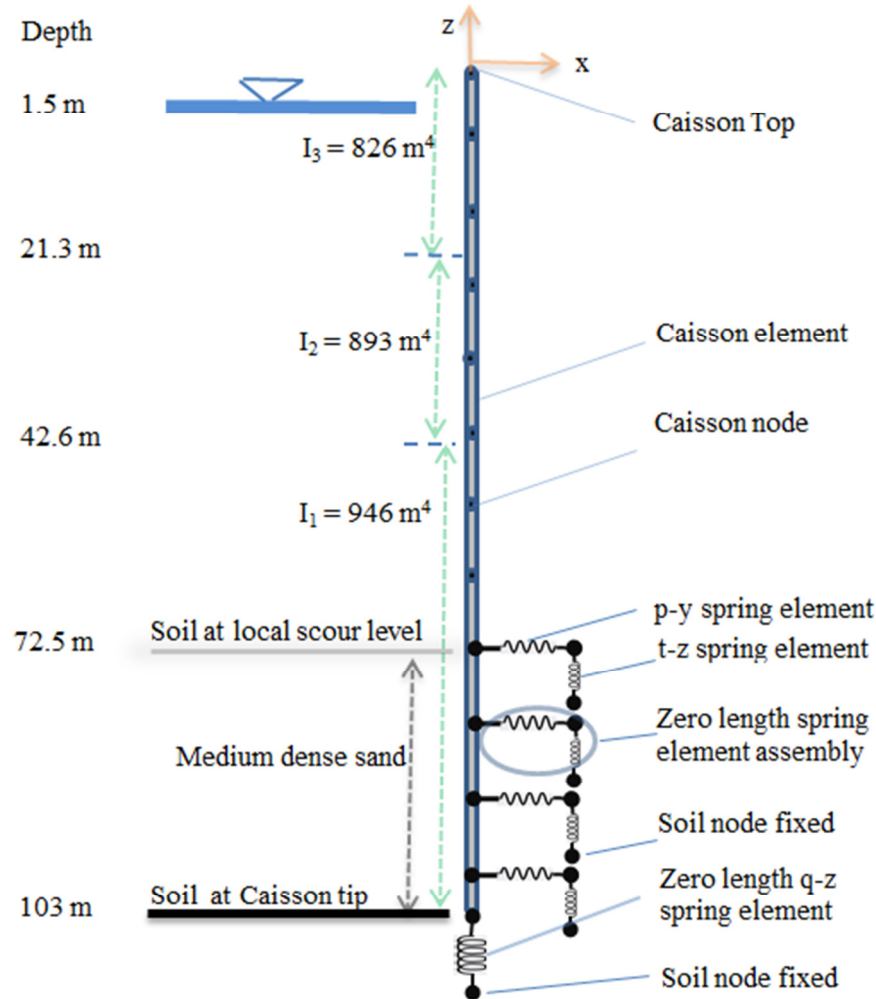


Figure 3: Details of BNWF model of caisson

5 SOIL-SPRING CONSTITUTIVE RELATIONSHIP

The constitutive relationship of the soil springs is modeled in such a way that the one-dimensional spring elements oriented in the horizontal direction represents p-y relationships used in API guidelines for the design of offshore structures (API, 1987; API, 1993; API, 2000). Vertical response of soil caused by vertical displacement (z) of the caisson shaft is represented by a series of t-z springs. Vertical movement of the caisson tip causes vertical deformation in the soil at the caisson tip. The constitutive behavior of soil at the caisson tip is represented by a q-z spring. In this study, p-y behavior with depth is modeled using the procedure in API (2000). The t-z behavior with depth is modeled using the procedure suggested by Mosher (1984). The q-z behavior at the caisson tip is modeled using the procedures of Meyerhof, and Vijayvergiya (Meyerhof, 1976; Vijayvergiya, 1977).

Several input soil parameters used in this study to define p-y, t-z and q-z springs are: effective soil unit weight of 8.3 kN/m^3 (Hinch et al., 1984), internal effective friction angle of 34 degree for medium dense to dense sand (Hinch et al., 1984), and sand shear modulus of 120000 kN/m^2 (Hardin and Kalinski, 2005). In the current study, the constitutive relationships of p-y spring, t-z and q-z spring are implemented in the PySimple1, TzSimple1 and QzSimple1 uniaxial material objects, respectively. These spring elements are available in the OpenSees material library. The OpenSees source code is written in this study in a way that the PySimple1 material object is oriented in the x-direction (direction of horizontal loading), while the TzSimple1, and the QzSimple1, material objects are oriented in the z-direction (vertical direction).

6 RESULTS FROM BNWF MODEL

The deflection, moment, shear and soil reaction with respect to distance from the top of the caisson as calculated with the BNWF model are presented in Figures 4 to 7.

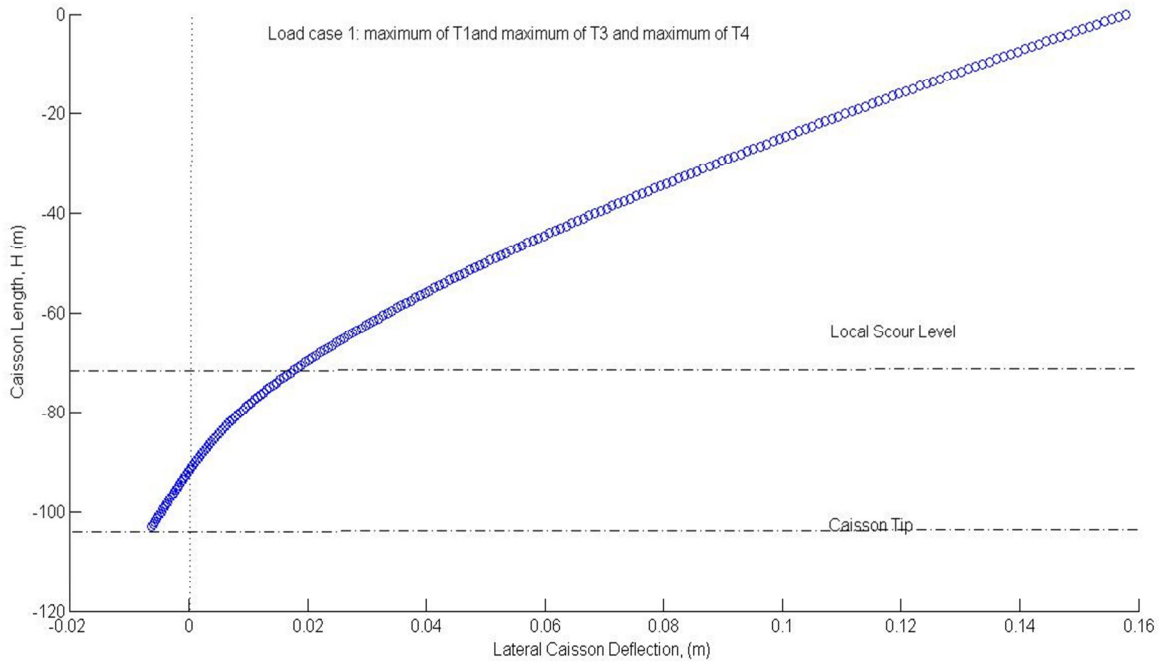


Figure 4: Deflection with respect to distance from top

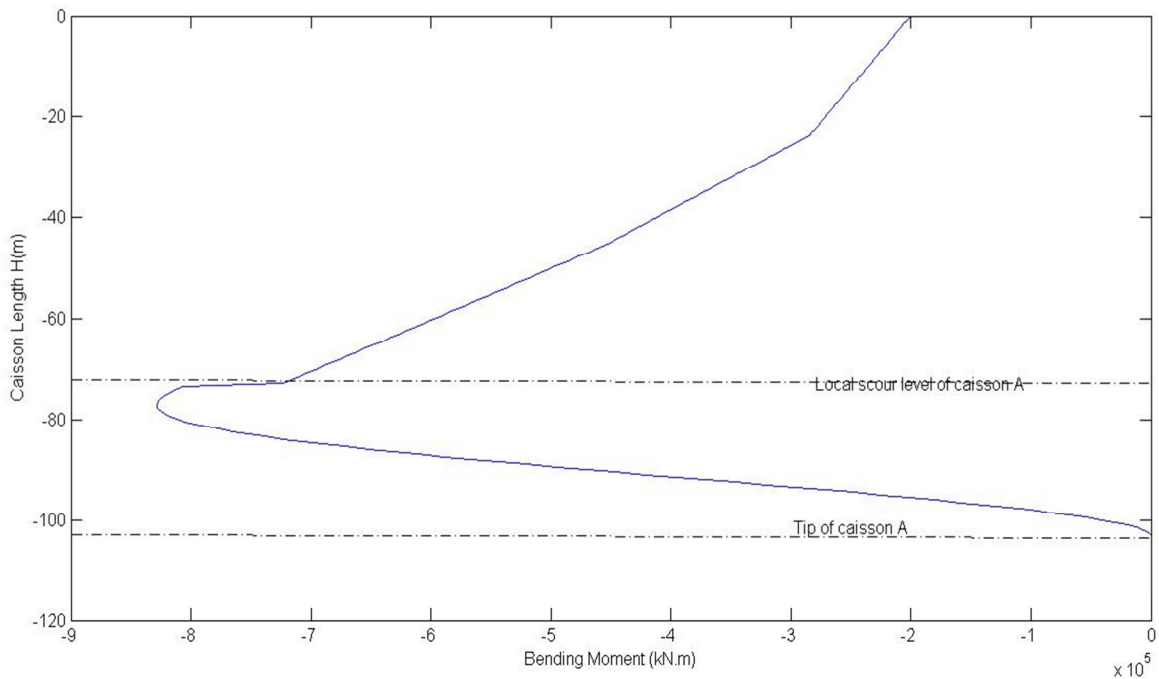


Figure 5: Moment with respect to distance from top

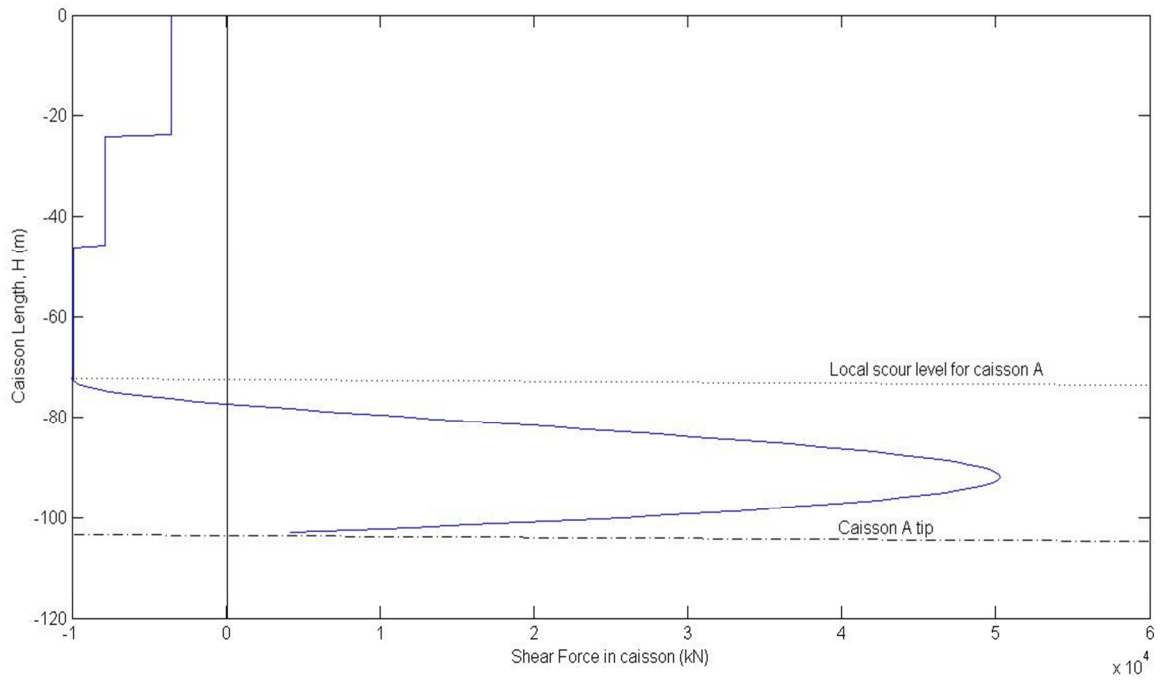


Figure 6: Shear with respect to distance from top

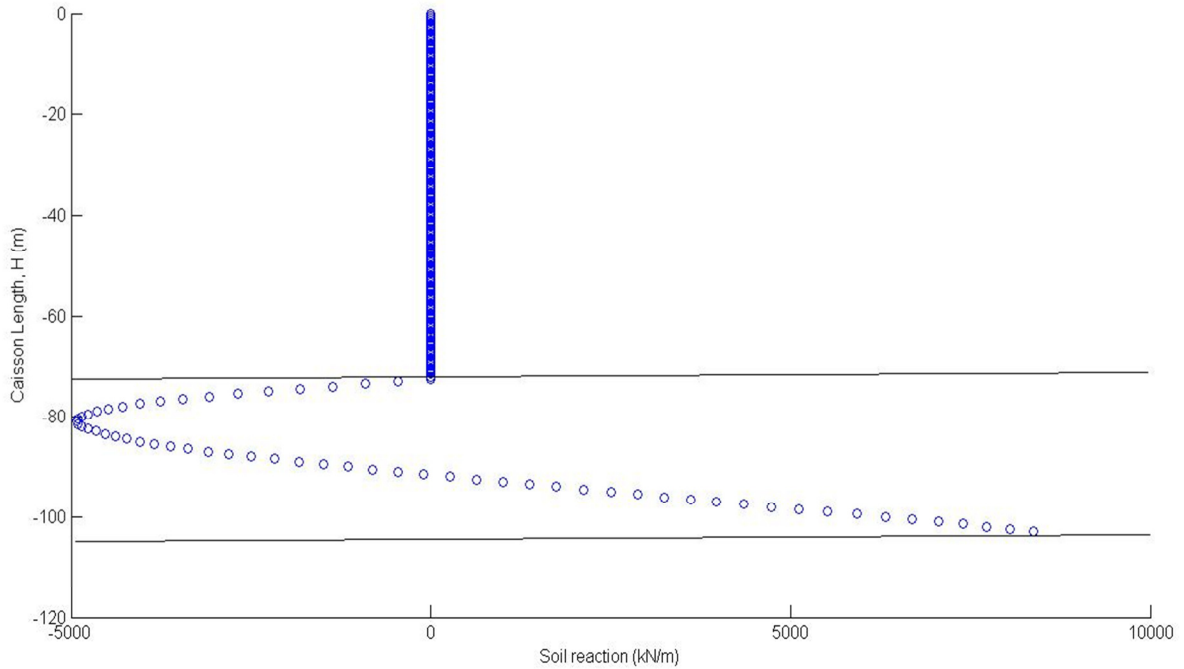


Figure 7: Soil reaction with respect to distance from top

7 CONCLUSION

The two different methods presented here produce useful results for the practical structure analyzed. Although there are fundamental differences between the two approaches they produce comparable results. Further investigation is ongoing to investigate accuracy and limitations of the predictions.

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