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Modification to Indian Standard Code Procedure on Lateral Capacity of Piles

by

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Introduction

The lateral capacity of piles is estimated based on limiting deflection at the pile head and the moment capacity of the pile. A number of methods are available for the estimation of pile head deflection and the maximum moment of taterally loaded piles. These methods can broadly be grouped into three categories, viz. (1) the methods based on modulus of subgrade reaction approach (Reese and Matlock 1956, Metlock Recse (1960) Davisson 1960, Broms, 1964 (*a*) and 1964 (*b*) Valsangkar 1969, Ramasamy, (1974), (2) the methods based on elastic theory (Spillers and Stoll 1964, Poulos 1971, Banerjee and Davis, 1978) and (3) the methods based on the principle of equivalent cantilever (Davisson and Robinson 1965, Nair *et al.* 1969, Zavriew 1976, Oteo, 1981). Of methods, the method proposed by Matlock and Reese (1960) is very popular and the nondimensional coefficients for deflection and moment obtained by them are widely reported in text books and used in computations. The Equivalent Cantilever Method proposed by Davisson and Robinson (1965) enables the pile to be treated conveniently as a cantilever and, therefore widely used in design. IS 2911 (Part I) —1979 also suggests the use of the Equivalent Cantilever Method and proposed a chart for the computation of equivalent cantilever lengths of fully embedded piles. An investigation into the accuracy of the procedure suggested by IS 2911 (Part I)—1979 is carried out and the shortcomings of the procedure are brought out.

There is a need for a simple approach for the analysis of partially embedded piles also, as their use is increasing, particularly in offshore Therefore, based on the results of a rigorous analysis of partially embedded piles reported elsewhere, (Ramasamy *et al.* 1982, Jain 1983) a modification to the IS Procedure on lateral capacity of both fully and partially embedded piles is suggested. The method is simple, accurate

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and applicable to long piles embedded in cohesive or cohesionless soils and subjected to lateral loads.

Equivalent Cantilever Method

The method is based on the concept that the pile can be considered to have fixed at some depth below ground level (Fig.1) and analysed by conventional methods of structural analysis. The values of depth of fixity, L_f have been suggested by Tomlinson (1977) as 1.5m for compact granular soils or stiff clay (below the zone of soil shrinkage in the latter case) and 3 m for a soft clay or silt. Davisson and Robinson (1965) suggest the following values of L_f.

$L_f = 1.4\ R$ for stiff clays (*i.e.* K is constant with depth)

$L_f = 1.8\ T$ for sands and normally loaded clay (*i.e.* K is linearly increasing with depth, $K = n_h\ x$)

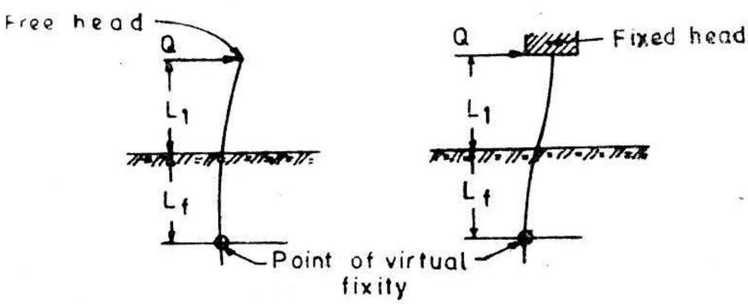

FIGURE 1 Piles Subjected to Lateral Loads Considered as Simple Cantilevers.

where,

K = modulus of subgrade reaction in kg/cm^2

x = depth below ground level

n_h = constant of horizontal subgrade reaction in kg/cm^3

R and T are relative stiffness factors defined as,

$$R = \sqrt[4]{\frac{EI}{K}} \quad \ldots (1)$$

$$T = \sqrt[5]{\frac{EI}{n_h}} \quad \ldots (2)$$

where E = Young's modulus of the pile material

I = Moment of inertia of the pile material

The IS 2911 (Part I)—1979 recommends a chart for the determination of the depth of fixity as shown in Fig. 2 for fully embedded piles.

Knowing the depth of fixity, L_f and the lateral load Q, the pile head deflection, Y_o and maximum moment in the pile, M_f (Fixed end moment) can be determined using the following expressions :

$$Y_o = \frac{Q\,(L_f+L_1)^3}{3\,EI} \qquad \text{for free head pile} \qquad \ldots (3)$$

$$= \frac{Q\,(L_f+L_1)^3}{12\,EI} \qquad \text{for fixed head pile} \qquad \ldots (4)$$

$$M_F = Q(L_f+L_1) \qquad \text{for free head piles} \qquad \ldots (5)$$

$$= Q(L_f+L_1)/2 \qquad \text{for fixed head piles} \qquad \ldots (6)$$

where,

L_1 = Length of the pile above ground level in the case of partially embedded piles

Evaluation of the I.S. Procedure

A rigorous analysis of partially embedded piles subjected to axial load, lateral load and moment was carried out based on the modulus of subgrade reaction approach and reported elsewhere (Ramasamy *et al.* 1982, Jain, 1983). Based on the results of the above investigation, the procedure recommended in IS 2911 (Part I)—1979 for the analysis of laterally loaded piles was examined. The investigation revealed the following limitations of the IS Procedure:

1. The depth of fixity depends on the relative stiffness factor, R or T of the pile soil system in addition to the pile head condition and the type of soil. In the case of partially embedded piles, it also depends on the length of the pile above groud level. The IS procedure covers only fully embedded piles and does not express the depth of fixity as a function of relative stiffness factor.
2. The depth of fixity is obtained by equating the pile head deflection to that of an equivalent cantilever, the loading remaining the same. This does not ensure the fixed end moment of the cantilever equal to the maximum moment in the pile.
3. The depth of fixity for fixed headed pile has presumably been obtained by equating the deflection of the fixed headed pile to that of a free headed cantilever. This means that the pile head deflection and the fixed end moment (*i.e.* the maximum moment in the pile) should be obtained using Eqs. (3) and (5) respectively instead of Eqs. (4) and (6) which are applicable for fixed headed system. These details have not been stated in the code and left to be presumed by the user.

The above discrepancies in the procedure lead to considerable over estimation of maximum moment in the pile and under estimation of pile head deflection. To illustrate this point, pile head deflection and maximum moment of a 30 cm diameter reinforced concrete long flexible pile are worked out using (*i*) IS procedure and (*ii*) Matlock and Reese (1960) procedure for the following cases :

1. Pile in sand
   (*a*) Free head pile
   (*b*) Fixed head pile
2. Pile in stiff clay
   (*a*) Free head pile
   (*b*) Fixed head pile

The data used in the computation are :

Pile reinforcement	=	4 bars of 16 mm dia. placed with a clear cover of 5cm.
E of concrete	=	2.1×10^5 kg/cm^2
n_h of sand	=	0.5 kg/cm^3
K of clay	=	50 kg/cm^2
Lateral load, Q	=	1000 kg.

The pile is assumed to be long and fully embedded, For solution according to IS procedure, the depth of fixity is obtained using the charts given in Fig. 2 and the deflection and maximum moment are obtained using Eqs. (3) and (5) respectively both for free and fixed head piles. (As stated earlier, the IS procedure does not specify the equation to be used in deflection and moment computations. However, the IS procedure presumably suggests the use of Eq. (3) for deflection computation and Eq. (5) for moment computation irrespective of pile head end condition. The use of Eqs. (4) and (6) for fixed head pile results in much larger error than

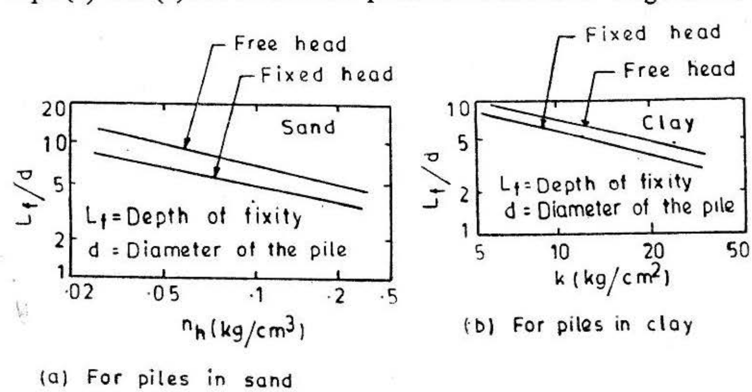

FIGURE 2 Depth of Fixity Charts Recommended by I.S. 2911.

when Eqs. (3) and (5) are used). The nondimensional coefficients and their numerical values used for the solution according to Matlock and Reese (1960) procedure are given in Table 1.

TABLE 1

Nondimensional Coefficients for the Computation of Pile Head Deflection and Maximum Moment -Matlock red Reese (1960) Procedure

Soil type	Values of Nondimensional Coefficients				Remark
	Deflection coefficient at pile head, A_y		Maximum moment coefficient, A_m		
	Free head	Fixed head	Free head	Fixed head	
Cohesive Soil (K-Constant with depth)	1.430	0.724	0.457	−0.674	The pile head deflection, $Y_0 = \frac{A_y QR^3}{EI}$ Maximum moment $M = A_M QR$
Cohesionless (K-Linearly increasing with depth)	2.435	0.925	0.772	−0.93	$Y_0 = \frac{A_y QT^3}{EI}$ $M = A_M QT$

The result of the above numerical example as obtained using the IS Code procedure and the Matlock and Reese (1960) procedure are presented in Table 2. The 'Equivalent Cantilever' procedure is a simple substitute to the Matlock and Reese (1960) procedure for obtaining pile head deflection and is expected to give the same deflection values as those of Matlock and Reese procedure. Therefore, a comparison of the results of the two methods are made. The difference in the results between the two methods brings out the error that has crept in due to wrong adaptation of the 'Equivalent Cantilever' approach.

The results shown in Table 2 clearly suggest that the IS Code Procedure (1979) shall result in significant under estimation of deflection and many-fold over estimation of maximum moment.

Suggested Procedure

A rigorous analysis based on the modulus of subgrade reaction approach was carried out for fully and partially embedded piles subjected to a generalised loading (axial load, lateral load and moment). Piles in cohesive and cohesionless soils and free and fixed pile head conditions

TABLE 2

Comparison of the Results Obtained Using Matlock and Reese (1960) and IS Procedures (1979)

Soil type and end conditions	Pile head deflection, cm		Maximum moment $\times 10^5$ kg/cm		Percentage error+over estimation—under estimation	
	Matlock and Reese, (1960)	IS 2911-(1979)	Matlock and Reese, (1960)	IS 2911-(1979)	In deflection values	In max. moment values
1. Cohesive						
(*a*) Free head	0.236	0.154	0.555	1.710	−34.8	208.0
(*b*) Fixed head	0.118	0.076	0.817	1.350	−39.2	65.0
2. Cohesionless						
(*a*) Free head	0.358	0.286	0.895	2.100	−20.1	134.5
(*b*) Fixed head	0.136	0.104	1.085	1.500	−23.6	38.4

were considered. The differential equations governing the pile deflection were converted into nondimensional form using the nondimensional coefficients defined by Matlock and Reese (1960). The solutions are obtained in non-dimensional form. The details of the investigation and the results are presented elsewhere (Jain, 1983). Based on these results, a simple procedure is suggested for the determination of lateral deflection at the pile head and the maximum moment of a fully or partially embedded pile subjected to lateral load

(*a*) *Determination of pile head deflection*

The pile is considered to be long (i.e. the embedded length of the pile $>4R$ or $5\,T$) and treated as an equivalent cantilever fixed at some depth below the ground level. The procedure of obtaining the pile head deflection may be outlined in the following steps.

(*i*) Estimate the value of the modulus of subgrade reaction, K or the constant of horizontal subgrade reaction, n_h of the soil from Tables 3 and 4 The values given in Table 3 and 4 are those recommended in IS 2911 (Part I)-1979.

(*ii*) Knowing the pile properties (i.e. E and I of pile), compute the relative stiffness factor R or T of the pile using Eqs. (1) or (2) as the case may be.

(*iii*) Knowing the nondimensional free standing length, L_1/R or L_1/T (L_1 free standing length or the pile, i.e. the length above ground level) of the pile, obtain the nondimensional depth of fixity, L_f/R or L_f/T (L_f— depth of fixity), using the chart shown in Fig. 3.

TABLE 3*

Values of K for Preloaded Clays

Unconfined compressive strength (kg/cm²)	Range of values of K (kg/cm²)	Probable values of K (kg/cm²)
0.2 to 0.4	7 to 42	7.73
1 to 2	32 to 65	48.79
2 to 4	65 to 130	97.73
> 4	—	195.46

TABLE 4*

Values of n_h

Soil Type	n_h in kg/cm³	
	Dry	Submerged
Loose sand	0.260	0.146
Medium sand	0.775	0.526
Dense sand	2.076	1.245
Very loose sand under repeated loading	—	0.041

* as per IS 2911 (Part I)-1979.

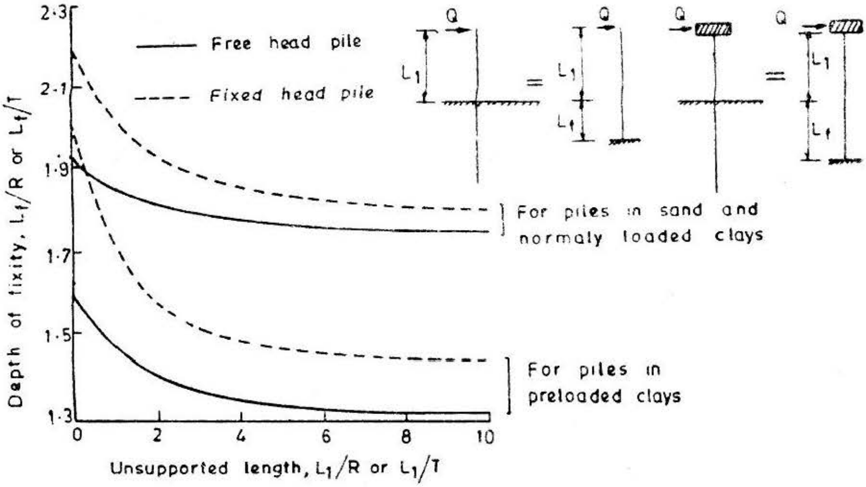

FIGURE 3 Recommended Depth of Fixity

Use the appropriate curve depending on the type of soils and the pile head condition.

(*iv*) Determine the pile head deflection using Eq. (3) for free head pile and using Eq. (4) for fixed head pile.

(*b*) *Determination of Maximum Moment*

(*i*) Obtain the fixed end moment of the pile using Eq. (5) for free head pile and Eq. (6) for fixed head pile.

(*ii*) The fixed end moment of the equivalent cantilever is larger than

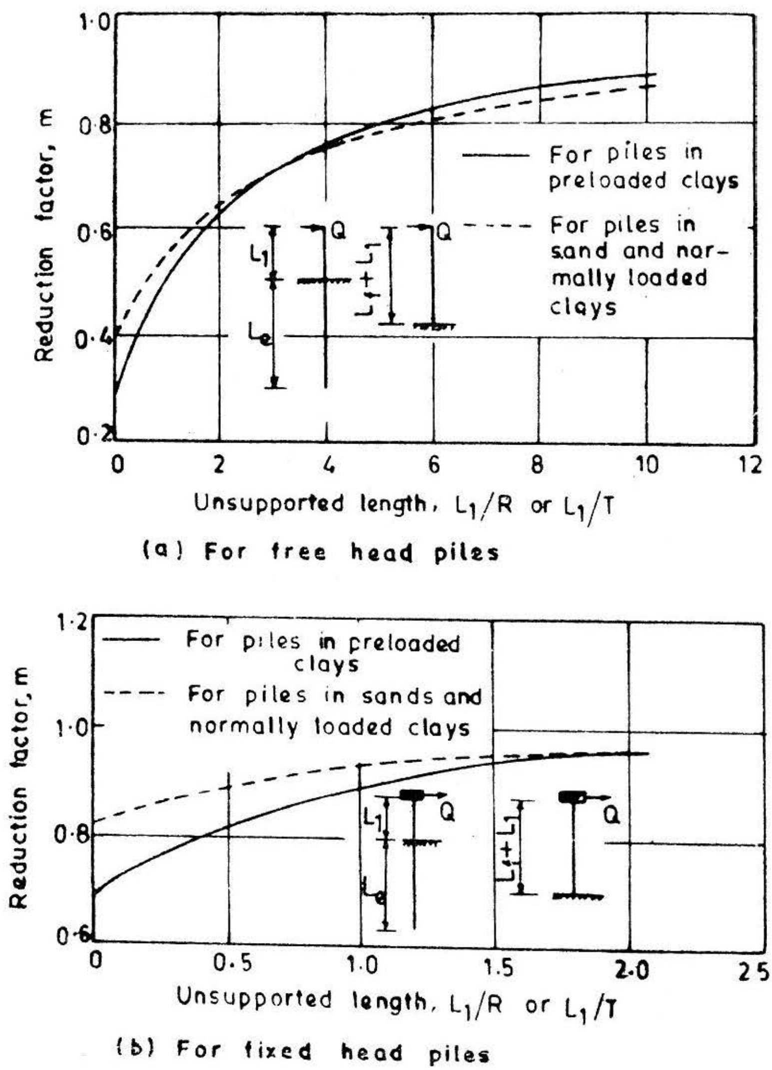

FIGURE 4 Reduction Factor, 'm' for the Computation of Maximum Moment in Pile

the actual maximum of the pile. Therefore, the actual maximum moment is obtained by multiplying the fixed end moment by a multiplying factor '*m*' obtained from **Fig.** 4. **Use the appropriate** curves of Fig. 4, depending on the type of soil and pile head condition to obtain '*m*'.

The pile head deflection and the maximum moment obtained using the above procedure are practically the same as those obtained using the rigorous analysis based on the modulus of subgrade reaction approach. (Jain, 1983). The procedure is recommended for adoption by the I.S.

Conclusions

1. The IS procedure as outlined in IS 2911 (Part I) for the determination of pile head deflection and maximum moment of a laterally loaded pile is examined. The procedure is found to significantly underestimate deflection and overestimate maximum moment of the pile.

2. Based on the results of a rigorous analysis, a simple and accurate procedure of obtaining pile head deflection and maximum moment of a fully or partially embedded pile subjectcd to lateral load is recommended. The procedure can be used for piles in cohesive or eohessionless soils with free or fixed head conditions. The procedure may be adopted by IS and the Code of Practice, IS 2911 (Part I) may be modified incorporating the procedure.

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