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ANALYSIS OF LATERALLY LOADED PILE IN COHESIONLESS SOIL BASED ON KINEMATICS

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ABSTRACT: Piles are especially for lowland areas frequently penetrate through loose soil deposits. In loose soils, this piles likely to exhibit excessive displacements at ground level under lateral loads. Several methods are available to predicting the ultimate lateral resistance of rigid pile in cohesive and cohesionless soils. In this paper, a new approach based on kinematics and hyperbolic model (nonlinear approach) has been developed to study the rigid free head pile in cohesionless soils. Based on this approach ultimate lateral resistance, rotating point for corresponding displacements at ground level of rigid pile for different subgrade reaction of soil(k_{so}), Lateral soil pressure(q_{max}), Diameter of pile(D) and Length of pile(L) has been studied.

Keywords: Lateral load, rigid pile, cohesionless soil, Nonlinear subgrade reaction, ultimate lateral load

I. INTRODUCTION

It is a challenging task to design the Foundations subjected to large lateral forces like the forces due to Earthquake, Wave action and Lateral Earth pressure. The design will be a challenging task if the foundations are in soft soils usually prevalent in lowland areas. Structures like Bridges, Tall buildings, Transmission towers are usually founded on piles must be designed to support both axial, lateral loads and moments. Hansen (1961), Broms (1964), Meyerhof *et al*. (1981), Prasad & Chari (1999), Zhang et al. (2005), etc., proposed theories for the estimation of ultimate resistance of piles, piers and poles in cohesionless soils under various pile head and base conditions.
Padmavathi *et al*. (2007) presented analysis of single rigid free head pile in cohesionless soils based on kinematics and subgrade reaction approach. The Lateral resistance of the pile is governed by several factors like subgrade reaction of soil (k_{so}), lateral soil pressure (q_{max}), diameter of pile(D) and length of pile. The different subgrade reaction conditions of the soil are mentioned below (Condition A, B, C, D). Important consideration in this analysis is that the soil does not mobilize any pressure close to the point of rotation because the displacement there is zero.

II. STATEMENT OF THE PROBLEM

A rigid pile of diameter (D) and length (L) is installed in a coarse-grained soil. The lateral force (H) acting at an eccentricity (e) is creating a moment (M) at ground level. Since the pile is unrestrained, due to this lateral force, the pile rotates through an angle (θ) about a point 'O' at depth Z_0 from the ground surface. The displacement at ground line is ρ_0 due to the rotation of the pile. Modulus of horizontal subgrade reaction, K_{so}, ultimate lateral soil pressure, q_{max}, unit weight of soil, γ_0, angle of internal friction, φ' are the relevant properties of the soil. The displacements at ground level may be too high from structural considerations in many of the cases.

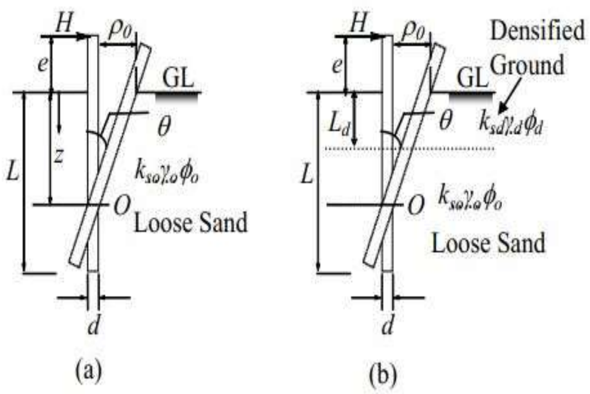

Fig. 1: (a) Original Ground (b) Improved Soil Layer near the Ground Surface

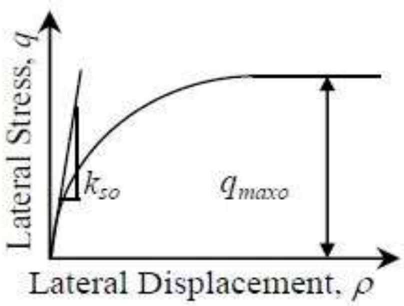

Fig. 2: Non-Linear Hyperbolic Response of the Soil

Following conditions are studied in this paper:

- Condition A - Base Rotation + Constant Stiffness
- Condition B - Above the Base Rotation + Constant Stiffness
- Condition C - Above the Base Rotation + Varying Stiffness (Increasing Stiffness from top to bottom)
- Condition D - Above the Base Rotation + Modified Stiffness at ground level (GL) (More Stiffness at Ground level)

Variations of Stiffness Conditions and Formulas used:

The lateral stress, q is related to the lateral displacement, ρ_z, as below,

$$q = \frac{K_{so}\rho_z}{(1+\frac{K_{so}\rho_z}{q_{max}})}$$

Where, ρ_z is the displacement of the pile at depth z from GL in m

k_{so} is Subgrade reaction of Soil in kN/m^3

q_{max} is Lateral Soil Pressure in kN/m^2

For equilibrium, from the fig 1(a) the applied lateral force, H, is equal to the total response from the soil as,

$$H = \int_0^{z_0} \frac{K_{so}\rho_z\, d}{1+\frac{K_{so}\rho_z}{q_{max}}} dz - \int_{z_0}^{L} \frac{K_{so}\overline{\rho_z}\, d}{1+\frac{K_{so}\overline{\rho_z}}{q_{max}}} dz$$

and the normalized equation for lateral force is as,

$$dH^* = \frac{dH}{q_{max}\, d\, L} = \frac{\frac{K_{so}\,\rho z\, d}{q\max d\, L}}{1+\frac{K_{so}\,\rho z}{q\max}} dz = \frac{\frac{K_{so}\, L}{q\max} * \frac{\rho z}{L} * \frac{1}{L}}{1+\frac{K_{so}\, L}{q\max} * \frac{\rho z}{L}} dz = \frac{\mu * \rho z *}{1+\mu * \rho z *} dz *$$

Therefore for Lateral resistance of a pile for a particular displacement is,

$H = (\sum dH^*) \times q_{max} \times D \times L$

Taking moments about the point of application of the load

$$M = He = \int_0^{Z0} \frac{K_{so}\rho_z\, z\, d}{1+\frac{K_{so}\rho_z}{q_{max}}} dz - \int_{Z0}^{L} \frac{K_{so}\overline{\rho_z}\, z\, d}{1+\frac{K_{so}\overline{\rho_z}}{q_{max}}} dz$$

Where $\rho_z = (z_0 - z)\tan\theta$ and $\overline{\rho_z} = (z - z_0)\tan\theta$ are displacements above and below the point of rotation at depth z and z_0.

By equating $M_{calculated}$ and M_{actual}, the Height of rotating points can find.

$M_{calculated} = (\sum dM^*) \times q_{max} \times D \times L^2$

$M_{actual} = H \times (L+e)$

If $M_{calculated} < M_{actual}$, then pile has to be rotated above the base.

Table 1: Modulus of Subgrade Reaction(k_s) for different Soils

Type of Soil	K_s(kN/m^3)
Loose Sand	4800 - 16000
Medium Dense Sand	9600 – 80000
Dense Sand	64000 – 128000
Clayey Medium Dense Sand	32000 – 80000
Silty Medium Dense Sand	24000 - 48000

Courtesy of Foundation Analysis and Design - Fifth edition by Joseph E. Bowles, RE., SE

III. RESULTS AND DISCUSSIONS

The variation of lateral load resistance of pile with displacement at ground level are evaluated based on the proposed model for different combinations of k_{so} with the values of 3000, 5000, 8000, 10000, 15000 and 20000 kN/m^3; lateral soil pressure, q_{max} of 300, 500, 800, 1000 and 2000 kN/m^2, diameter of pile, D varying from 0.3, 0.5, 0.7, 0.9 and 1.2 m, length of pile, L varying from 10, 12, 14, 18 and 20.

CONDITION (A): BASE ROTATION WITH CONSTANT STIFFNESS

Lateral Force acting on the pile with an eccentricity e=0.5 m with ground level (GL). Pile length is divided into No. of partitions (dz) to predict the lateral resistance of pile at a particular point for all the conditions studied in this paper.

Pile is rotated about base of the pile and surrounding soil of pile with constant subgrade reaction for the condition (A) gives the following results.

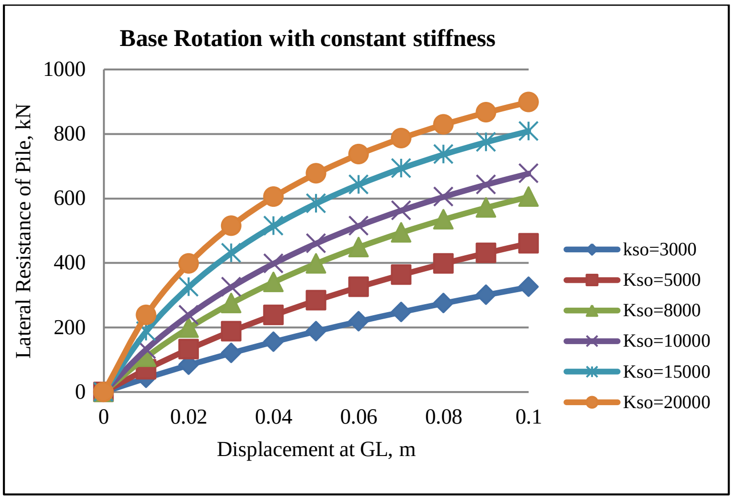

Fig. 3: Displacement at GL, m vs Lateral resistance of Pile, kN for q_{max}=500 kN/m^2, D=0.3 m, L=10 m

Figure 3 presents the variation of lateral resistance of pile with displacement of pile at ground level for different values of k_{so} for q_{max}=500 kN/m^2, D=0.3 m, L=10 m. The lateral resistance of the pile increases with increasing subgrade reaction of soil. For displacement of 0.1 m, 100% increase in k_{so} has caused 46.96% increase in lateral resistance of pile.

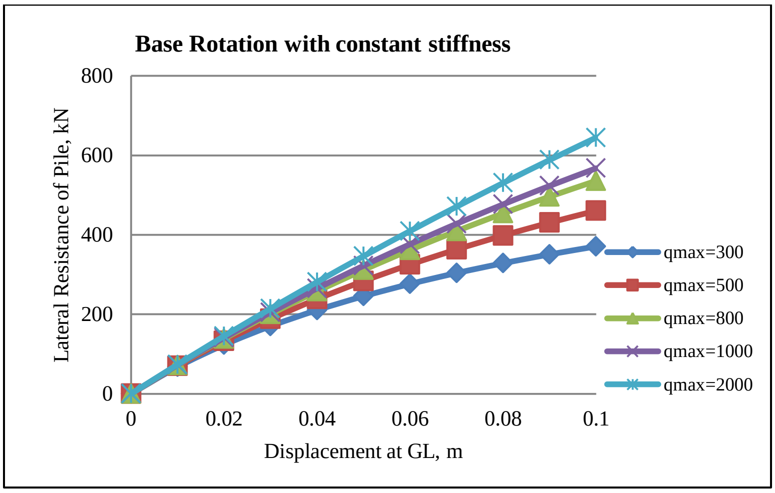

Fig. 4: Displacement at GL, m vs Lateral resistance of Pile, kN for k_{so}=5000 kN/m^3, D=0.3 m, L=10 m

Figure 4 presents the variation of lateral resistance of pile with displacement of pile at ground level for different values of q_{max} for k_{so}=5000 kN/m^3, D=0.3 m, L=10 m. The lateral resistance of the pile will increases with increasing of lateral soil pressure of soil. For displacement of 0.1 m, 100% increase in q_{max} has caused 23.19% increase in lateral resistance of pile.

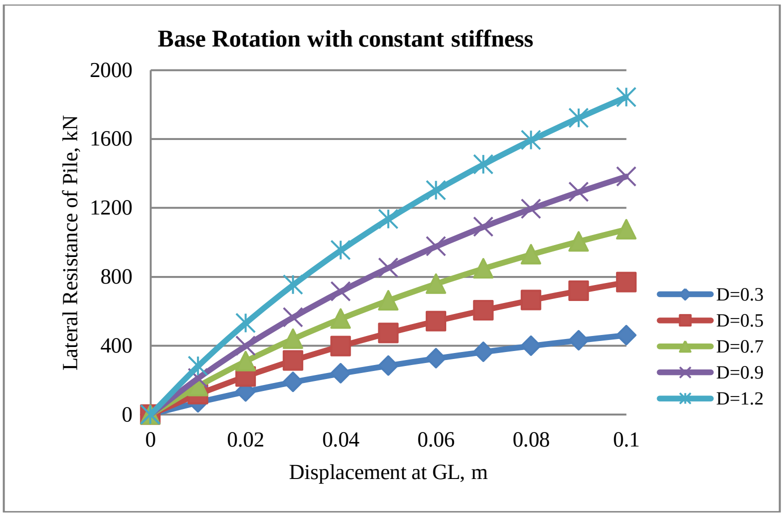

Fig. 5: Displacement at GL, m vs Lateral resistance of Pile, kN for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, L=10 m

Figure 5 presents the variation of lateral resistance of pile with displacement of pile at ground level for different values of D for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, L=10 m. The lateral resistance of the pile will increases with increasing of diameter of pile. For displacement of 0.1 m, 200% increase in D has caused 200% increase in lateral resistance of pile.

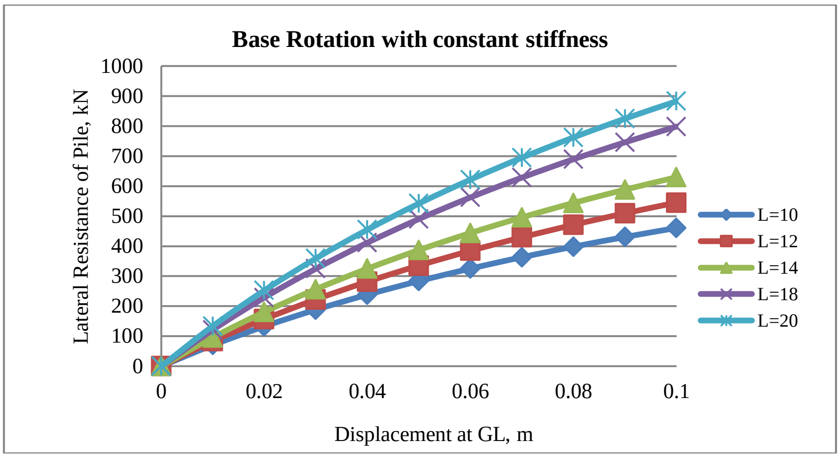

Fig. 6: Displacement at GL, m vs Lateral resistance of Pile, kN for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, D=0.3 m

Figure 6 presents the variation of lateral resistance of pile with displacement of pile at ground level for different values of L for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, D=0.3 m. The lateral resistance of the pile will increases with increasing of length of pile. For displacement of 0.1 m, 100% increase in L has caused 91.71% increase in lateral resistance of pile.

CONDITION (B): ROTATION ABOVE THE BASE WITH CONSTANT STIFFNESS

Pile is rotated above the base of the pile and surrounding soil of pile with constant subgrade reaction for the condition (B) gives the following results.

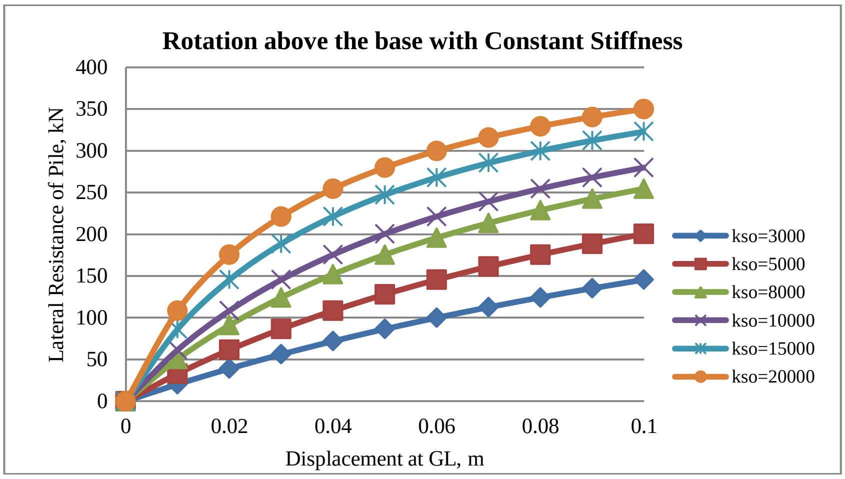

Fig. 7: Displacement at GL, m vs Lateral resistance of Pile, kN for q_{max}=500 kN/m^2, D=0.3 m, L=10 m

Figure 7 presents the variation of lateral resistance of pile with displacement of pile at ground level for different values of k_{so} for q_{max}=500 kN/m^2, D=0.3 m, L=10 m. The lateral resistance of the pile will increases with increasing of subgrade reaction of soil. For displacement of 0.1 m, 100% increase in k_{so} has caused 39.7% increase in lateral resistance of pile.

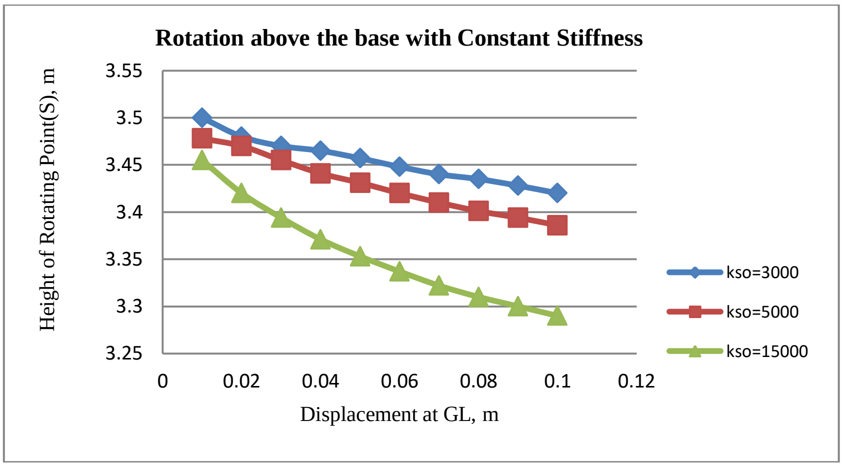

Fig. 8: Displacement at GL, m vs Height of Rotating Point above the base(S), m for q_{max}=500 kN/m^2, D=0.3 m, L=10 m

As shown in figure 8, for Rotation above the base with constant Stiffness (B), the height of the rotating point above the base has decreased with increase in displacement at ground level, ρ_0 and k_{so} respectively.

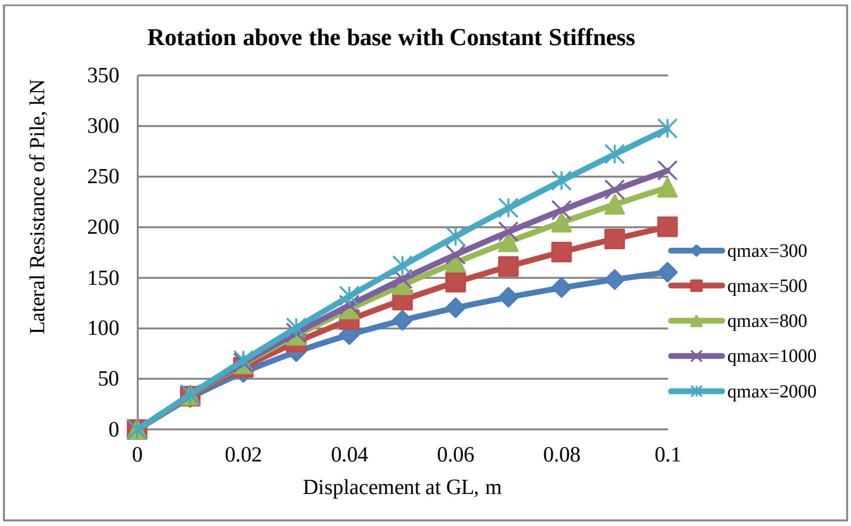

Fig. 9: Displacement at GL, m vs Lateral resistance of Pile, kN for k_{so}=5000 kN/m^3, D=0.3 m, L=10 m

Figure 9 presents the variation of lateral resistance of pile with displacement of pile at ground level for different values of q_{max} for k_{so}=5000 kN/m^3, D=0.3 m, L=10 m. The lateral resistance of the pile will increases with increasing of lateral soil pressure of soil. For displacement of 0.1 m, 100% increase in q_{max} has caused 27.76% increase in lateral resistance of pile.

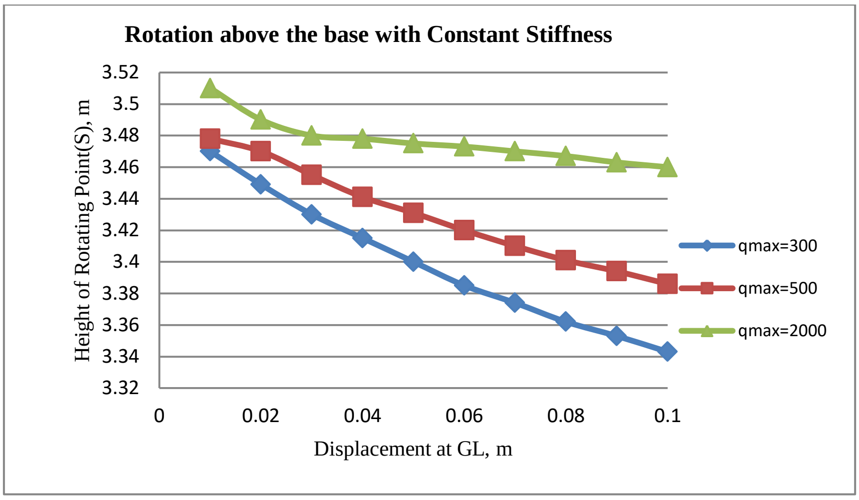

Fig. 10: Displacement at GL, m vs Height of rotating point above base(S), m for k_{so}=5000 kN/m^3, D=0.3 m, L=10 m

As shown in figure 10, for Rotation above the base with constant Stiffness (B), the height of the rotating point above the base has decreased with increase in displacement at ground level(ρ_0) and increased with increase in lateral soil pressure (q_{max}).

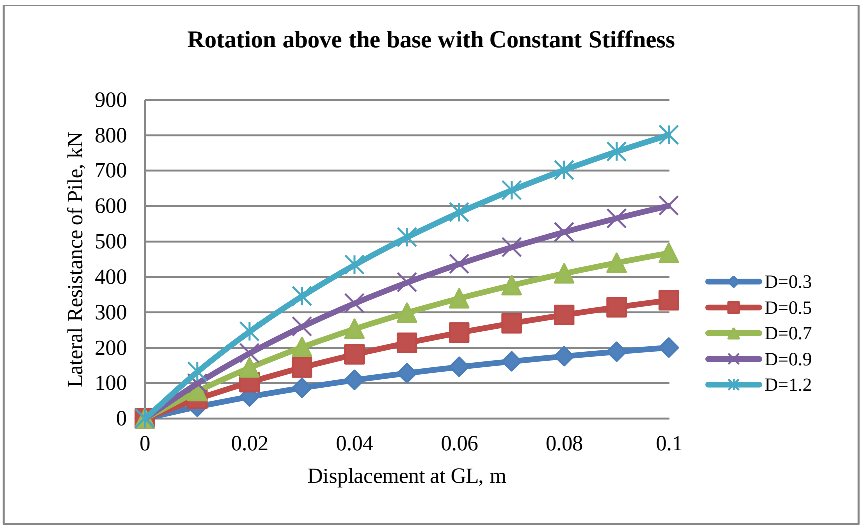

Fig. 11: Displacement at GL, m vs Lateral resistance of Pile, kN for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, L=10 m

Figure 11 presents the variation of lateral resistance of pile with displacement of pile at ground level for different values of D for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, L=10 m. The lateral resistance of the pile will increases with increasing of diameter of pile. For displacement of 0.1 m, 200% increase in D has caused 200% increase in lateral resistance of pile.

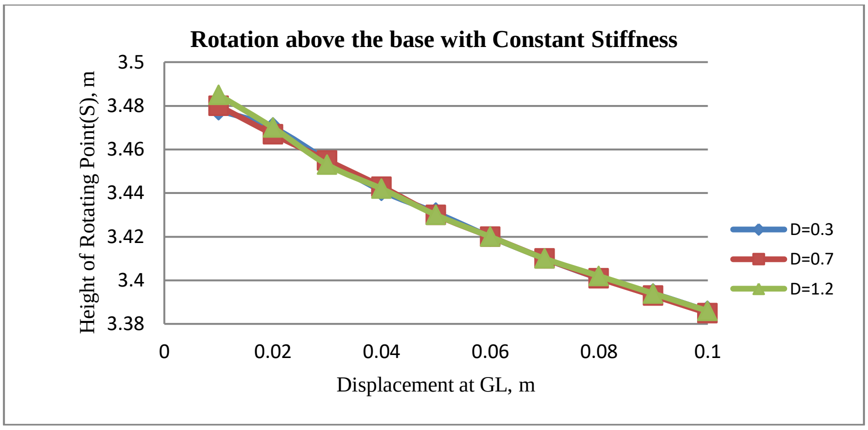

Fig. 12: Displacement at GL, m vs Height of Rotating Point above the base(S), m for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, L=10 m

As shown in figure 12, for Rotation above the base with constant Stiffness (B), the height of the rotating point above the base has decreased with increase in displacement at ground level(ρ_0). But the rotating point is not influenced by increase in diameter of the pile.

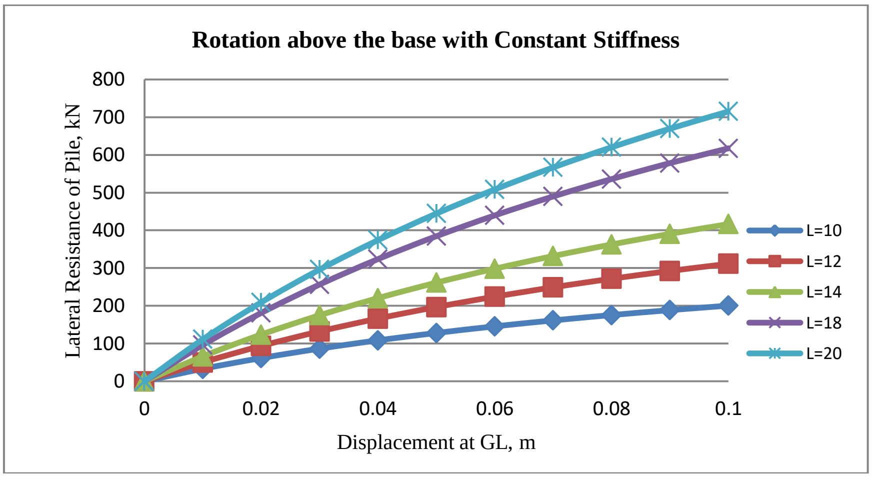

Fig. 13: Displacement at GL, m vs Lateral resistance of Pile, kN for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, D=0.3 m

Figure 13 presents the variation of lateral resistance of pile with displacement of pile at ground level for different values of L for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, D=0.3 m. The lateral resistance of the pile will increases with increasing of length of pile. For displacement of 0.1 m, 100% increase in L has caused 256.88% increase in lateral resistance of pile.

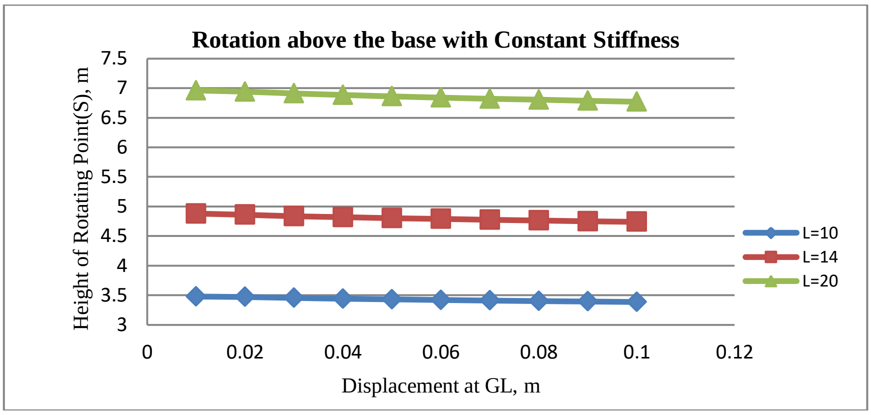

Fig. 14: Displacement at GL, m vs Height of Rotating Point above the base(S), kN for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, D=0.3 m

As shown in figure 14, for Rotation above the base with constant Stiffness (B), the height of the rotating point above the base has decreased with increase in displacement at ground level(ρ_0) and increased with increase in length of pile (L).

CONDITION (C): ROTATION ABOVE THE BASE WITH VARYING STIFFNESS

Pile is rotated about base of the pile and varying stiffness increases from top to bottom of levels of soil surrouned by the pile (C).

Below equation used to analyze the Stiffness of the soil from ground level to lower depths.

$$k_{sz}= k_{so}(1+\beta_s(Z/L))$$

Where, β_s is Increase of k_s with depth

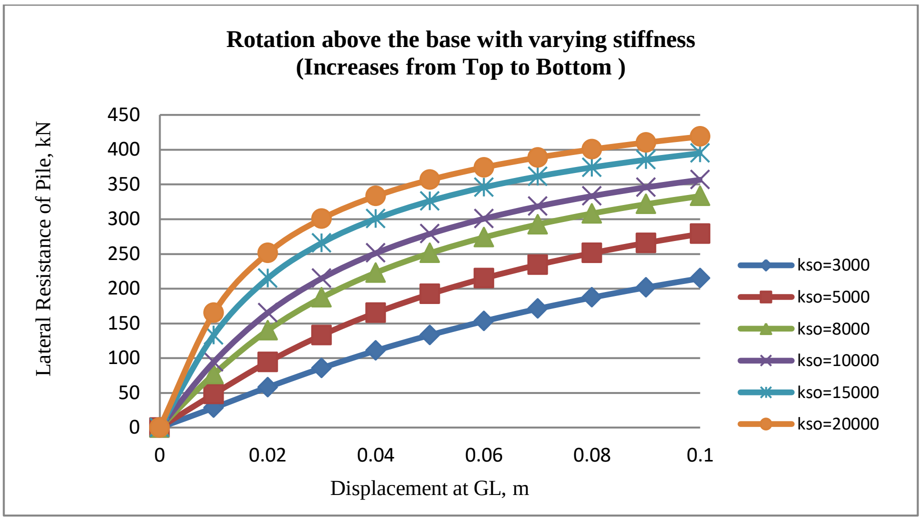

Fig. 15: Displacement at GL, m vs Lateral resistance of Pile, kN for q_{max}=500 kN/m^2, D=0.3 m, L=10 m

Figure 15 presents the variation of lateral resistance of pile with displacement of pile at ground level for different values of k_{so} for q_{max}=500 kN/m^2, D=0.3 m, L=10 m. The lateral resistance of the pile will increases with increasing of subgrade reaction of soil. For displacement of 0.1 m, 100% increase in k_{so} has caused 27.94% increase in lateral resistance of pile.

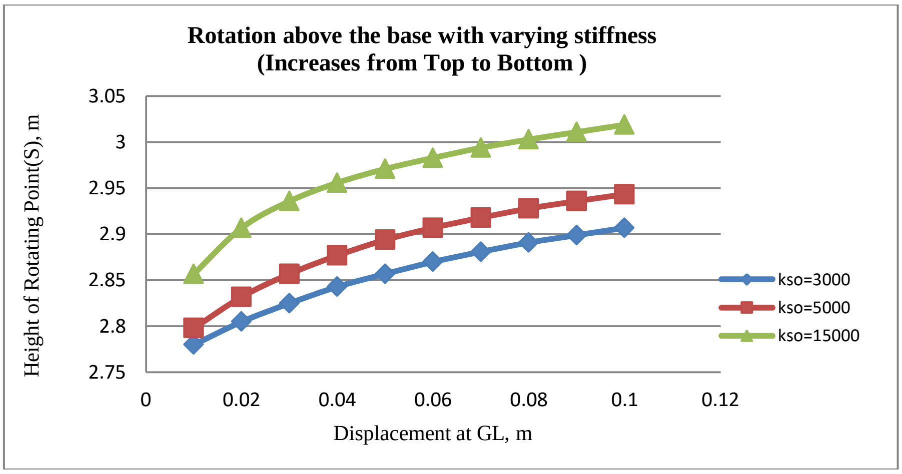

Fig. 16: Displacement at GL, m vs Height of Rotating Point above the base(S), m for q_{max}=500 kN/m^2, D=0.3 m, L=10 m

As shown in figure 16, for Rotation above the base with varying Stiffness condition (C), the height of the rotating point above the base has increased with increase in displacement at ground level, ρ_0 and k_{so} respectively.

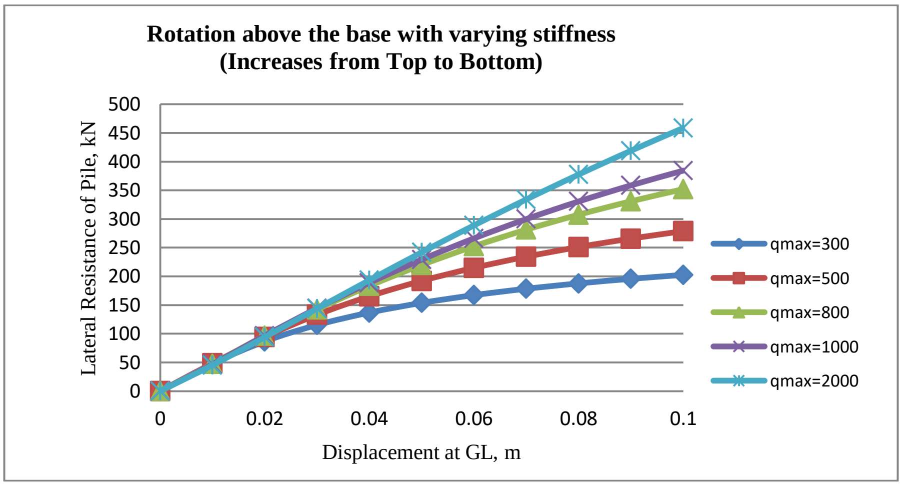

Fig. 17: Displacement at GL, m vs Lateral resistance of Pile, kN for k_{so}=5000 kN/m^3, D=0.3 m, L=10 m

Figure 17 presents the variation of lateral resistance of pile with displacement of pile at ground level for different values of q_{max} for k_{so}=5000 kN/m^3, D=0.3 m, L=10 m. The lateral resistance of the pile will increases with increasing of lateral soil pressure of soil. For displacement of 0.1 m, 100% increase in q_{max} has caused 37.8% increase in lateral resistance of pile.

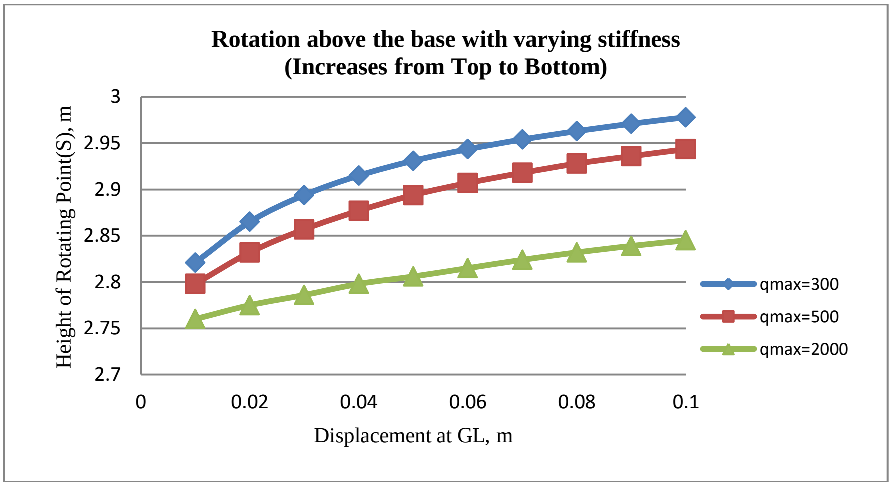

Fig. 18: Displacement at GL, m vs Height of Rotating Point above the base(S), m for k_{so}=5000 kN/m^3, D=0.3 m, L=10 m

As shown in figure 18, for Rotation above the base with varying Stiffness condition (C), the height of the rotating point above the base has increased with increase in displacement at ground level(ρ_0) and decreased with increase in lateral soil pressure (q_{max}).

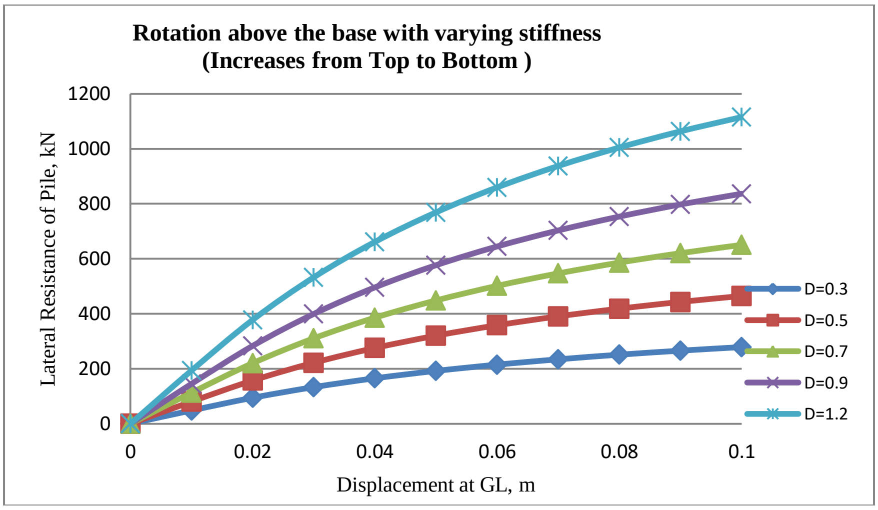

Fig. 19: Displacement at GL, m vs Lateral resistance of Pile, kN for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, L=10 m

Figure 19 presents the variation of lateral resistance of pile with displacement of pile at ground level for different values of D for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, L=10 m. The lateral resistance of the pile will increases with increasing of diameter of pile. For displacement of 0.1 m, 200% increase in D has caused 200% increase in lateral resistance of pile.

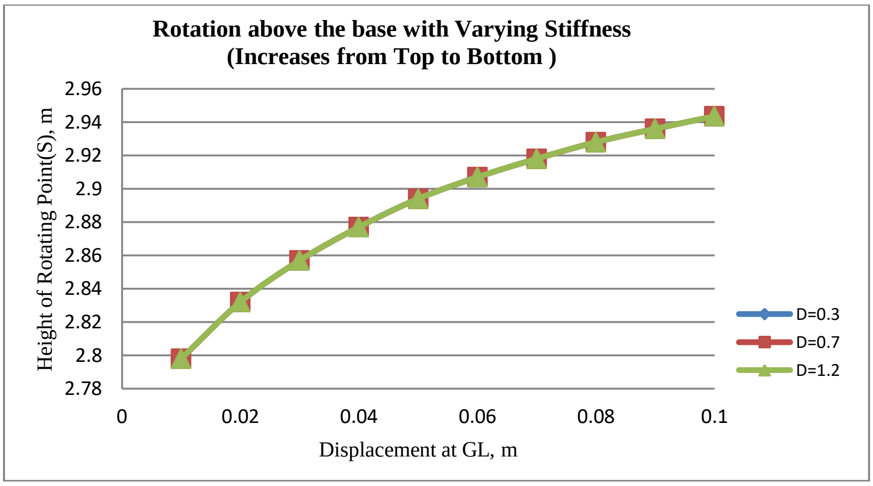

Fig. 20: Displacement at GL, m vs Height of Rotating Point above the base(S), m for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, L=10 m

As shown in figure 20, for Rotation above the base with varying Stiffness condition (C), the height of the rotating point above the base has increased with increase in displacement at ground level(ρ_0). But the rotating point is not influenced by increase in diameter of the pile.

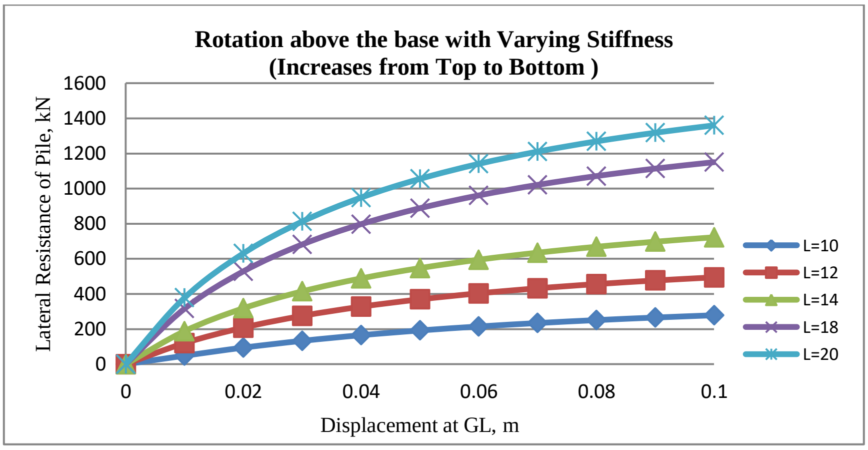

Fig. 21: Displacement at GL, m vs Lateral resistance of Pile, kN for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, D=0.3 m

Figure 21 presents the variation of lateral resistance of pile with displacement of pile at ground level for different values of L for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, D=0.3 m. The lateral resistance of the pile will increases with increasing of length of pile. For displacement of 0.1 m, 100% increase in L has caused 387.76% increase in lateral resistance of pile.

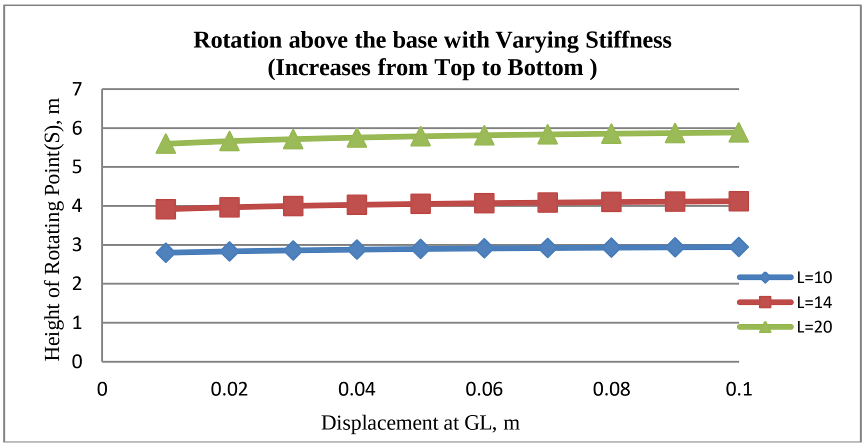

Fig. 22: Displacement at GL, m vs Height of Rotating Point above the base(S), m for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, D=0.3 m

As shown in figure 22, for Rotation above the base with varying Stiffness condition (C), the height of the rotating point above the base has increased with increase in displacement at ground level(ρ_0) and increased with increase in length of pile (L).

CONDITION (D): DENSIFIED SOIL AT GROUND LEVEL

The near surface soil can be densified so that the soil modulus increases in that portion and the displacements get reduced. The modulus and maximum soil pressure for the improved soil over the depth, L_d, from ground level are considered as K_{sd} and q_{maxd} respectively as shown in Fig 1(b). Stiffness of the soil can be more at ground level due to compaction, surcharge loads etc.,

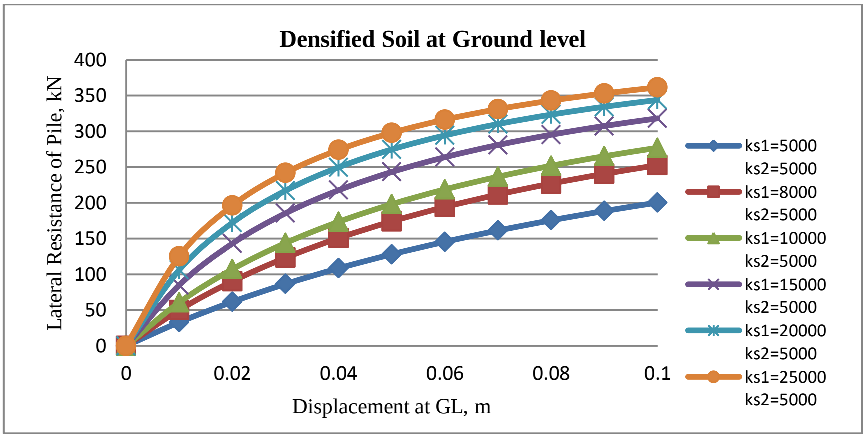

Fig. 23: Displacement at GL, m vs Lateral resistance of Pile, kN for q_{max}=500 kN/m^2, D=0.3 m, L=10 m

Figure 23 presents the variation of lateral resistance of pile with displacement of pile at ground level for different values of k_{so} for q_{max}=500 kN/m^2, D=0.3 m, L=10 m. The lateral resistance of the pile will increases with increasing of subgrade reaction of soil. For displacement of 0.1 m, 100% increase in k_{so} has caused 38.5% increase in lateral resistance of pile.

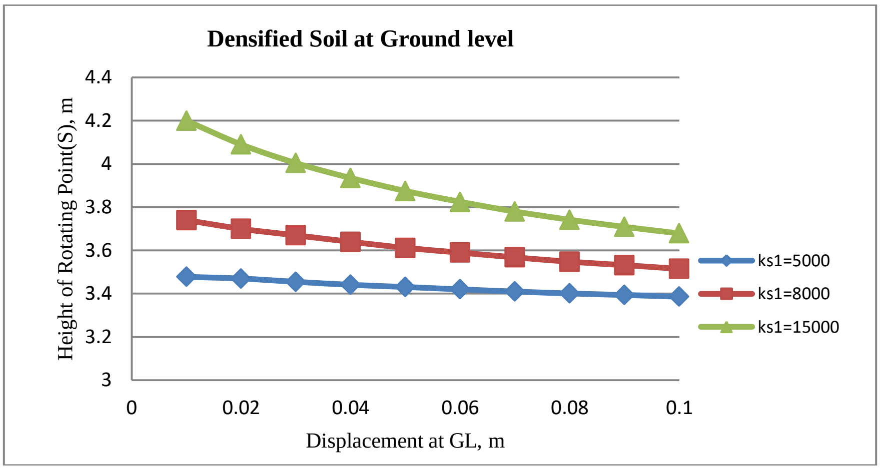

Fig. 24: Displacement at GL, m vs Height of Rotating Point above the base(S), m for q_{max}=500 kN/m^2, D=0.3 m, L=10 m

As shown in figure 24, for Rotation above the base with modified Stiffness at GL (D), the height of the rotating point above the base has decreased with increase in displacement at ground level, ρ_0 and increased with increase in k_{so}.

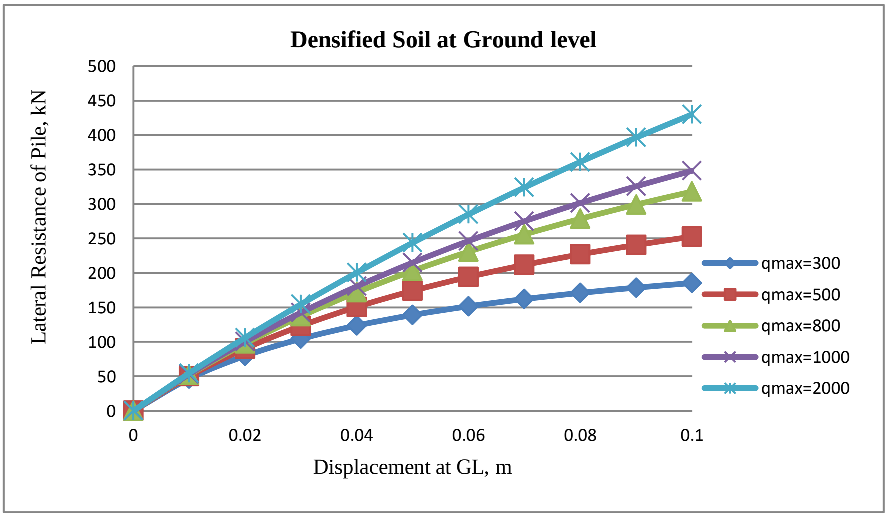

Fig. 25: Displacement at GL, m vs Lateral resistance of Pile, kN for k_{so}=5000 kN/m^3, D=0.3 m, L=10 m

Figure 25 presents the variation of lateral resistance of pile with displacement of pile at ground level for different values of q_{max} for k_{so}=5000 kN/m^3, D=0.3 m, L=10 m. The lateral resistance of the pile will increases with increasing of lateral soil pressure of soil. For displacement of 0.1 m, 100% increase in q_{max} has caused 37.6% increase in lateral resistance of pile.

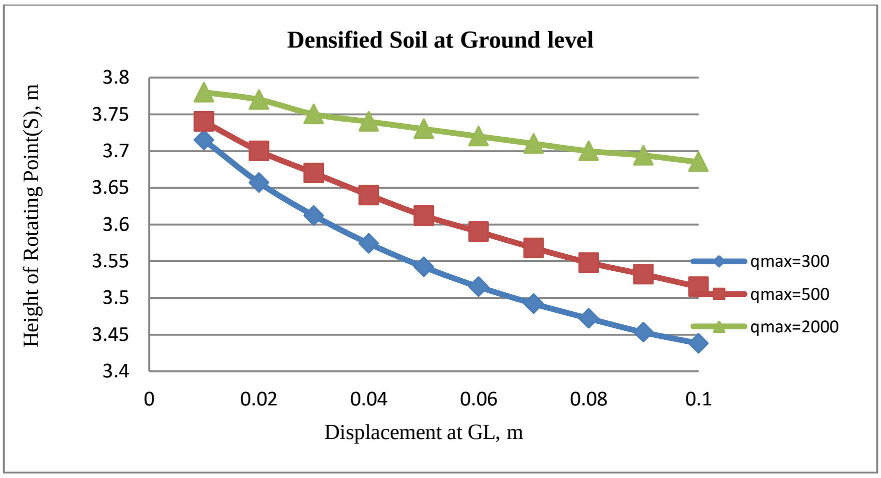

Fig. 26: Displacement at GL, m vs Height of Rotating Point above the base(S), m for k_{so}=5000 kN/m^3, D=0.3 m, L=10 m

As shown in figure 26, for Rotation above the base with modified Stiffness at GL (D), the height of the rotating point above the base has decreased with increase in displacement at ground level(ρ_0) and increased with increase in lateral soil pressure (q_{max}).

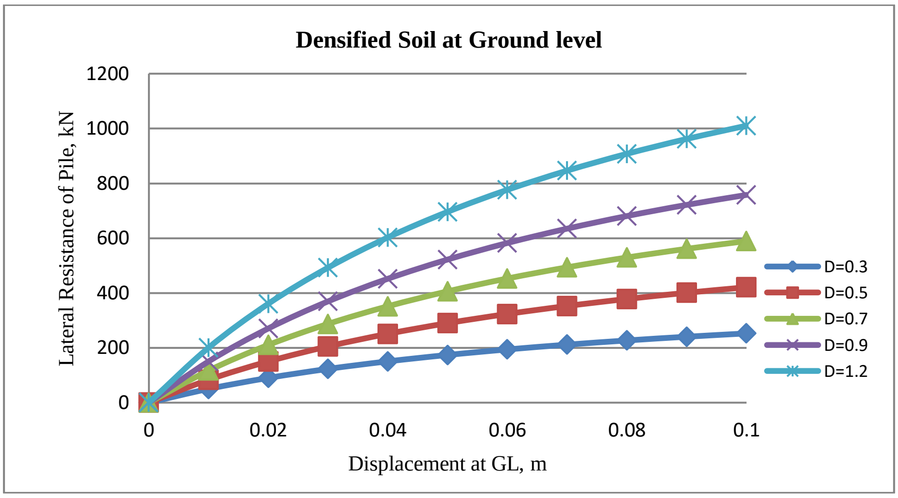

Fig. 27: Displacement at GL, m vs Lateral resistance of Pile, kN for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, L=10 m

Figure 27 presents the variation of lateral resistance of pile with displacement of pile at ground level for different values of D for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, L=10 m. The lateral resistance of the pile will increases with increasing of diameter of pile. For displacement of 0.1 m, 200% increase in D has caused 200% increase in lateral resistance of pile.

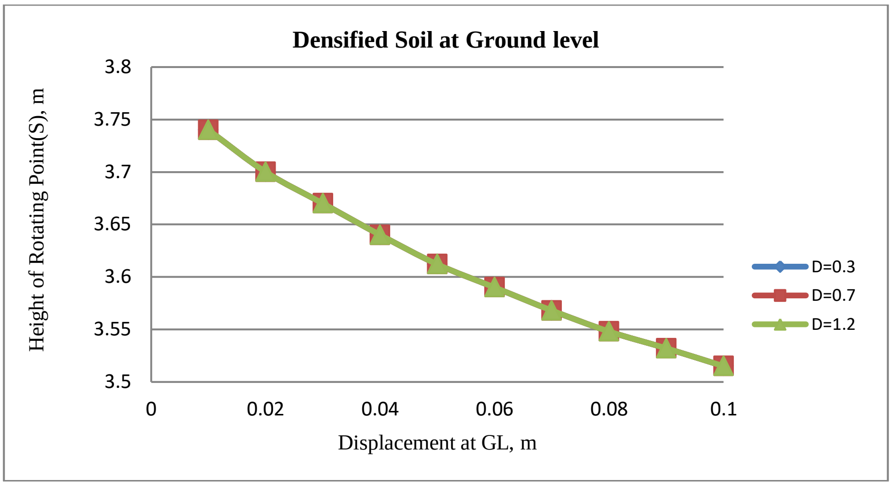

Fig. 28: Displacement at GL, m vs Height of Rotating Point above the base(S), m for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, L=10 m

As shown in figure 28, for Rotation above the base with modified Stiffness at GL (D), the height of the rotating point above the base has decreased with increase in displacement at ground level(ρ_0). But the rotating point is not influenced by increase in diameter of the pile.

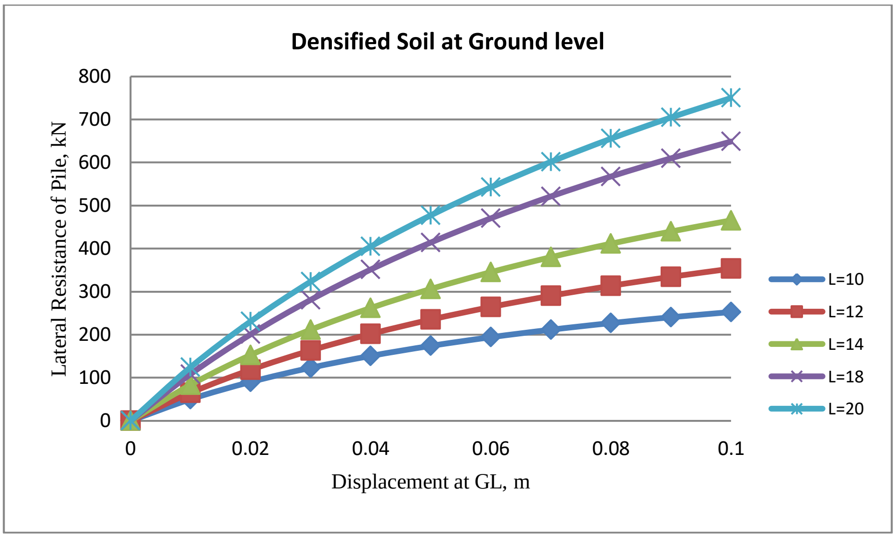

Fig. 29: Displacement at GL, m vs Lateral resistance of Pile, kN for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, D=0.3 m

Figure 29 presents the variation of lateral resistance of pile with displacement of pile at ground level for different values of L for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, D=0.3 m. The lateral resistance of the pile will increases with increasing of length of pile. For displacement of 0.1 m, 100% increase in L has caused 196.83% increase in lateral resistance of pile.

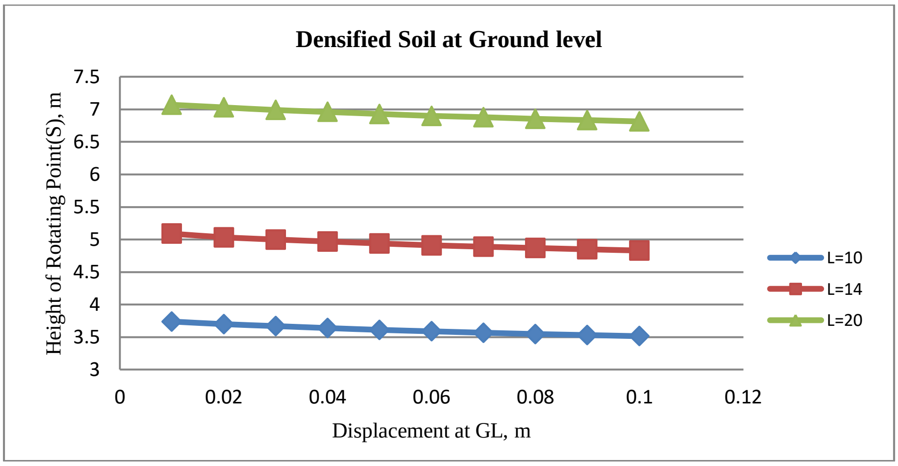

Fig. 30: Displacement at GL, m vs Height of Rotating Point above the base(S), m for k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, D=0.3 m

As shown in figure 30, for Rotation above the base with modified Stiffness (D), the height of the rotating point above the base has decreased with increase in displacement at ground level(ρ_0) and increased with increase in length of pile (L).

COMPARSION OF THE CONDITIONS A, C AND D:

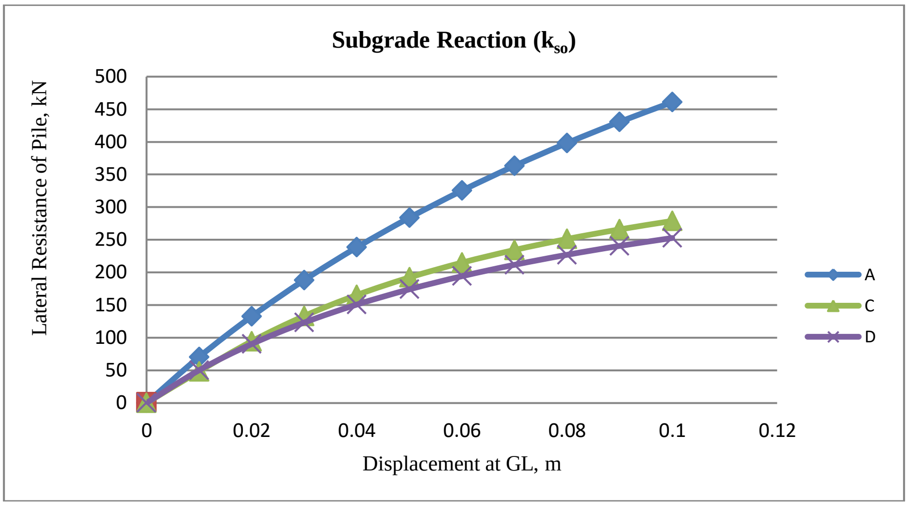

Fig 31: Comparison graph for Condition A, C, D for the Parameters k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, D=0.3 m, L=10 m

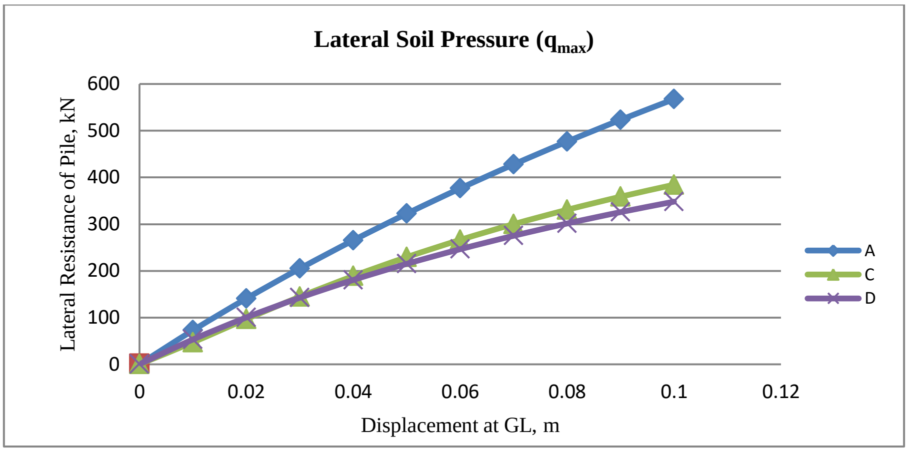

Fig. 32: Comparison graph for Condition A, C, D for the Parameters k_{so}=5000 kN/m^3, q_{max}=1000 kN/m^2, D=0.3 m, L=10 m

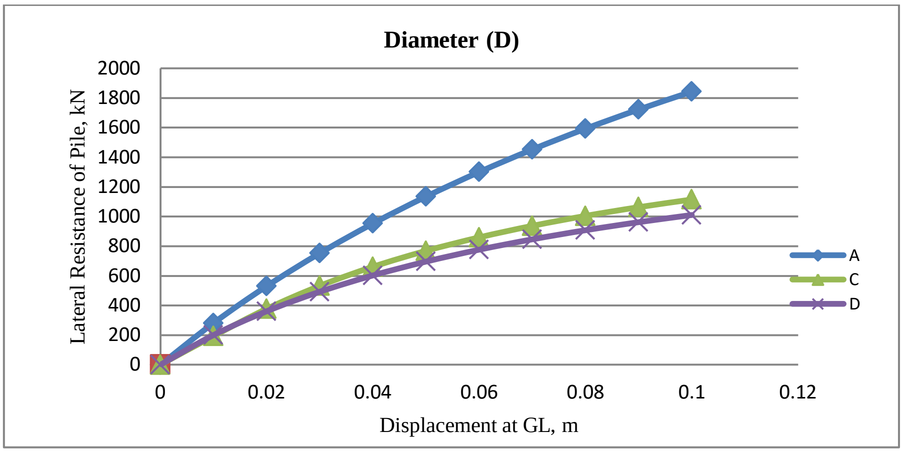

Fig. 33: Comparison graph for Condition A, C, D for the Parameters k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, D=1.2 m, L=10 m

As shown in figure 31, 32 and 33, for a particular Subgrade Reaction (k_{so}), q_{max} and D, the conditions A, C and D considered in the present study are compared. It is observed that Base Rotation with Constant Stiffness (A) has the Maximum Lateral Resistance at a particular displacement at GL of all the 3 conditions (A, C and D).

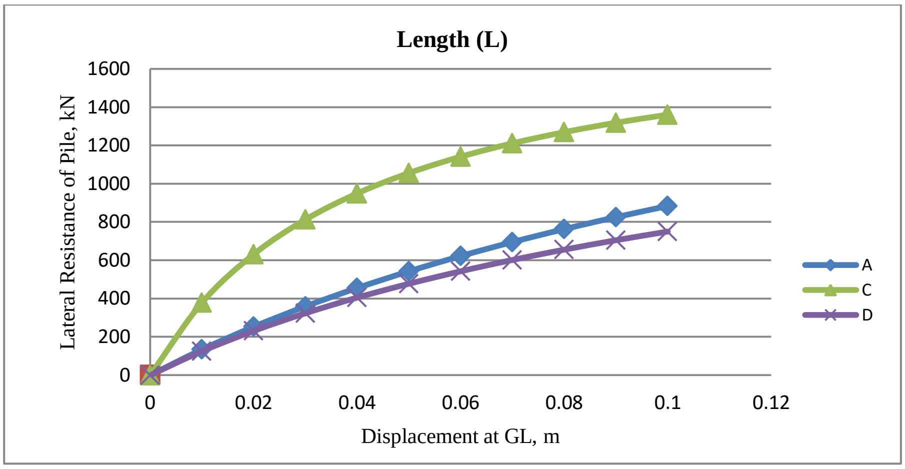

Fig. 34: Comparison graph for Condition A, C, D for the Parameters k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, D=0.3 m, L=20 m

As shown in figure 34, for a particular length of pile (L), the conditions A, C and D considered in the present study are compared. It is observed that Base Rotation above the base with varying Stiffness (C) has the Maximum Lateral Resistance at a particular displacement at GL of all the 3 conditions (A, C and D).

COMPARSION OF THE CONDITIONS B, C AND D:

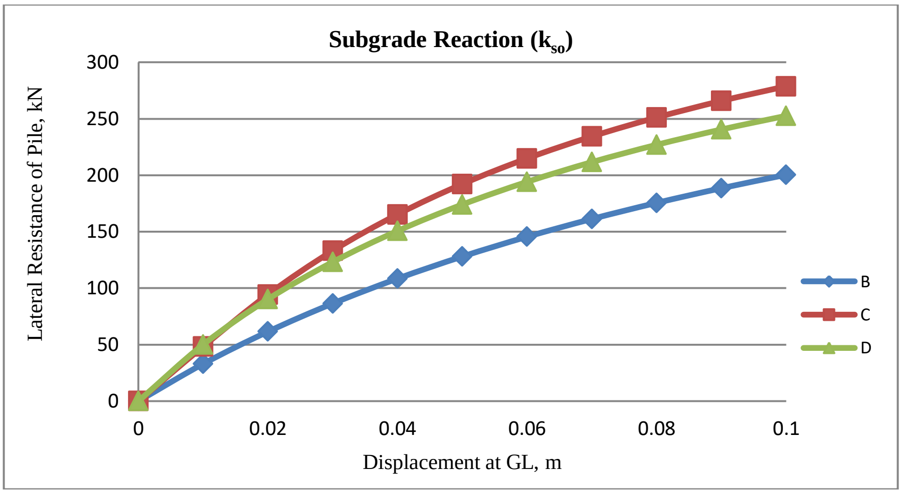

Fig. 35: Comparison graph for Condition B, C, D for the Parameters k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, D=0.3 m, L=10 m

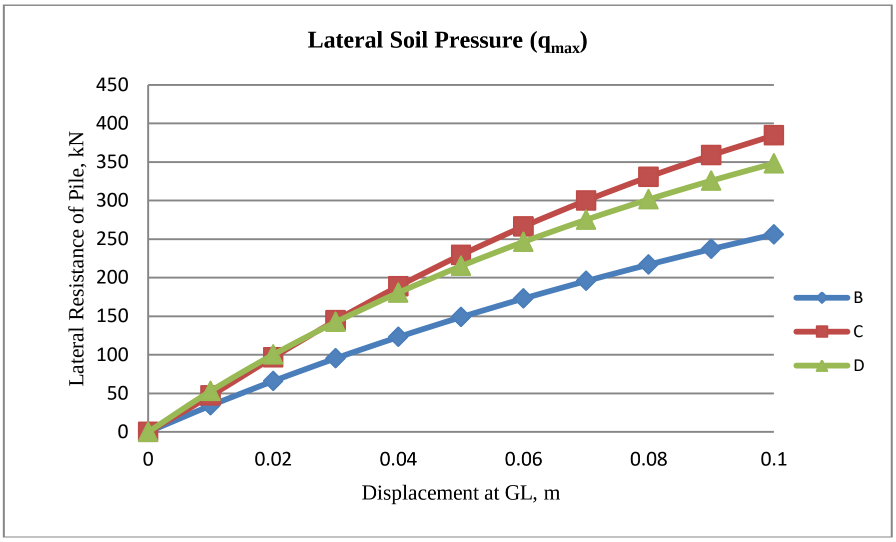

Fig. 36: Comparison graph for Condition B, C, D for the Parameters k_{so}=5000 kN/m^3, q_{max}=1000 kN/m^2, D=0.3 m, L=10 m

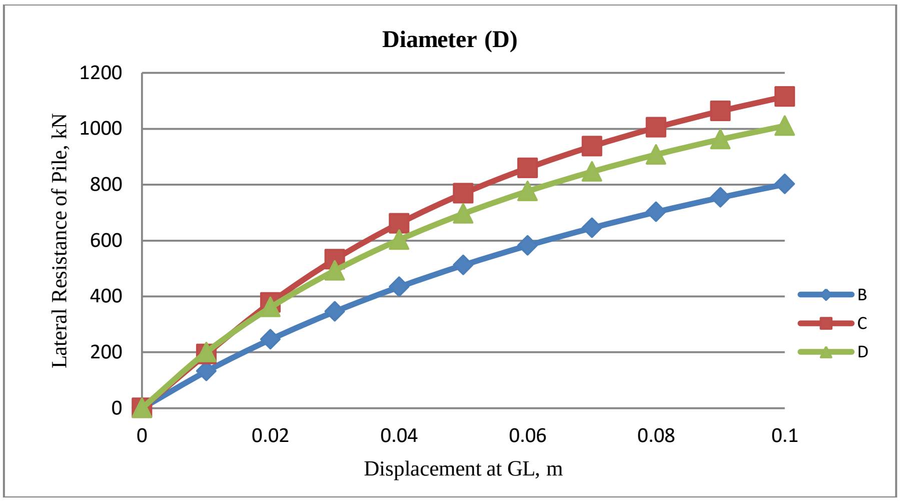

Fig. 37: Comparison graph for Condition B, C, D for the Parameters k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, D=1.2 m, L=10 m

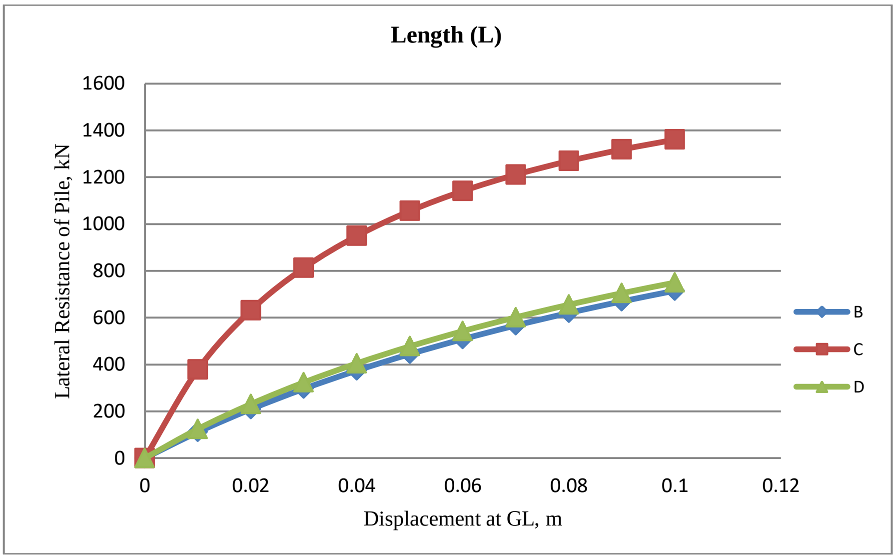

Fig. 38: Comparison graph for Condition B, C and D for the Parameters k_{so}=5000 kN/m^3, q_{max}=500 kN/m^2, D=0.3 m, L=20 m

As shown in figure 35, 36, 37 and 38, for different combinations of subgrade reaction, lateral soil pressure, diameter of pile and length of pile, the conditions B, C and D considered in the present study are compared. It is observed that Above the Base Rotation with Varying Stiffness(C) has the Maximum Lateral Resistance at a particular displacement at GL of all the 3 conditions (B, C and D).

IV. CONCLUSIONS

The following conclusions are made based on the work presented,

1. In the case of Base rotation with constant stiffness condition (A), for displacement of 0.1 m, 100% increase in k_{so}, 100% increase in q_{max}, 200% increase in D and 100% increase in L has caused 46.96%, 23.19%, 200% and 91.71% increase in lateral resistance respectively.
2. Of all the parameters i.e., k_{so}, q_{max}, D, L, the diameter of pile greatly influences the lateral resistance of the pile for a particular displacements at GL for all the conditions (A, B, C, D). This is because of the area of contact between the soil and pile.
3. In the case of Above the Base rotation with constant stiffness condition (B), for displacement of 0.1 m, 100% increase in k_{so}, 100% increase in q_{max}, 200% increase in D and 100% increase in L has caused 39.7%, 27.76%, 200% and 256.88% increase in lateral resistance respectively.
4. For Rotation above the base with constant Stiffness (B), Rotation above the base with Varying Stiffness(C) and Rotation above the Base with Modified Stiffness condition (D), the height of the rotating point above the base has changed considerably with increase in k_{so}, q_{max} and L. But the rotating point is not influenced by increase in Diameter of the pile.
5. In the case of Above the Base rotation with varying stiffness condition (C), for displacement of 0.1 m, 100% increase in k_{so}, 100% increase in q_{max}, 200% increase in D and 100% increase in L has caused 27.94%, 37.8%, 200% and 387.76% increase in lateral resistance respectively.
6. In the case of Above the Base rotation with Modified stiffness at GL condition (D), for displacement of 0.1 m, 100% increase in k_{so}, 100% increase in q_{max}, 200% increase in D and 100% increase in L has caused 38.5%, 37.6%, 200% and 196.83% increase in lateral resistance respectively.
7. For a particular Subgrade Reaction (k_{so}), the conditions A, C and D considered in the present study are compared. It is observed that Base Rotation with Constant Stiffness (A) has the Maximum Lateral Resistance at a particular displacement at GL of all the 3 conditions (A, C and D).
8. For a particular Subgrade Reaction (k_{so}), the conditions B, C and D considered in the present study are compared. It is observed that Above the Base Rotation with Varying Stiffness(C) has the Maximum Lateral Resistance at a particular displacement at GL of all the 3 conditions (B, C and D).
9. Among the 4 conditions (A, B, C, D) considered in the present study, the condition which relevant to the field conditions is chosen. Based on the Lateral Load transmitted to the pile the parameters (k_{so}, q_{max}, D and L) are estimated.

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