ANALYSIS OF LATERALLY LOADED PILES IN TWO-LAYERED SOILS

L'ANALYSE DES PIEUX CHARGES LATERALEMENT PENETRANT UN SOL DE DEUX COUCHES

АНАЛИЗ РАБОТЫ СВАЙ НА ГОРИЗОНТАЛЬНУЮ НАГРУЗКУ В ДВУХСЛОЙНОМ ОСНОВАНИИ

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SYNOPSIS. Problem of piles constructed in layered soils and subjected to lateral loads and moments is frequently encountered in practice. Penetration of such piles in hard bottor layhr, for varying thicknasd ol overlying soil nas a significant influence on the pile behaviour. Analysis of pile foundations in such situations is carried out. A vertical pile penetrating through the upper soft layer into the lower hard stratum for different distances is considered for varying combinations of sub-grade modulii. Equations obtained for different boundary conditions are solved with the help of computer using numerical thechniques. The results are presented in non-dimensiohal form and comments are offered on the practical considerations invloved in such problems.

INTRODUCTION

Piles are frequently required to transmit large lateral loads caused by wind. earthquakes or impact from ships. Analysis of such piles is commonly made, by using the theory of sub-grade reaction (Terzaghi, 1955). The basic governing equation for this problem is given below:

$$EI.\frac{d^4y}{dx^4} = K_h.y \qquad (1)$$

where EI is the flexural rigidity of pile,y is the lateral displacement at distance x from the top of the pile, K_h is the lateral force over unit length of pile required to produce unit displacement.

The value of K_h at a given depth is found to depend on a number of factors. This value can be considered as constant with depth as in the case of homogeneous deposits of clays whereas, it is found to increase more or less linearly with depth as in the case of sandy deposits. In actual field problems combinations of the above variations need to be examined.

Number of research workers have attempted to study the problem of laterally loaded piles. Matlock and Reese(1960) have given generalized solutions using non-dimensional parameters for different variations of K_h witl deptl. They (1961) have also suggested methods for taking into account non-linear character of K_h. Broms (1964 a & 1964 b) has discussed the behaviour of piles as influenced by the type of soil. Davisson and Gill (1963) have analysed the case of piles in layered soils where the dessicated top layer has higher value of K_h.

In a number of instances piles transferring horizontal loads and moments pass through soft layer at the top, into stiff layer at the bottom as in the case of soft marine clay or granular deposits underlain by compact murrum / weathered rock. In such situations, the piles need sufficient embedment in the lower stratum to ensure their stability.

Depth of penetration of the pile in hard bottom layer has also a considerable influence on the pile deformation and bending moment. A detailed analysis of pile behaviour in these situations was therefore, carried out, (Rizvi, 1971). Solutions are obtained in non-dimensional form for generalized use. These are given as deflection and moment coefficients along the pile length. Since piling operations at that depth in hard bottom layer are

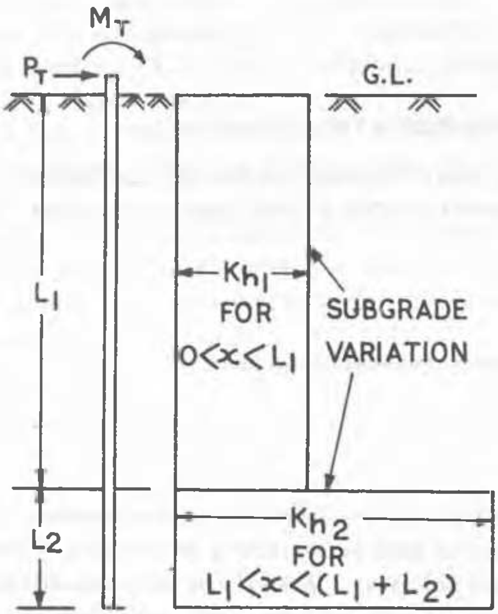

FIG.1 PILE IN TWO-LAYERED SOIL

very costly and time consuming, it is felt that such analysis would be useful in determining the required optimum length of penetration.

THEORETICAL ANALYSIS

Consider a vertical pile passing through a distance L_1 in the soft top layer and a distance L_2 into the hard bottom layer. The sub-grade modulus of the upper stratum would be constant or varying with depth depending on the soil profile. In order to understand the behaviour of piles in different field conditions, in the present analysis, the following variables are considered (Fig.1).

L_1 / R_f = 1, 2, 3 and 4

L_2 / L_1 = 0, 2/100, 5/100 and 10/100

K_{h2} / K_{h1} = 1, 10, 100 and 1000

where $R_f = \sqrt[4]{\frac{EI}{K_{h1}}}$ (2)

K_{h1} & K_{h2} = sub-grade modulus values (Fig.1)

Additional values of the above ratios and even the linear variation of the modulus in the upper layer are considered in the analysis but these are not reported here for want of space.

The following three cases of loadings at the top of the pile are considered in the analysis;

a) Free Head - subjected to horizontal load,
b) Free Head - subjected to moment, and
c) Pile Head restrained from rotation - subjected to horizontal load

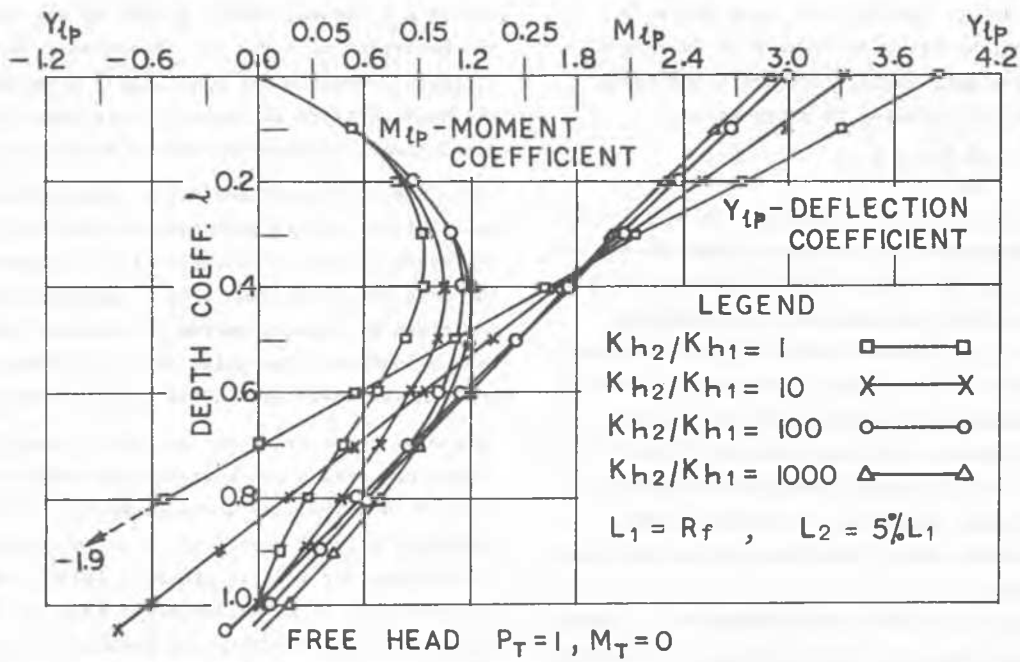

FIG.2 DEFLECTION AND MOMENT Vs DEPTH

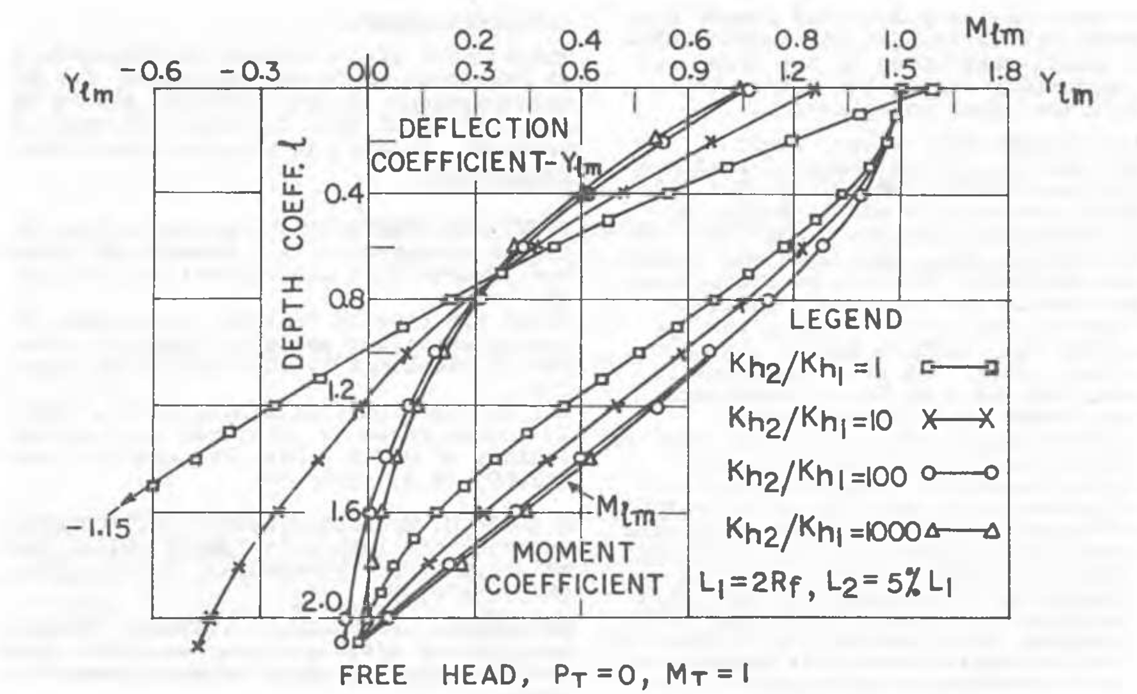

FIG. 3 DEFLECTION AND MOMENT Vs DEPTH

The solution of the above cases consists in solving the governing differential equation consistent with the necessary boundary conditions. In order to make the solution more general, the length of the pile is expressed in terms of R_f.

The pile is divided into a large number of increments of length 'h' (100 in this analysis) and corresponding finite difference equations are written at all these nodal points. Numerical procedure based on central differences (Matlock and Reese) is used and on the lines of Davisson and Gill, the computer solution of the problem for all combinations is obtained.

PRESENTATION OF DATA

The moment and deflection coefficients along the pile length for various combinations of the parameters mentioned earlier are given in non-dimensional form from which values of moments (M_l) and deflections (Y_l) can be obtained as under:

a) Free Head-Horizontal shear P_t case, here

$$Y_l = P_t . Y_{lp} . R_f^3 / EI \quad (3) \quad \& \quad M_l = P_t . M_{lp} . R_f \quad (4)$$

where Y_{lp} and M_{lp} are the non-dimensional coefficients obtained from the above analysis. Similarly, coefficients are also obtained for the other two cases i.e. Y_{lm} ${}_{lm}$ for moment loads; Y_{lf} and ${}_{lf}$ for fixed head case. Equations similar to (3) & (4) are obtained for cases (b) and (c) also. Only a few typical solutions are presented below because of limitations of space.

Moment and deflection coefficients along the length of the pile for the case where $L_1 = R_f$ and $K_{h2} / K_{h1} = 1, 10, 100$ and 1000 are shown in Fig.2 for 5% embedment when shear load is applied on a free headed pile. Similar details for $L_1 = 2R_f$ but for moment load are given in Fig.3.

DISCUSSION

Data from the above theoretical analysis are examined and the main points emerging from the same are briefly mentioned below.

a) Free Headed Pile - Shear load:

For lengths upto $L_1 = 3R_f$, it is observed that even with slight increase in L_2 from 0% to 5%, the deflection coefficient Y_{lp} at the top decreases considerably while the maximum moment coefficient M_{lp} increases. Deflection at top is also found to decrease with the improvement in the value of K_{h2}/K_{h1} only upto a value of 100 beyond which the change in the layer coefficient does not influence the pile behaviour very much. For length $L_1 = 4R_f$, however, the deflection and moment coefficients remain unaffected by the other variables apparently due to the fixity being attained in the upper layer itself.

b) Fixed Headed Pile -Shear load:
When $L_1=R_f$ and $2R_f$, it is observed that the whole pile upto the tip gets displaced from its original position in the direction of the load. With the increase in the layer coefficient ratio K_{h2}/K_{h1} and embedment L_2, the deflection decreases but this is accompanied by an increase in the negative moment. For $L_1=3R_f$, the top deflection coefficient Y_{1f} decreases and the negative moment also gets reduced. For $L_1=4R_f$, the pile behaviour is not altered very much by these parameters.

c) Free Headed Pile- Moment Load:
For $L_1=R_f$, the length of the pile is found to be relatively small to resist the moment load. The pile behaviour improves with the increase in the length upto $3R_f$ after which increased length of pile does not contribute to its stability. In general, it may be summed up that the embedment of the pile in the lower hard layer has a considerable influence on the behaviour of piles of short and intermediate lengths. Such penetration as also the fixity at pile top influence the pattern and magnitude of deformation and moment in the pile. Short piles can be stabilized against the lateral loads by a reasonable penetration in the lower layer. Whereas for $L_1=2R_f$ and $3R_f$, it would be possible to arrive at the value of minimum embedment in the lower layer by knowing the permissible lateral deformations. In the theoretical analysis considered in this paper, the problem is attempted by making certain simplifying assumptions. In actual practice, it would be necessary to take into account the different pattenrs of variations of K_{h1} and K_{h2} as also the vertical load acting on the piles. It would also be desirable to pay attention to stress concentration in the lower layer near the junction. In general, the problem of minimum embedment in lower hard stratum consistent with the required factor of safety and permissible deformation calls for a careful analysis coupled with possible field studies.

CONCLUSIONS

Theoretical analysis of the behaviour of piles subjected to lateral loads and moments in two-layered soil is presented in this paper and the following conclusions are drawn from the same:

It is found that the stiff bottom layer affects the behaviour of laterally loaded piles particularly in the case of piles of short and intermediate lengths. Embedment of piles in the hard layer, for these lengths, is quite important and it can be estimated with the help of the above analysis. With the increase in the depth of embedment in lower stratum the pile movement at top decreases and the bending moment increases. Improvement in the pile behaviour is observed with the increase in layer coefficient ratio only upto a particular range.

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