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Numerical Analysis of Piles in Layered Soils: A Parametric Study

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NUMERICALANALYSISOFPILESINLAYEREDSOILSAPARAMETRICSTUDY

Strictly as per the compliance and regulations of :

Numerical Analysis of Piles in Layered Soils: A Parametric Study

C. Ravi Kumar Reddy [α] & T. D. Gunneswara Rao [σ]

Abstract- In this paper, numerical analysis of a pile-soil interaction problem is presented considering the parameters influencing the axial load-deformation behavior of the pile embedded in a layered soil medium. The analysis is demonstrated with parametric solutions of a pile with underlain model soil strata under the axial force. An attempt is made to ascertain the extent of influence of elastic properties of the pile, geometry of the pile, end conditions of the pile and the elastic properties of the underlain soil strata on the response of the piles under axial loads lying in a model soil layers in terms of the settlement of the pile and the internal deformation of the pile. The study revealed that the increase in modulus of elasticity of pile improves the settlement resistance of the pile, increase in the ratio of cross sectional dimensions causes decrease in the top deformations of the pile, the settlement of the pile reduced to a great extent when the cross section of the pile adopted is non circular instead of circular and increase in the elastic modulii of top and bottom layers of soil has decreased the settlement of the pile to a great extent, but elastic modulus of soil layers other than top and bottom has got negligible influence on the settlement of the pile.

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I. Introduction

The design of pile foundations to resist axial loads completes when one can perform evaluation of ultimate bearing load, settlement prediction under the design load and structural design. Numerous studies have been carried out on the behavior of axially loaded piles (Basu et al.[2], Guo[4], Guo and Randolph[5], Lee and Small[7], Motta[10], Mylonakis[11], Rajapakse[15], Randolph and Worth[17]) and laterally loaded piles (Lee et al.[8], Poulos[13], Randolph[16]). Extensive research has concerned the evaluation of ultimate bearing capacity but little attention has been given for settlement of pile as well as the compression of the pile under the axial loads. Usually the methods of analyzing the behavior of piles are the load transfer method (Coyle and Reese[3], Hazarika and Ramasamy[6], Matlock and Reese[9]) and elastic continuum method (Poulos[12], Banerjee and Davis[1], Poulos and Davis[14]). The subgrade reaction theory idealizes the pile as an elastic beam supported by a series of discrete linear springs representing the soil. Simplicity of the subgrade reaction theory lies in its straight forward computations and the disadvantage is the approximation in subgrade reaction modulus leads to inaccurate solutions. The most powerful continuum approach is the finite element approach. Theoretically elastic solution is more realistic because it considers the soil as a continuum rather than a series of unconnected springs as in the subgrade reaction analysis.

In this paper, extensive parametric studies are performed and presented in graphical form to facilitate the understanding of settlement prediction, which will be useful in the design and analysis of piles under the axial loads in layered soil. The main purpose of this study is to investigate the more practical case of the behavior of piles under the axial loads in layered soils using the continuum based numerical analysis.

II. Pile with Extended Soil Layers

Pile with underlain soil layers in model soil strata is presented in fig.1. The pile having three different cross sections viz., rectangular with dimensions a x b (example 1), square (example 2) and circular (example 3) of length L and axial load P is considered for the analysis.

The governing differential equation for the pile settlement given by Basu et al.[2]:

$$\frac{d^2u}{dz^2} - \frac{k_i}{1+2t_i}u_i = 0 \qquad (1)$$

Where u_i is the displacement function u(z) in the i^{th} layer, k_i is the term which accounts for the shear resistance developed between soil columns due to differential movement of the soil columns, t_i is the term which accounts for spring effect of the soil (compression of the soil columns due to vertical movement of the pile) The general solution of the differential equation (Eq. 1) is

$$u_i(z) = C_1 \sinh \beta_i z + C_2 \cosh \beta_i z \qquad (2)$$

The evaluation of the integration constants (C1 and C2 in Eq. 2) for each layer is a difficult process if the layers in soil strata are more in number. In the present study the pile and soil layers are modeled with 20-noded three dimensional solid elements in the ANSYS (A powerful finite element analysis program) to carry out finite element analysis. No slip condition is assumed at the interface of pile and soil. The horizontal extent of the soil domain from the pile axis is taken as 15 times the

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pile width and the vertical extent of the soil domain below the pile base is taken as the pile length.

a) Model Soil Strata

The top layer having a thickness of H_1 consists of yellow sand and its elastic modulus and Poisson's ratio are Es_1 and ν_1 respectively. The next two layers below the yellow sand are consisting of grey sand with their elastic modulii Es_2, Es_3 and Poisson's ratios ν_1, ν_2. The bearing layer (Bottom layer) consists of brownish sand with elastic modulus Es_4 and Poisson's ratio ν_4.

i. *Example 1*

A rectangular pile (Fig. 2) of cross sectional dimensions 2m x 1m having a length of 40m and underlain soil strata with top layer consisting of yellow sand (SPT (10) - Es_1 = 25MPa, $\nu_1 = 0.35$) extending to a depth of 4m. The next layer is a grey sand (SPT (20) - Es_2 = 45MPa, $\nu_2 = 0.3$) extending to a depth of 12m. The next layer is a grey sand (SPT (25) - Es_3 = 55MPa, $\nu_3 = 0.25$) extending to a depth of 18m. The bearing layer consists of brownish sand (SPT (45) - Es_4 = 75MPa, $\nu_4 = 0.2$) extending to a depth of 46m. The axial load on the pile is taken as 9700kN.

ii. *Example 2*

A square pile (Fig. 3) of cross sectional area 2300cm^2 having a length of 15m and underlain soil strata with top layer consisting of black clay (SPT (10) - Es1 = 12MPa, $\nu 1 = 0.3$) extending to a depth of 3m. The next layer is a yellow sand (SPT (10) - Es2 = 25MPa $\nu 2 = 0.25$) extending to a depth of 4m. The next layer is a grey sand (SPT (15) - Es3 = 35MPa, $\nu 3 = 0.2$) extending to a depth of 6m. The bearing layer consists of brownish sand (SPT (50) - Es4 = 80MPa, $\nu 4 = 0.2$) extending to a depth of 17m. The axial load on the pile is taken as 3300kN.

iii. *Example 3*

A circular pile (Fig. 4) having diameter of 1.5m, length of 40m and underlain soil strata with top layer consisting of yellow sand (SPT (10) - Es1 = 25MPa, $\nu 4 = 0.2$) extending to a depth of 4m. The next layer is a grey sand (SPT (20) - Es2 = 45MPa,$\nu 2 = 0.3$) extending to a depth of 12m. The next layer is a grey sand (SPT (25) - Es3 = 55MPa, $\nu 3 = 0.25$) extending to a depth of 18m. The bearing layer consists of brownish sand (SPT (45) - Es4 = 75MPa, $\nu 4 = 0.2$) extending to a depth of 46m. The axial load on the pile is taken as 9700kN.

The analysis is carried out using the above examples to evaluate the effect of grade of concrete of the pile, effect of ratio of cross sectional dimensions (a/b), elastic modulus of each underlain soil layers and the shape of the cross section (circular, non-circular) on the top deformation of the pile as well as the internal deformation of the pile with the two end conditions of the pile namely floating pile condition and the fix-base condition.

III. Results and Discussions

a) Effect of Elastic Modulus of Pile (Floating Base Condition)

Fig.5 shows the variation of settlement of the rectangular pile (example 1) with pile depth, for different grades of pile material (concrete). Fig.6 gives the variation of settlement of the square pile (example 2) with pile depth, for different grades of pile material (concrete). Fig.7 represents the variation of settlement of the circular pile (example 3) with pile depth, for different grades of pile material (concrete).

From Fig.5, 6 and 7 it is observed that, as the grade of concrete of pile increases the axial deformations in the pile decreases and this decrease in the deformation is very less when compared with the extent of increase in the grade of concrete. For example the decrease in the settlement at the top of the pile is about 14% as the grade of concrete is increased from M20 to M100.

As the pile is taken as the floating pile, the internal deformation in the pile is calculated as the difference between top and bottom deformations in the pile and it is evident from the fig.5, 6 and 7 that the internal deformation in the pile is decreased to a higher extent than the decrease in the top deformation of the pile when the grade of concrete is increased. For example the decrease in the internal deformation of the pile is about 55% if the grade of concrete is increased from M20 to M100 (5 times).

Hence, Increase in modulus of elasticity of pile has decreased the top deformation of the pile to a little extent however increase in the modulus of elasticity of pile decreased the internal compression of the pile.

b) Effect of Elastic Modulus of Pile (Fixed Base Condition)

Fig.8 shows the variation of settlement of the rectangular pile (example 1) with pile depth, for different grades of pile material (concrete). Fig.9 shows the variation of settlement of the square pile (example 2) with pile depth, for different grades of pile material (concrete). Fig.10 shows the variation of settlement of the circular pile (example 3) with pile depth, for different grades of pile material (concrete).

Fig.8, 9 and 10, it is evident that the top deformation of the pile decreases with increase in the grade of concrete of the pile. As the base of the pile is fixed (in case of a pile resting on a very hard stratum), the top deformation of the pile itself is the internal deformation of the pile. For example the decrease in the settlement of the pile is about 55% if the grade of concrete is increased from M20 to M100.

Increase in the grade of concrete of the pile decreases the settlement of the pile. Hence increase in modulus of elasticity of pile improves the settlement resistance of the pile.

c) Effect of Ratio of Cross Sectional Dimensions of the Pile

Fig.11 shows the variation of settlement of the pile (example 1) with pile depth, for different ratios of the cross sectional dimensions of the pile, keeping the cross sectional area of the pile constant for floating base condition.

Fig.12 shows the variation of settlement of the pile (example 1) with pile depth, for different ratios of the cross sectional dimensions of the pile, keeping the cross sectional area of the pile constant for fixed base condition.

For a floating pile condition (Fig.11) it is observed that as the ratio of cross sectional dimensions increases the deformation of top of the pile decreases, but the change in the internal deformation of the pile is almost negligible because all other parameters (viz., area of cross section axial force, underlain soil profile, boundary conditions etc.) being kept same. For example if the ratio of cross sectional dimensions is increased from 1.0 to 4.0 without changing the area of cross section of the pile the decrease in the settlement of the top of the pile is about 14% and the internal deformation is almost constant.

This can be viewed as, increase in the ratio of cross sectional dimensions increases the perimeter of the pile, which increases the area of contact of the surrounding soil with the pile which in-turn improve the resistance from the soil on the settlement of the pile. Hence we see the decrease in the deformations of the pile. In other words the pile – soil friction improves the resistance to the pile settlement.

For a fix-base pile condition (Fig.12) it is observed that the increase in the ratio of the cross sectional dimensions of the pile does not have a significant influence on the top deformation of the pile as well as the internal deformation of the pile. Because all other parameters (viz., area of cross section axial force, underlain soil profile, boundary conditions etc.) being the same fix-base pile has got less influence on the deformations of the pile with respect to its contact with the surrounding soil and the settlement of the pile is almost constant and it is about 7mm for all the cases shown (fig.12).

Hence change in the ratio of cross sectional dimensions has got no influence on the settlement of the pile for a fixed base pile condition, all other factors being the same.

d) Effect of Elastic Modulus of the Soil in Top and Bottom Layers

Fig.13 shows the variation of settlement of the rectangular pile (example 1) with pile depth, for different values of elastic modulii of the soil in the top layer for floating base condition, keeping the elastic modulii of all other layers constant. Fig.14 shows the variation of settlement of the rectangular pile (example 1) with pile depth, for different values of elastic modulii of the soil in the bearing layer for floating base condition, keeping the elastic modulii of all other layers constant.

Pile behavior in layered soil strata for floating pile condition from fig.13 and 14 can be assessed as the change in the elastic modulus of the soil in the top layer and bearing (bottom) layer has got great influence on the deformation of the pile.

For example, it is observed for the elastic modulus values from 2.5MPa to 70Mpa (normal range of elastic modulus of cohesive soils and sands for the earlier case the top deformation of the pile has decreased about 27% and also the internal deformation of the pile has decreased about 30% where as in the later case the top deformation of the pile has decreased about 85% and the internal deformation of the pile is increased about 65%.

Hence there is a possibility to reduce the settlement of the pile by engineering the top layer; generally the sandy soils with SPT values 50-80 can be the choice to arrive at the lower pile settlement values.

The above discussion infers that the bearing layer greatly influence the settlement of the pile, for lower values of elastic modulus of the bearing layer fig.14 show that the pile has got almost the rigid body motion which says that though the pile is embedded in the strong soil layers (in terms of elastic modulus) above the bearing layer the settlement of the pile can be very high.

As it is practically impossible to have proper care on bearing area, however it is to be noted that the bearing layer should have larger value of elastic modulus than any other layer in the soil strata.

e) Effect of Elastic Modulus of the Intermediate Soil Layers

Fig.15 shows the variation of settlement of the rectangular pile (example 1) with pile depth, for different values of elastic modulii of the soil in the layer just below the top layer for floating base condition, keeping the elastic modulii of all other layers constant.

Fig.16 shows the variation of settlement of the rectangular pile (example 1) with pile depth, for different values of elastic modulii of the soil in the layer just above the bearing layer for floating base condition, keeping the elastic modulii of all other layers constant.

From fig.15 and 16 it is observed that the increase in the elastic modulus of the intermediate soil layers has got almost negligible effect on the deformations of the pile. It can also be noted that the change in the internal deformation of the pile is also negligible. Hence the change in the elastic modulii of the underlain soil layers other than top layer and bearin layer has got no influence on the settlement of the pile.

f) Effect of Shape of the Cross Section of the Pile

To study the effect of shape of cross section of the pile, soil domain and the geometry of the pile used in example1 is considered with floating base condition. It is solved for three different cross sections namely, rectangular, square and circular keeping area of the cross section of pile and all other parameters same as that of the parameters used in example1. Results are furnished in the form of a plot shown in Fig.17.

The plot (Fig.17) clearly indicates that the axial deformation of the pile having circular cross section is very high when compared to the piles having square and rectangular cross sections. For example the reduction in the axial deformation of the pile is about 25% when the pile cross section is changed from circular to non-circular. Also the internal deformation of the pile is reduced about 25% as the cross section of the pile changes from circular to non-circular.

IV. Conclusions

With the help of numerical simulation using ANSYS, pile – soil interaction problem for axial loads has been solved and the parametric study revealed that,

- Increase in modulus of elasticity of pile has decreased the top deformation of the pile to a little extent however increase in the modulus of elasticity of pile decreased the internal compression of the pile. Increase in the grade of concrete of the pile decreases the settlement of the pile. Hence increase in modulus of elasticity of pile improves the settlement resistance of the pile.
- Increase in the ratio of cross sectional dimensions has decreased the top deformations of the pile. Hence the settlement of the pile decreases with increase in the ratio of cross sectional dimensions of the rectangular pile with floating base condition, whereas change in the ratio of cross sectional dimensions has got no influence on the settlement of the pile for a fix-base pile condition all other factors being the same.
- Increase in the elastic modulii of top and bottom layers has decreased the axial deformations of the pile to a great extent, hence there is a possibility to reduce the settlement of the pile by proper care given to the top layer, generally the sandy soils with SPT values 50-80 can be the choice to arrive at the lower pile settlement values, As it is nearly impossible and not feasible to have proper care on bearing area, it is to be noted that the bearing layer should have larger value of elastic modulus than any other layer in the soil strata.
- Change in the elastic modulii of the underlain soil layers other than top layer and bearing layer has got negligible influence on the settlement of the pile.
- When compared to the circular cross section, the non-circular cross sections of piles reduce the settlement of the pile to a great extent though the reduction in the internal deformation is taking place to a lesser extent than the settlement of the pile.

References Références Referencias

1. Banerjee, P. K. and Davies, T. G. (1978), "The behaviour of axially and laterally loaded single piles embedded in non-homogeneous soils", Geotechnique, 28(3), pp. 309-326.
2. Basu, D., Prezzi, M., Salgado, R., and Chakraborty, T. (2008). "Settlement analysis of piles with rectangular cross sections in multi-layered soils." Computers and Geotechnics, 35, pp. 563-575.
3. Coyle, H.M. and Reese, L.C. (1966), "Load transfer for axially loaded pile in clay", J. Soil Mech. Found. Eng. ASCE, 92(2), pp. 1-26.
4. Guo, W.D. (2000)." Vertically loaded single piles in Gibson soil." j. Geotech Geoenviron. Eng., ASCE, 126(2), pp. 189-193.
5. Guo, W.D., and Randolph, M.F. (1997)." vertically loaded piles in non-homogeneous media." Int. j. Numer. Anal. Methods., Geomech, 21(8), pp. 507-532.
6. Hazarika, P.J. and Ramasamy, G. (2000), "Response of Piles under Vertical Loading", Indian Geotech. J., 30(2), pp. 73-91.
7. Lee, C.Y., and Small, J.C. (1991)." Finite-layer analysis of axially loaded piles." J. Geotech Eng., ASCE, 117(11), pp. 1706-1722.
8. Lee, S. L., Kog, Y.C., and Karunaratne, G. P. (1987)." Laterally loaded piles in layered soil." Soils and foundations, Japanese Society of Soil Mechanics and Foundation Engrg., 27(4), pp. 1-10.
9. Matlock, H., an Reese, L.C. (1960)." Generalized solutions for laterally loaded piles." J. Soil Mech. Fdn. Div., Am. Soc. Civ. Engrs, 86, No. SM5, pp. 63-91.
10. Motta, E. (1994)." Approximate elastic-plastic solution for axially loaded piles." J. Geotech Eng., ASCE, 120(9), pp. 1616-1624.
11. Mylonakis, G. (2001)." Winkler modulus for axially loaded piles." Geotechnique, 51(5), pp. 455-461.
12. Polous, H. G. (1968), "Analysis of settlement of pile", Geotechnique, 18(4), pp. 449-471.
13. Poulos, H. G. (1971), "Behaviour of laterally loaded piles: II- group of piles", J. Soil Mech. Found. Eng. Div. ASCE, 97(5), pp. 733-751.
14. Poulos, H.G., and Davis, E.H. (1968)." The settlement behavior of single axially loaded incompressible piles and piers." Geotechnique, London, England 18(2), pp. 351-371.
15. Rajapakse, R.K.N.D. (1990)." Response of axially loaded elastic pile in a Gibson soil." Geotechnique, 40, pp. 237-249.
16. Randolph, M.F. (1981)."Response of flexible piles to lateral loading. " Geotechnique, 31(2), pp. 247-259.
17. Randolph, M.F., and Worth, C.P. (1978)." Analysis of deformation of vertically loaded piles." J. Geotechnique. Engrg. Div., ASCE, 104(12), pp. 1465-1488.

Figures

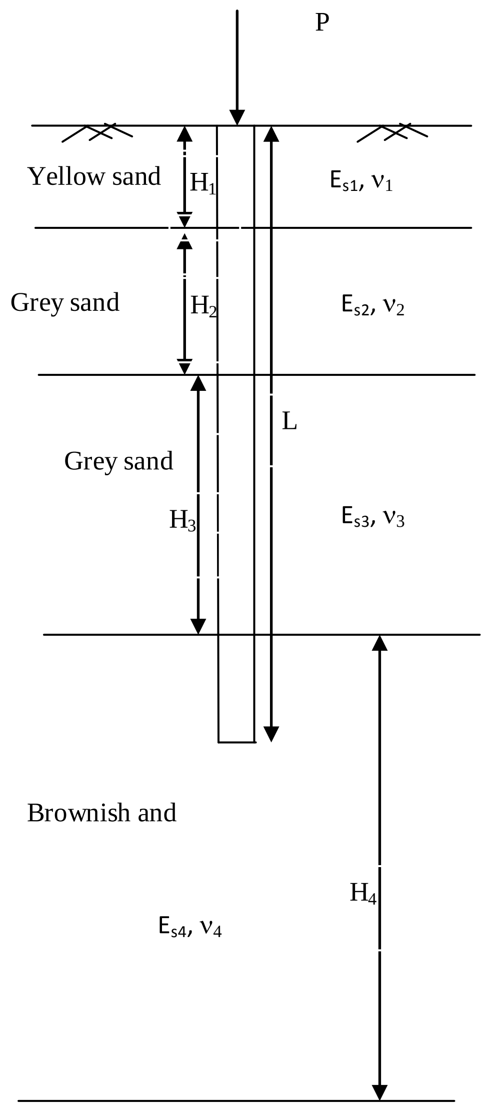

Fig.1 : Pile embedded in a model soil strata with axial load

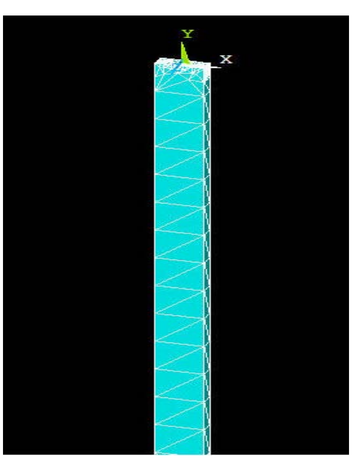

Fig. 2 : Rectangular pile

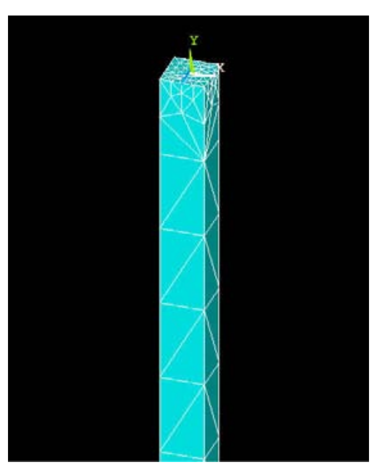

Fig. 3 : Square pile

Fig. 4 : Circular pile

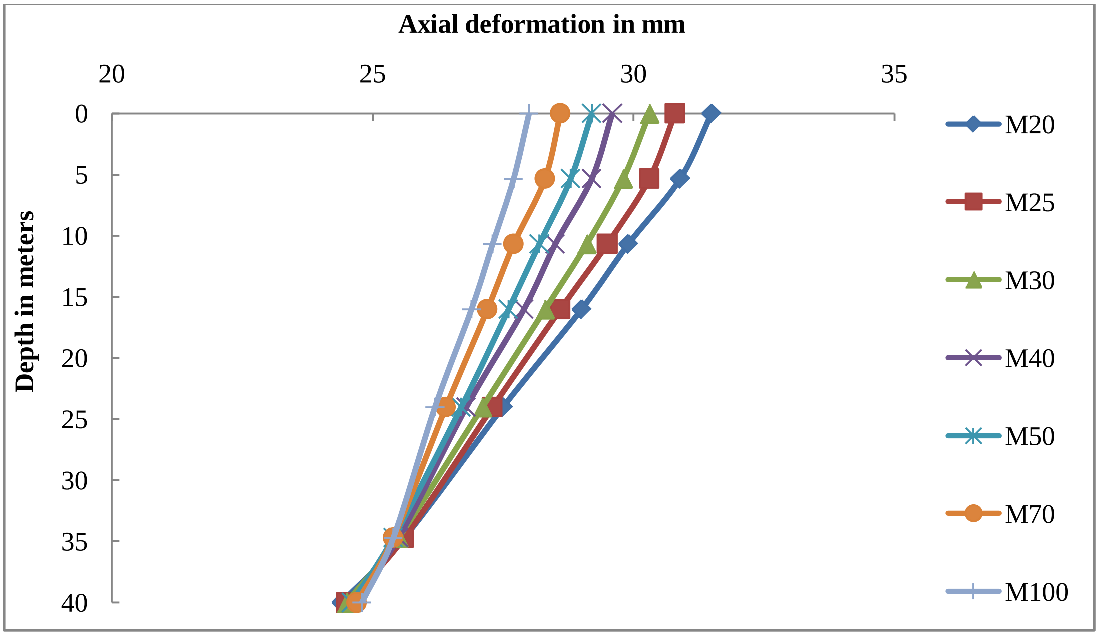

Fig. 5 : Vertical deformations of axially loaded rectangular pile in layered soil for various grades of concrete of pile for floating base condition

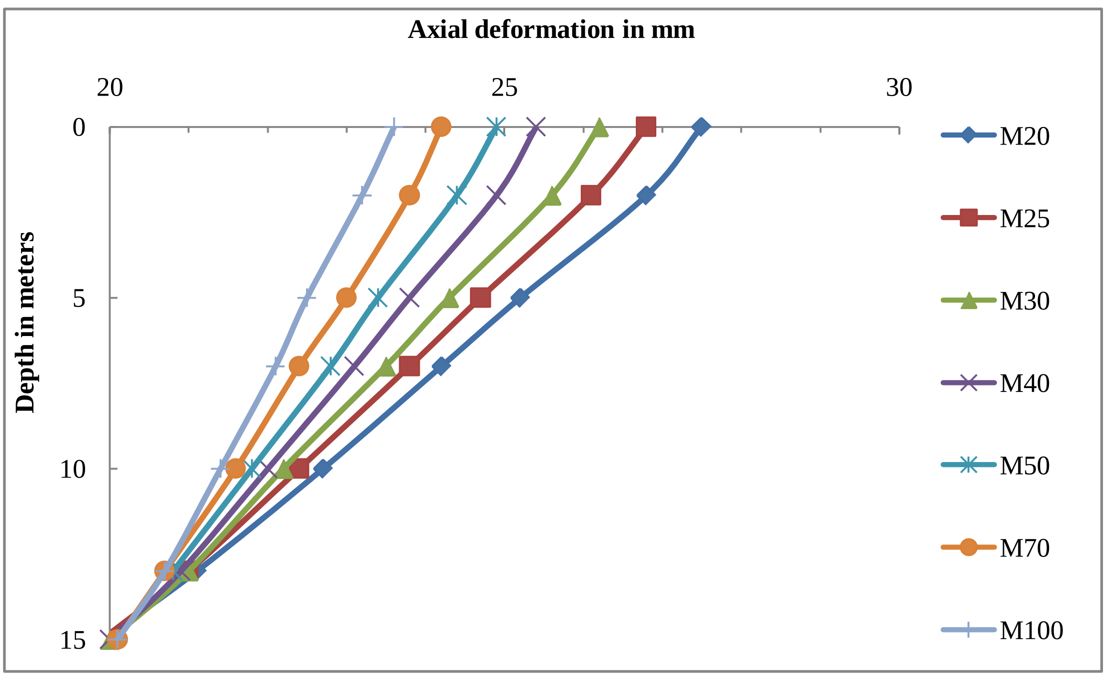

Fig. 6 : Vertical deformations of axially loaded square pile in layered soil for various grades of concrete of pile for floating base condition

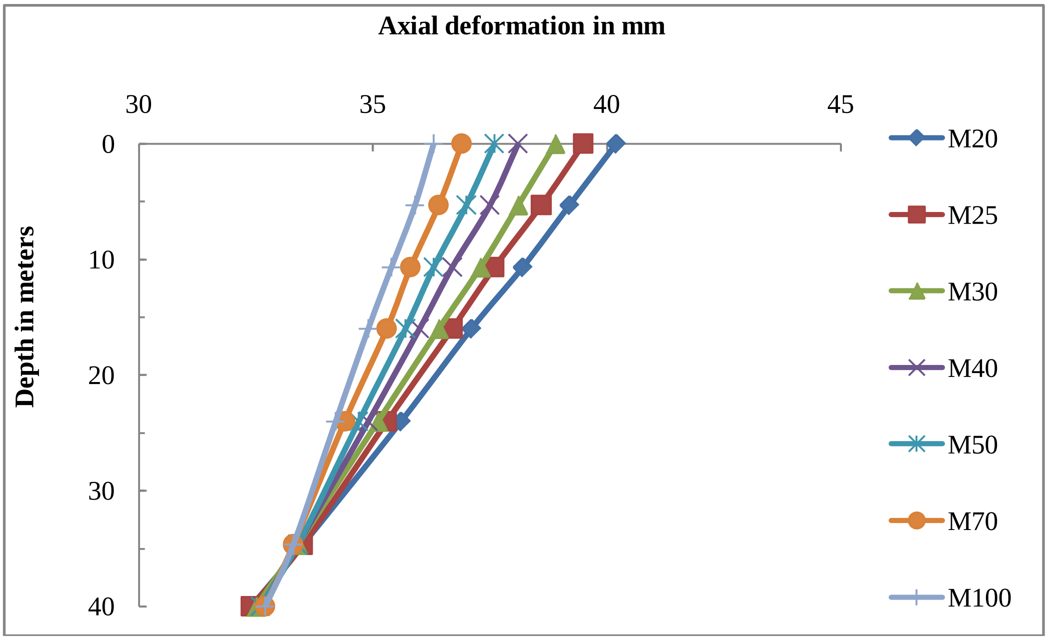

Fig. 7 : Vertical deformations of axially loaded circular pile in layered soil for various grades of concrete of pile for floating base condition

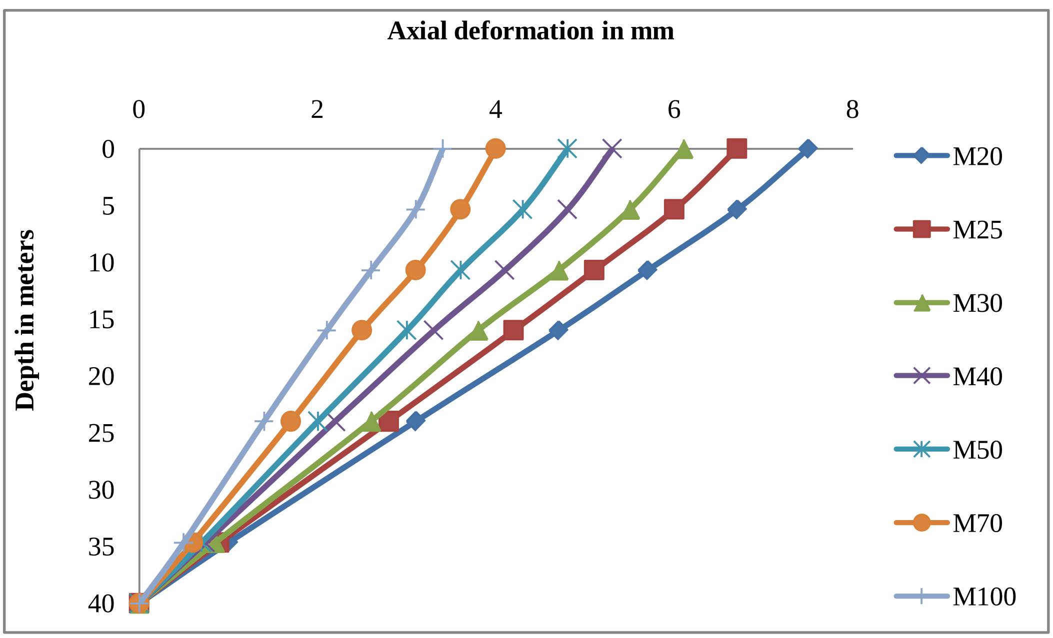

Fig. 8 : Vertical deformations of axially loaded rectangular pile in layered soil for various grades of concrete of pile for fixed base condition

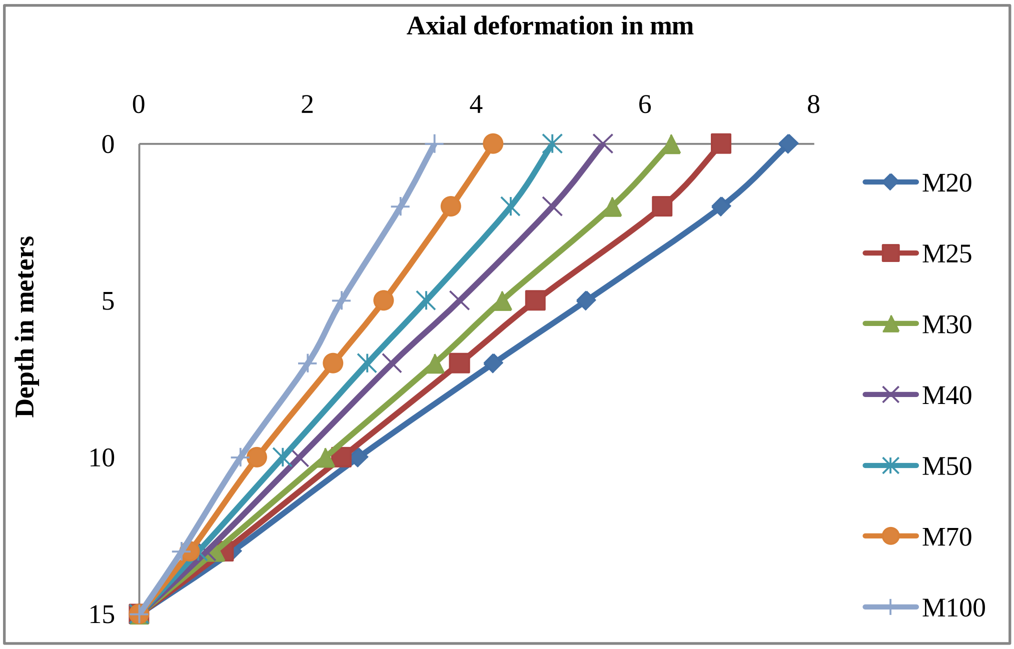

Fig. 9 : Vertical deformations of axially loaded square pile in layered soil for various grades of concrete of pile for fixed base condition

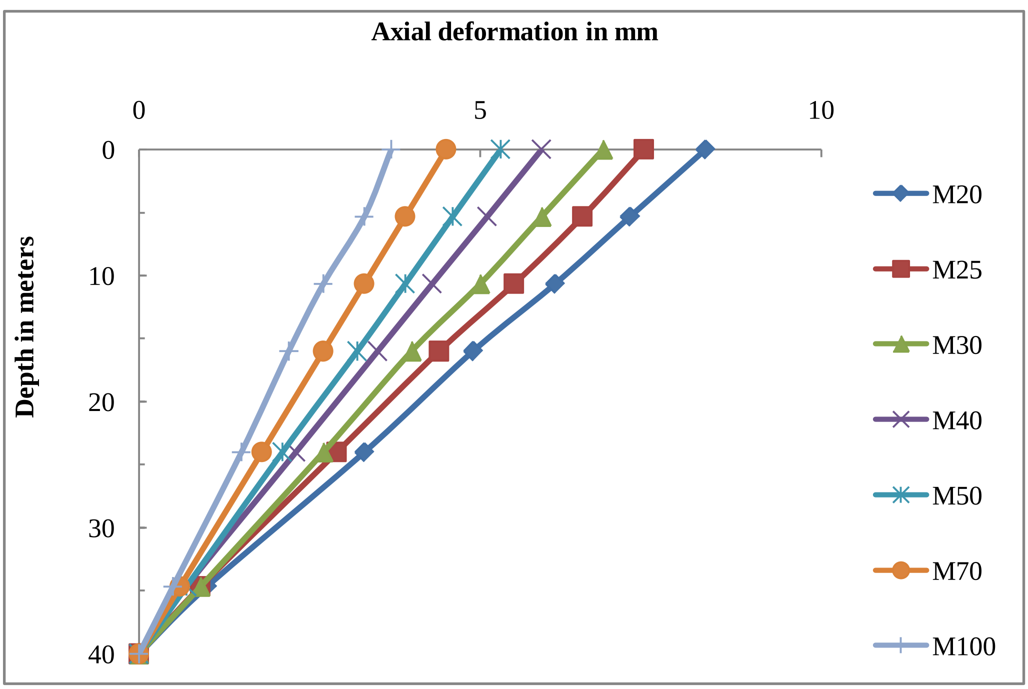

Fig. 10 : Vertical deformations of axially loaded circular pile in layered soil for various grades of concrete of pile for fixed base condition

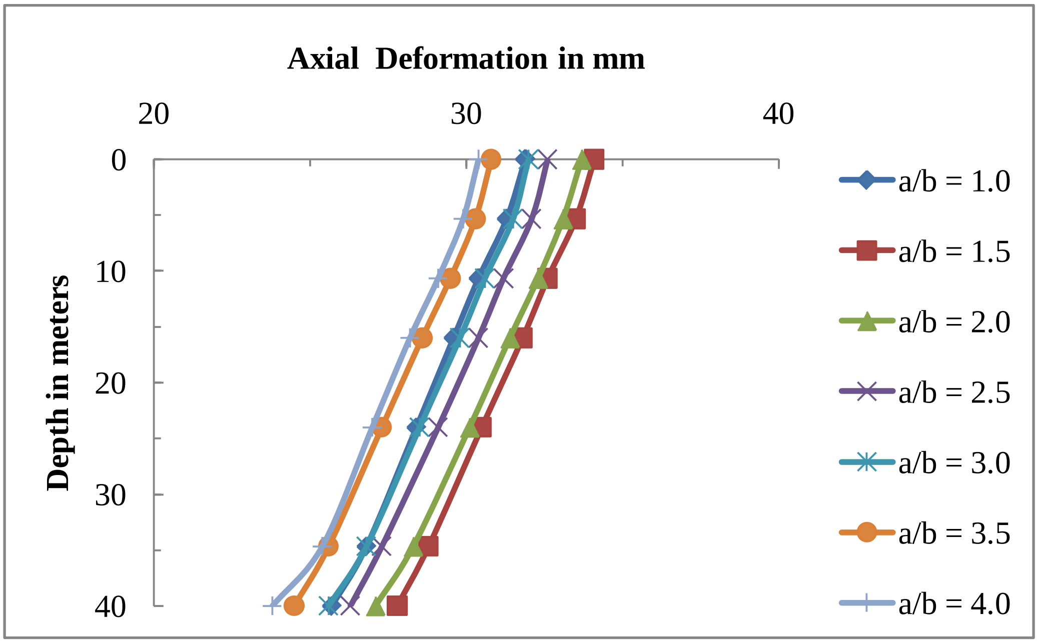

Fig. 11 : Vertical deformations of axially loaded pile in layered soil for various ratios of cross sectional dimensions of pile for floating base condition

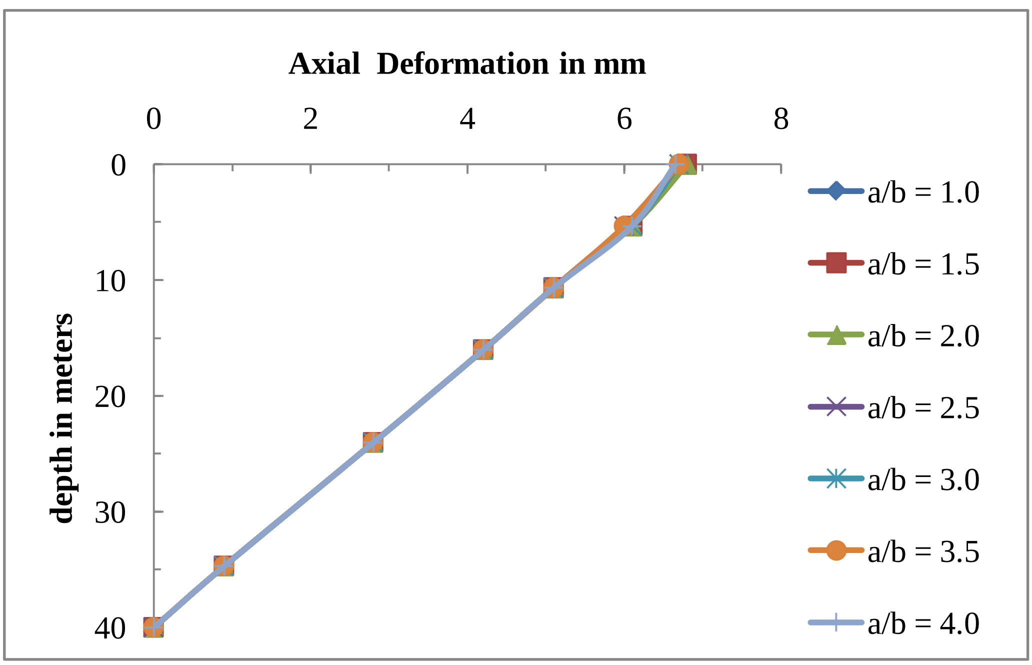

Fig. 12 : Vertical deformations of axially loaded pile in layered soil for various ratios of cross sectional dimensions of pile for fixed base condition

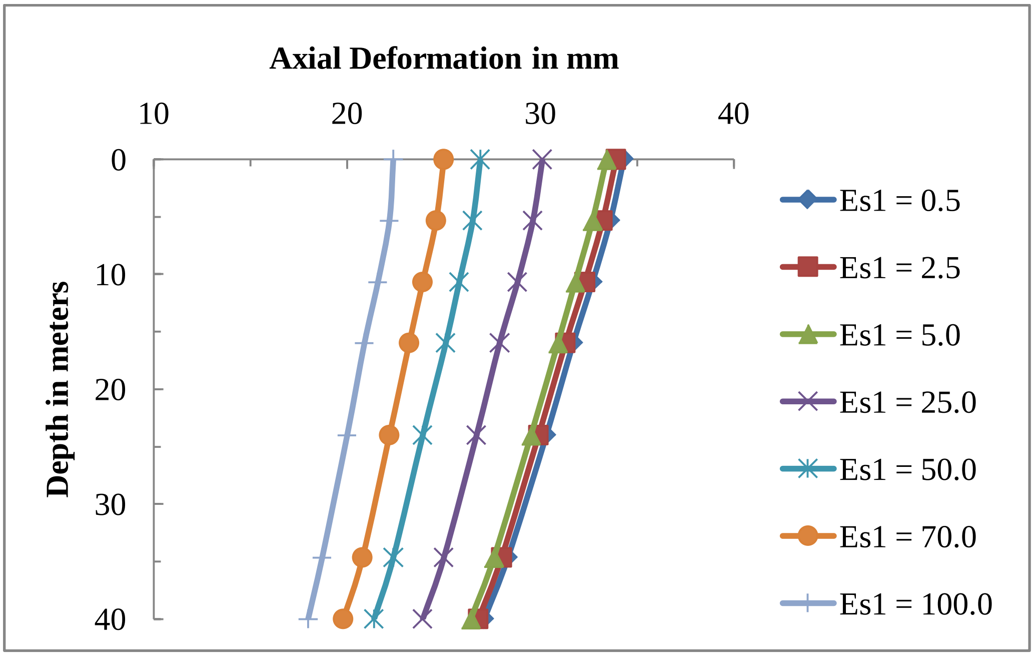

Fig. 13 : Vertical deformations of axially loaded rectangular pile in layered soil for various values of elastic modulii of soil in the top layer for floating base condition

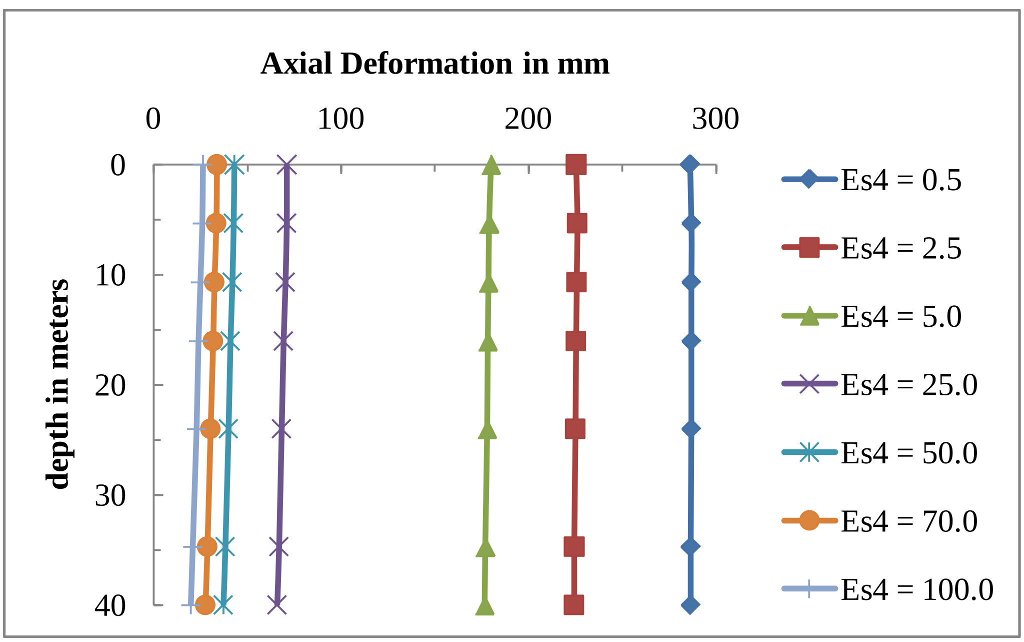

Fig. 14 : Vertical deformations of axially loaded rectangular pile in layered soil for various values of elastic modulii of soil in the bearing layer for floating base condition

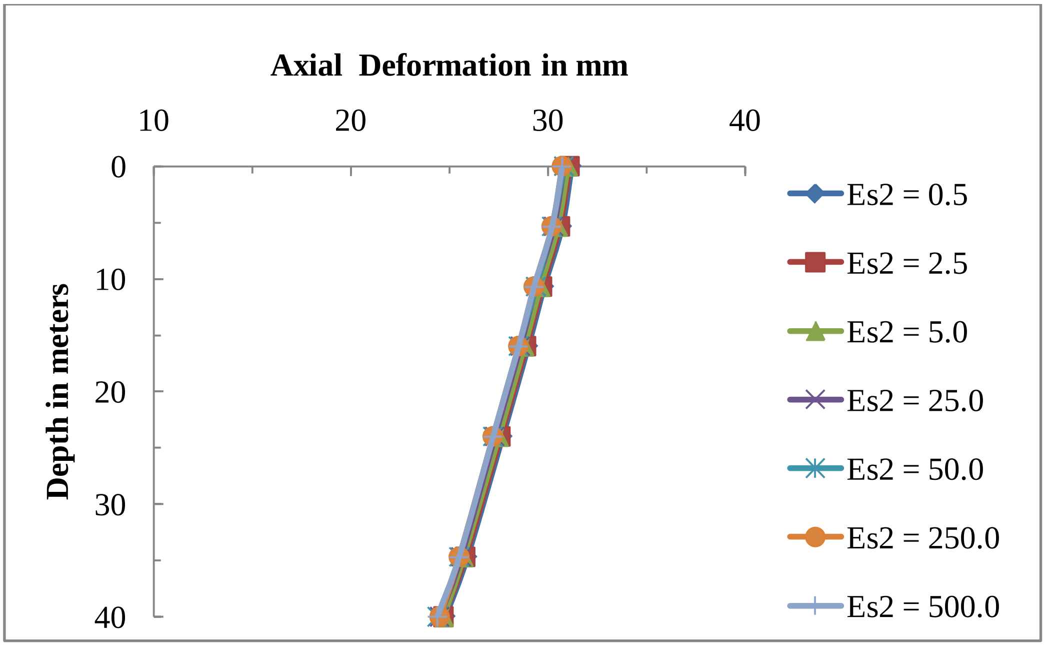

Fig. 15 : Vertical deformations of axially loaded rectangular pile in layered soil for various values of elastic modulii of soil in the intermediate layer for floating base condition

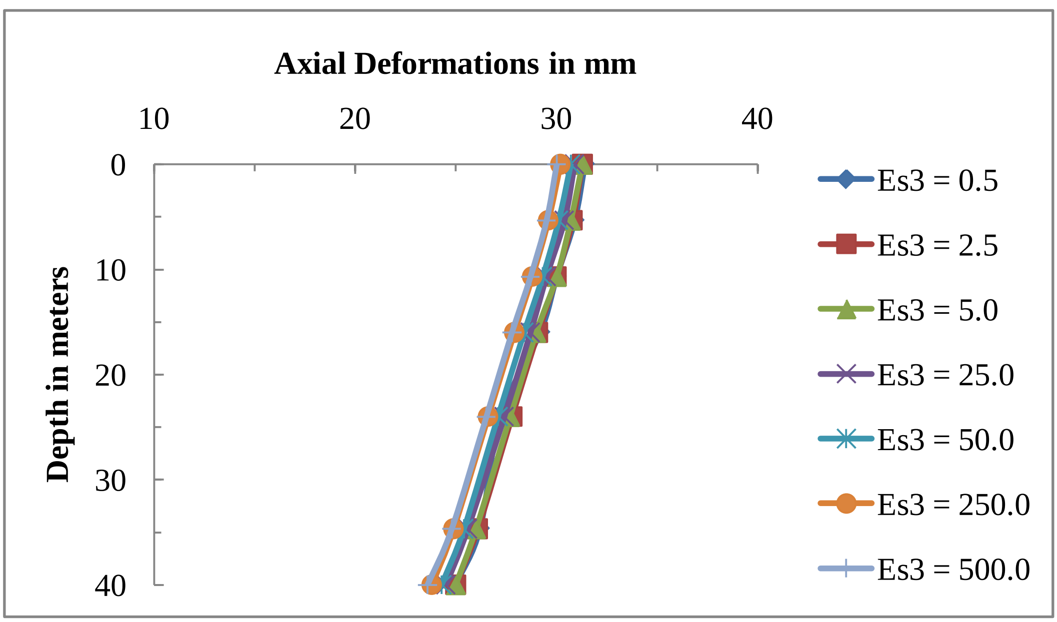

Fig. 16 : Vertical deformations of axially loaded rectangular pile in layered soil for various values of elastic modulii of soil in the intermediate layer for floating base condition

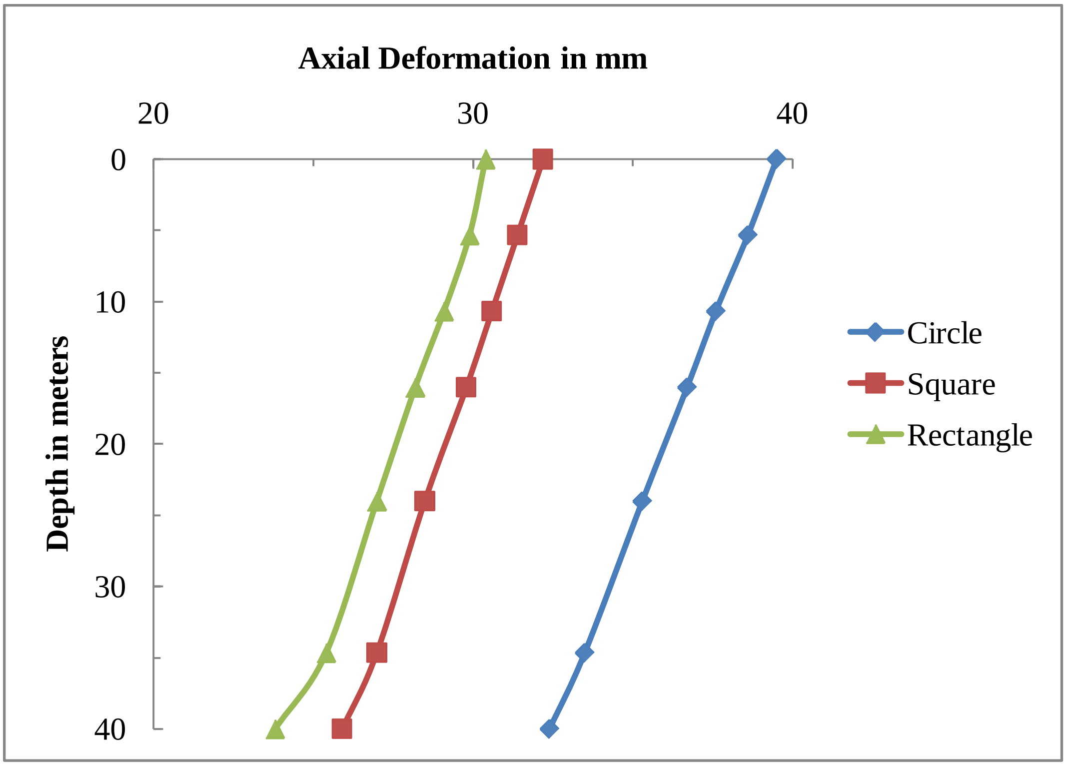

Fig. 17 : Vertical deformations of axially loaded circular, square and rectangular cross sectional shaped piles for floating base condition