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Behavior of Piles under Lateral Loading Soil Structure Interaction

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Abstract: *This paper focuses on the application of sub grade reaction method for the analysis of laterally loaded piles embedded in cohesion less soils. The sub grade reaction method considers the pile as a flexible beam on the elastic foundation and replaces soil as a series of elastic, closely spaced but independent springs. This method has the advantage of being relatively simple, and single layer foundation in cohesion less soil is considered in the present study. The pile deflection, Slope, bending moment and shear force is calculated using this method and the same has been validated with finite element based ANSYS software. The code IS 1911 has been used for values of Constant subgrade reaction.*
Keywords: *Lateral loads. Deflection, Slope, Bending moment, Shear force.*

I. Introduction

Piles are usually slender, having high length to width ratio mainly designed to resist axial loads. Pile foundation is often used in bridges and other structures to support the applied axial loads and lateral loads.

A pile may be subjected to lateral force for a number of causes, such as, wind, earthquake, water current, earth pressure, effect of moving vehicles or ships, plant and equipment, etc. The lateral load capacity of a single pile depends not only on the horizontal sub grade modulus of the surrounding soil but also on the structural strength of the pile shaft against bending, consequent upon application of a lateral load.

Because of the complexity of the problem and limited information on horizontal sub grade modulus of soil, and pending refinements in the theoretical analysis only a procedure for an approximate solution, that is presented in IS codes. And also there is no exact solution for the analysis of laterally loaded piles as in case of vertically loaded piles. Situations that need a rigorous analysis shall be dealt with accordingly.

II. Objectives

The main aim of this study is to understand the interaction between ground and piles when subjected to lateral loading, that is Deflection, Slope, Bending moment, Shear force is calculated along the length of pile and the same is validated with finite element based ANSYS software.

III. Theoretical Analysis

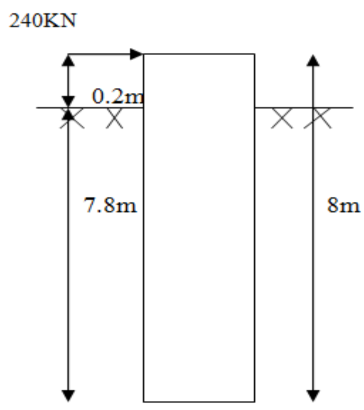
a. Soil Structure Interaction:

Generally structures are assumed to be fixed at their bases in most of the civil engineering analysis. But in reality, the response of a structure varies according to the supporting soil stiffness. Conventional structural design methods neglect the SSI effects. Neglecting SSI is reasonable for light structures in relatively stiff soil such as low rise buildings and simple rigid retaining walls. The effect of SSI however becomes prominent for Structures subjected to lateral loads and massive structures resting on relatively soft soils. The soil-structure interaction SSI affects the distribution of pressure between the foundation and the soil.

In the present study, the effect of supporting soil flexibility, on lateral load response of concrete pile is investigated. The long flexible pile response is observed, Compressibility of surrounding soil is modeled with Winkler springs. Free head piles are considered in this method. The pile deflection, Slope, bending moment and Shear force can be calculated using this method. The proposed study has been validated by comparison of the results with those calculated using finite element based ANSYS Software.

Theoretical Example To Show Behavior Of Laterally Loaded Piles:

Particulars	Corresponding values
Pile size	0.5mx0.5m
Length of pile (L)	8m
Factored Lateral load	240KN
Moment	48KN-m
Young's modulus of pile (Ec)	22.4Gpa
Type of soil	Cohesion less soil
Constant of Sub grade reaction (nh)	52400KN/m³



b. Assumptions:

Pile be a square pile of cross-section 500mmx500mm
Modulus of elasticity of pile be E = 2.24x10^7KN/m²

Moment of inertia, $I = \frac{bd^3}{12}$ $\qquad I = \frac{0.5x0.5^3}{12} = 0.00521m^4$

$T = \sqrt[5]{\left(\frac{EI}{nh}\right)}$, $T = 1.173m$

Where
T= relative stiffness factor
nh = Constant sub grade reaction
Zmax = Maximum depth coefficient
Ls = Length of Pile below ground level
Qhg. = Factored lateral load
Mg = Factored moment

Zmax = $\frac{Ls}{T}$, Zmax = 6.64 < 5, Long pile.
Qhg. = 240kN
Mg = 240x0.2 = 48kN-m

i. Deflection at the free end

$$yx = yA + yB = Ay\frac{QgT^3}{EI} + By\frac{MgT^2}{EI}$$

Yx = 9mm at the free end.

ii. 3.2.2 Slope at free end of pile

$$Sx = SA + SB = As\frac{QgT^2}{EI} + Bs\frac{MgT}{EI}$$

Sx = -0.0054 radians at the free end.

iii. Bending moment at the free end

$$Mx = MA + MB = AmQgT + BmMg$$

Bending moment at the free end Mx=48KN-m.

iv. Shear force at the free end.

$$Vx = VA + VB = AvQg + Bv\frac{Mg}{T}$$

Shear force at the free end is 240KN

v. Soil reaction at the free end

$$Px = PA + PB = Ap\frac{Qg}{T} + Bp\frac{Mg}{T^2}$$

Soil reaction at the free end is 0 KN.

IV. Finite Element Modelling

Based on the platform of ANSYS, reasonable and practical 2D-FE models were published. The bending moment and shear force plots can only be obtained in case of 2D or 1D models because of that reason the 2D models selected. In the present study the pile is created as 2D elastic beam element, and the soil created as linear springs are modeled using COMBIN14 element.

The pile foundation has been modeled using 2D elastic Beam 3 element, which is a uniaxial element with tension, compression, and bending capabilities. The element has three degrees of freedom at each node: translations in the nodal x and y directions and rotation about the nodal z-axis. The behaviors are assumed to be elastic. The concrete pile of M20 grade is considered having density of 24kN/m3. The modulus of elasticity of pile foundation E and poison's ratio μ of pile foundation are 22.4Gpa, 0.15.

In the Winkler model soil is modeled as linear springs. In the present study the linear springs are modeled using COMBIN14 element. No bending or torsion is considered, the spring damper element has no mass. The spring stiffness is calculated depending on the type and the contributing area for that spring.

The springs are provided only in the opposite phase to the application of load, because there won't be any contact between the soil and pile in the load application phase.

4.1 Problem Solving Using Ansys:

The interaction model for the pile-soil system is shown in Figure 4.1 the pile is assumed to be a Beam of length L with constant flexibility EI, and to be embedded into soil. Symbols H and M represent the horizontal load and moment applied at top of the pile respectively; and k1….kn denote the stiffness of the springs.

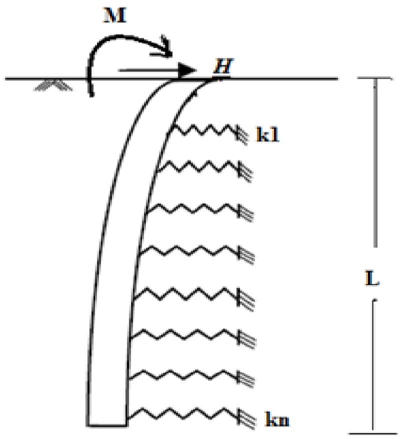


Figure 4.1 - Winkler model

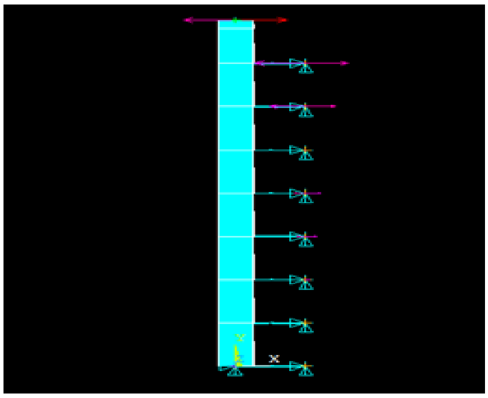


Figure 4.2 - 2D-FE Winkler model of pile and soil

1. The pile is modeled as a 2D elastic beam, to a depth of 8m. The springs are provided at every one meter along the depth of pile from the ground level.
2. As the stiffness of soil is linearly increases with depth, at the ground level the spring stiffness is 0, later on it increases with depth. One meter length of springs is considered because the length of pile is irrespective for the stiffness of springs.
3. The springs are provided at one phase of the pile opposite to the application of load, in other phase no need to provide springs because there won't be any contact between the soil and the foundation.
4. Fixed end condition is provided at the bottom pile because there is no rotation. Fixed end condition is also provided for springs it means the soil is fixed somewhere. The lateral load and moment is applied at the top of the pile. After solving the deflection, Slope, bending moment and Shear is obtained along the length of pile.

4.2.1 Example: 1

Particulars	Corresponding values
Pile size	0.5mx0.5m
Length of pile (L)	8m
Factored Lateral load	240KN
Moment	48KN-m
Grade of concrete	M20
Young's modulus of pile (Ec)	22.4Gpa
Poisson's ratio for Concrete (μc)	0.15
Type of soil	Cohesion less soil
Constant of Sub grade reaction (nh)	52400KN/m³

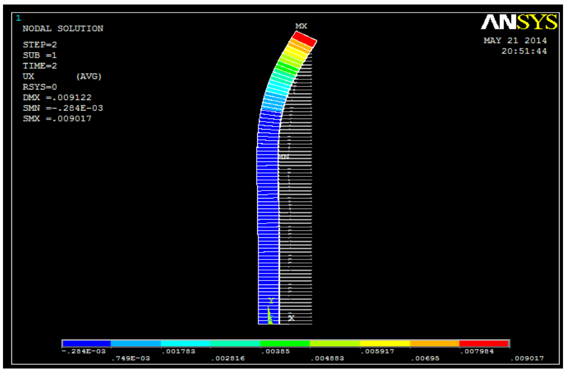


Figure 4.3 - Deflection of Pile in mm Subjected to lateral load

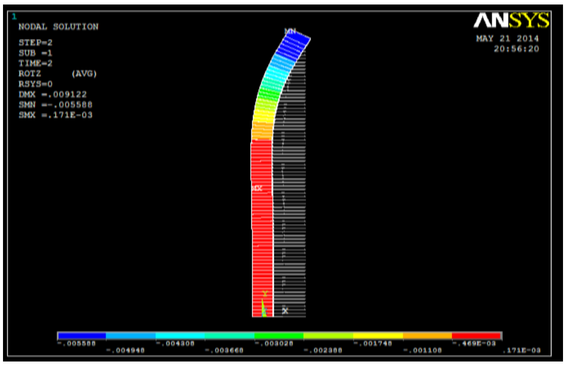


Figure 4.4 - Slope of Pile in radians Subjected to lateral load

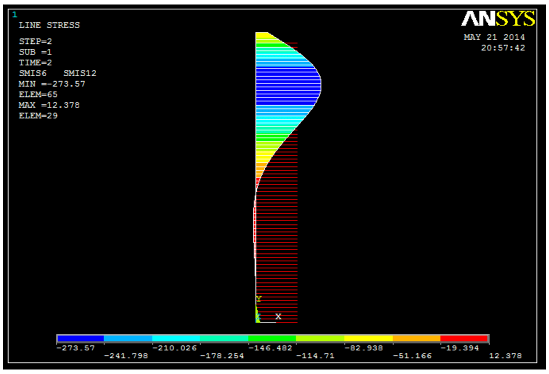


Figure 4.5 - Bending moment of Pile in KN-m Subjected to lateral load

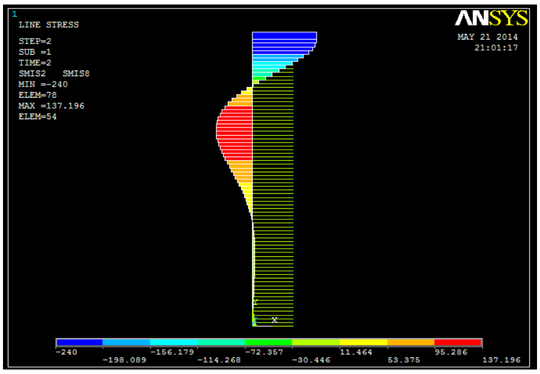


Figure 4.6 - Shear force of Pile in KN Subjected to lateral load

V. Validation Of Problem

The sub grade reaction method is used to predict the responses for single pile subjected to Lateral load. Winkler sub grade reaction approach is used for obtaining governing differential equations of pile. The pile deflection, Slope, bending moment and Shear force can be calculated using this method. And the same is validated using finite element based ANSYS software. These curves are used to analyze the lateral performance of piles.

5.1 Example: 1

Material properties:

Particulars	**Corresponding values**
Pile size	0.5mx0.5m
Length of pile (L)	8m
Factored Lateral load	240KN
Moment	48KN-m
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Assumptions:
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Modulus of elasticity of pile be E = 2.24x10^7KN/m²

Moment of inertia, $I = \frac{bd^3}{12}$ $\qquad I = \frac{0.5\text{x}0.5^3}{12} = 0.00521\text{m4}$

$T = \sqrt[5]{\left(\frac{EI}{nh}\right)}$, $T = 1.173$ $\qquad$ Qhg. = 160x1.5 = 240kN $\qquad$ Mg = 240x0.2 = 48kN-m

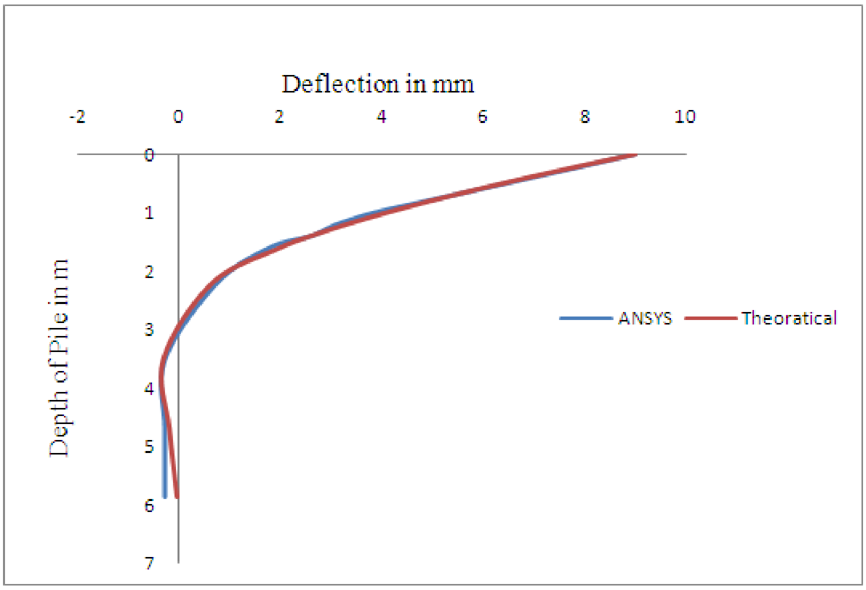

Figure 5.1 - Comparison of Theoretical and ANSYS results (Deflection)

Using the method of Sub grade reaction approach the theoretical results were calculated. The comparison has done on theoretical and ANSYS results. It has been observed that the maximum deflection occurs at the free end is 9mm, and it is goes on decreasing towards the length of pile, and the depth of Soil Subjected to deflection is 5.86m from the top of Pile from theoretical analysis. For verification, the response of Pile for lateral load was analyzed by Finite element method with the software ANSYS. The calculated theoretical and ANSYS results are shown above. It can be seen that the deflections calculated using the proposed method and FEM are in good agreement.

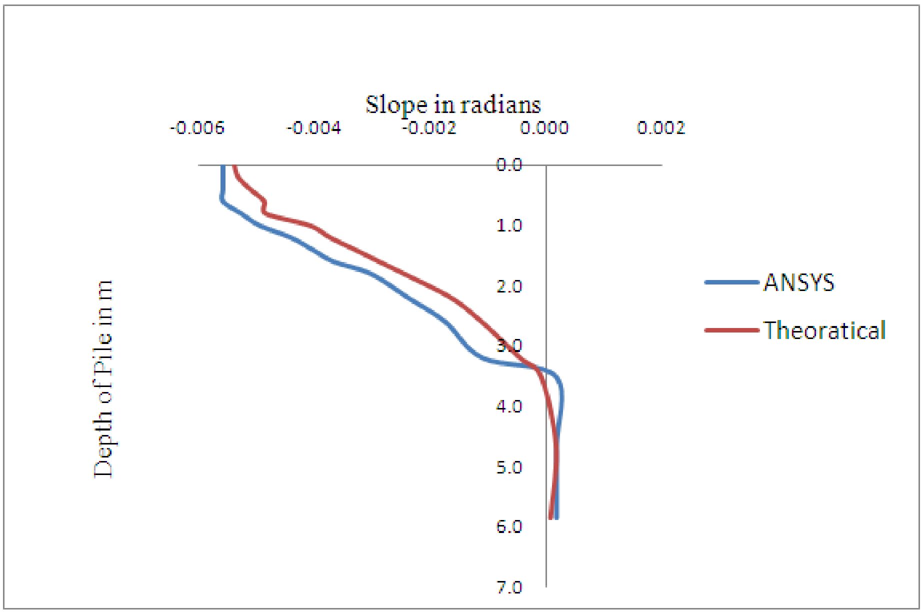

Figure 5.2 - Comparison of Theoretical and ANSYS results (Slope)

Using the method of Sub grade reaction approach the theoretical results were calculated. The comparison has done on theoretical and ANSYS results. It has been observed that the maximum Slope occurs at the free end is -0.00540rad, and it is goes on decreasing towards the length of pile, and the depth of Soil Subjected to Slope is 5.86m from the top of Pile, from theoretical analysis. For verification, the response of Pile for lateral load was analyzed by Finite element method with the software ANSYS. The calculated theoretical and ANSYS results are shown above. It can be seen that the deflections calculated using the proposed method and FEM are in good agreement.

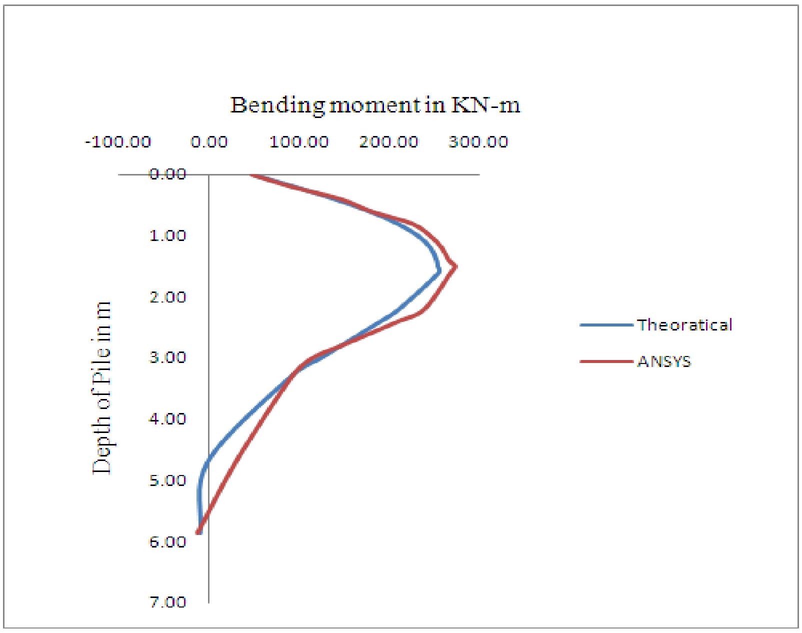

Figure 5.3 - Comparison of Theoretical and ANSYS results (Bending moment)

Using the method of Sub grade reaction approach the theoretical results were calculated. The comparison has done on theoretical and ANSYS results. It has been observed that the bending moment at the free end is 48Kn-m, maximum BM occurs at 1.6m from the free end, that is 255.40KN-m, and it is goes on decreasing towards the length of pile, and the depth of Soil Subjected to Bending moment is 5.86m from the top of Pile, from theoretical analysis. For verification, the response of Pile for lateral load was analyzed by Finite element method with the software ANSYS. The calculated theoretical and ANSYS results are shown above. It can be seen that the Bending moment calculated using the proposed method and FEM are in good agreement.

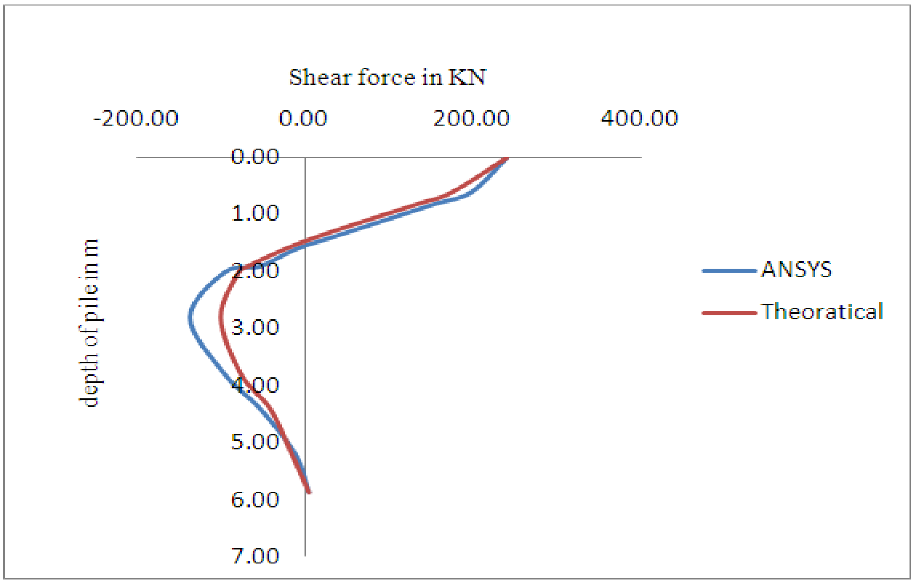

Figure 5.4 - Comparison of Theoretical and ANSYS results (Shear force)

Using the method of Sub grade reaction approach the theoretical results were calculated. The comparison has done on theoretical and ANSYS results. It has been observed that the maximum Shear force occurs at the free end that is 240KN, that is 0m from the top of pile, and it is goes on decreasing towards the length of pile, and the depth of Soil Subjected to shear force is 5.86m from the top of Pile, from theoretical analysis. For verification, the response of Pile for lateral load was analyzed by Finite element method with the software ANSYS. The calculated theoretical and ANSYS results are shown above. It can be seen that Shear force calculated using the proposed method and FEM are in good agreement.

VI. Conclusions

The analysis of laterally loaded piles is done with both theoretical and FEM based ANSYS software. It has been observed that the analysis of laterally loaded piles can be effectively carried out using ANSYS software. A Winkler method is adopted for the analysis of laterally loaded piles. The analysis of laterally loaded pile embedded in a single layer soil profile is carried out. The results show that the calculated deflections, Slope, Bending moment, Shear force using proposed method agree well with those obtained from FEM with software ANSYS. This method has the advantage over other procedures in that it is easy to understand and is adaptable to simple computer programs by engineers.

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