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Evaluation of Indian Standards Code Criteria for Safe Load on Piles in Compression

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Introduction

When pile foundations are used in major construction projects in India, pile load tests are generally conducted to assess the load capacity of the piles in compression. The test is usually a slow maintained load (SML) test and is carried out according to the standard procedure given in the Indian Code of Practice IS : 2911, Part 4 (1985). The test data is used to draw the load-settlement curve and to determine the safe load on the pile using the criteria specified in the IS code.

Alternatively, one may determine the safe load from an interpretation of the load-settlement curve. Several methods have been suggested for the determination of the ultimate load of piles from an interpretation of the load-settlement cruve (Brinch Hansen 1963, Chin 1970, Fellinius 1975 and 1980). The safe load can be determined using a factor of safety on the ultimate load obtained this way.

Scope of The Study

According to the IS code, the safe load on a uniform diameter pile is the least of the following:

(*a*) two-thirds of the final load at which the total settlement is 12 mm,

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unless a value different from 12 mm is specified depending upon the nature and type of structure.

(*b*) 50% of the load at which total settlement is equal to 10% of the pile diameter.

(*c*) the load at which the total permissible settlement is reached.

In the present study, the third criterion is not considered as it is not a general criterion but a case specific one. Similarly, while using the first criterion the general specification for total settlement is considered as 12 mm and the safe load is calculated as two-thirds of the load at which the total settlement is 12 mm. This criterion is referred to as the 12 mm total settlement criterion in this paper.

The second IS code criterion, referred to as 10% pile diameter total settlement criterion in the paper, can be used only if the failure load is reached in the load test. However, it is common to see piles being not loaded to failure and the safe load being determined using the first criterion alone. This is based on the implicit assumption that the second criterion would always give a higher safe load than the first criterion.

The first objective of the study is to evaluate the first two IS code criteria using the load test data where both the criteria can be used. Table 1 gives the details of the 29 piles used in the analysis. In only 17 of these piles both the criteria could be used. The other 12 piles are included so as to serve as a larger data base for the second objective of the study. The first 18 piles, namely TP1 to TP18, were tested in India according to the procedure specified in the IS code. The other data have been collected from published literature.

The second objective of the study is to compare the safe load obtained by the various methods of analysis of load-settlement curve with the respective values obtained using the IS code criteria. This is intended to throw more light on the nature of prediction of ultimate load by the several methods proposed for this purpose.

The third objective of the study is to obtain a criterion for the estimation of the safe load based on the ratio of the pile head settlement to the pile diameter.

Evaluation of Indian Standard Code Criteria

Let Q_{s1} be two-thirds of the load at which the settlement is 12 mm. Let Q_{s2} be 50% of the load at which the settlement is equal to 10% of pile diameter. Thus, Q_{s1} and Q_{s2} are the safe loads according to the two criteria of the IS code. Let the ratio of these two loads be defined as

TABLE 1

Details of the piles

Sl. No.	Pile Designation	Diameter (mm)	Method of installation	Base type	Soil type	Method of load test	Source
1	TP1	500	D	S	NC	SML	(1)
2	TP2	450	D	S	NC	SML	(1)
3	TP3	500	D	S	NC	SML	(1)
4	TP4	500	D	S	NC	SML	(1)
5	TP5	400	D	S	NC	SML	(1)
6	TP6	400	D	S	NC	SML	(1)
7	TP7	400	D	S	NC	SML	(1)
8	TP8	400	D	S	NC	SML	(1)
9	TP9	500	D	S	C	SML	(1)
10	TP10	450	D	S	NC	SML	(1)
11	TP11	1070	B	S	NC	SML	(1)
12	TP12	530	D	S	NC	SML	(1)
13	TP13	530	D	S	C	SML	(1)
14	TP14	450	D	S	NC	SML	(1)
15	TP15	450	D	S	NC	SML	(1)
16	TP16	530	D	S	C	SML	(1)
17	TP17	1000	B	S	C	SML	(1)
18	TP18	750	B	S	C	SML	(1)
19	TP29	406	D	S	C	SML	(1)
20	TP30	406	D	S	C	SML	(1)
21	TP31	406	D	S	C	SML	(1)
22	TP32	406	D	S	C	SML	(1)
23	TP33	150	D	S	NC	SML	(2)
24	TP38	350	B	S	C	SML	(3)
25	TP39	425	B	S	C	SML	(3)
26	TP40	400	D	S	C	SML	(3)
27	TP42	700	B	S	C	SML	(3)
28	TP43	917	B	S	C	SML	(3)
29	TP48	320	B	S	C	SML	(3)

(1) — Chakraborty (1989)
(2) — Franx (1736)
(3) — ABEF Research on Foundation Engineering (1989)
NC = non-cohesive soil
C = cohesive soil
D = driven pile
B = bored pile
S = straight shaft pile
SML = slow maintained load test

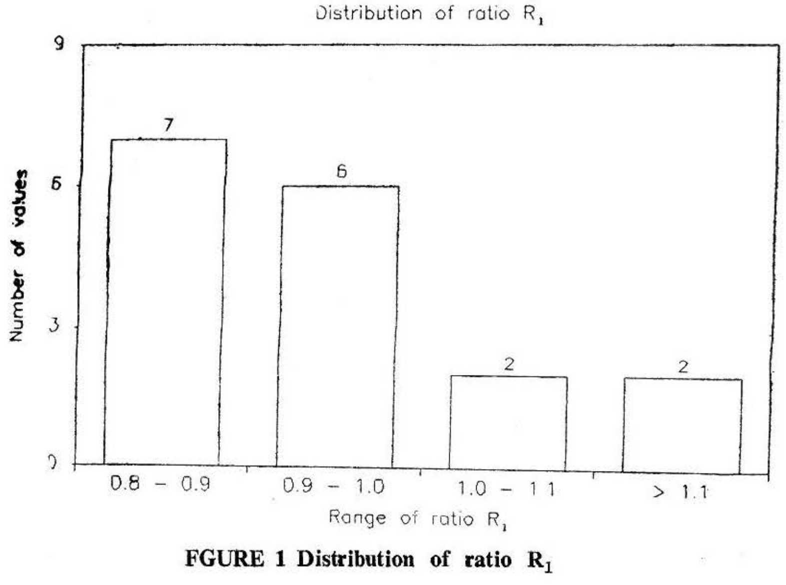
$$R_1 = \frac{Q_{s2}}{Q_{s1}} \qquad (1)$$

Figure 1 shows the distribution of R_1 over selected ranges of values. Most of the values lie within the range of 0.8 to 1.1. To calculate the probable average value of R_1, the average of all the R_1 values is first computed. The R_1 values which are more than 1.5 times or are less than 0.5 times of this average value are discarded. The average of the remaining R_1 values is computed again and the process of elimination of the extreme values is repeated. Figure 4 shows the range of variation of R_1 and the average value. R_1 ranges from 0.83 to 1.35 and has an average value of 0.95.

Figures 1 and 4, and the average value of R_1 imply that the two criteria of the IS code give nearly the same safe load. The procedure of obtaining the safe load in practice, often by using the 12 mm total settlement criterion alone, therefore, appears to be satisfactory. This inference is not likely to be valid for large diameter piles or where the end bearing component is predominant. In such cases, the 12 mm total settlement criterion is likely to give a smaller safe load than the 10% pile diameter total settlement criterion. However, in such cases it is either the permissible settlement or the permissible stress on the pile material which may govern the safe load on the pile.

Safe load from Interpretation of Load-settlement Curve

Several methods have been suggested to determine the ultimate load of piles from an interpretation of the load-settlement curve. A detailed



FGURE 1 Distribution of ratio R_1

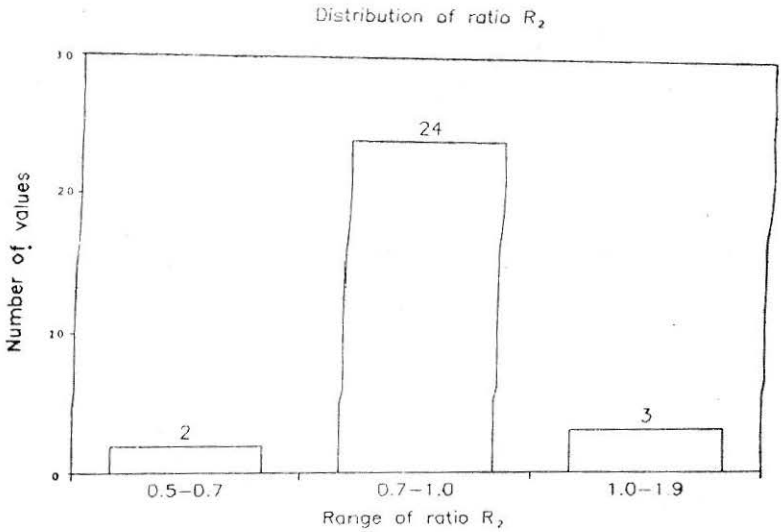


FIGURE 2 Distribution of ratio R_2

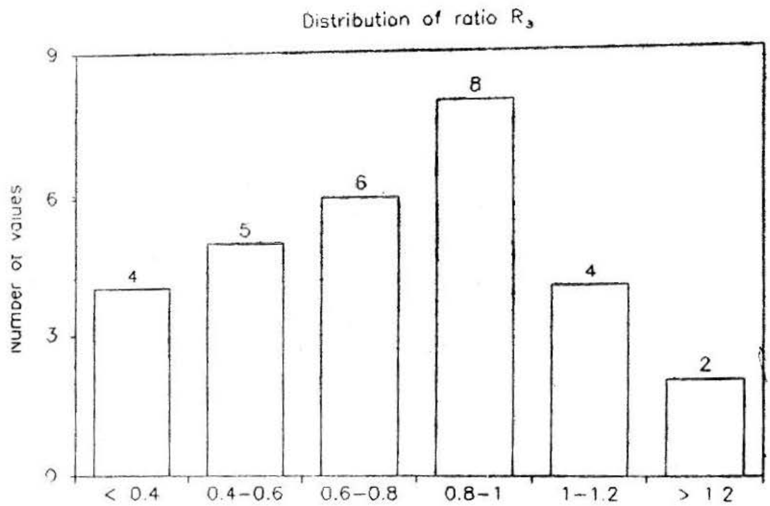


FIGURE 3 Distribution of ratio R_3

description of these methods is given by Fellinius (1975, 1980, 1989). A probable ultimate load based on the mean of the values obtained by the different methods suggested for the evaluation of ultimate loads of SML tests is considered. The methods that are suggested and used for SML tests are, the single tangent method, double tangent method, Vander Veen's method (Vander Veen 1953), Brinch Hansen's 80% method (Brinch Hansen 1963), De Beer's method (De Beer 1967), Chin's method (Chin 1970),

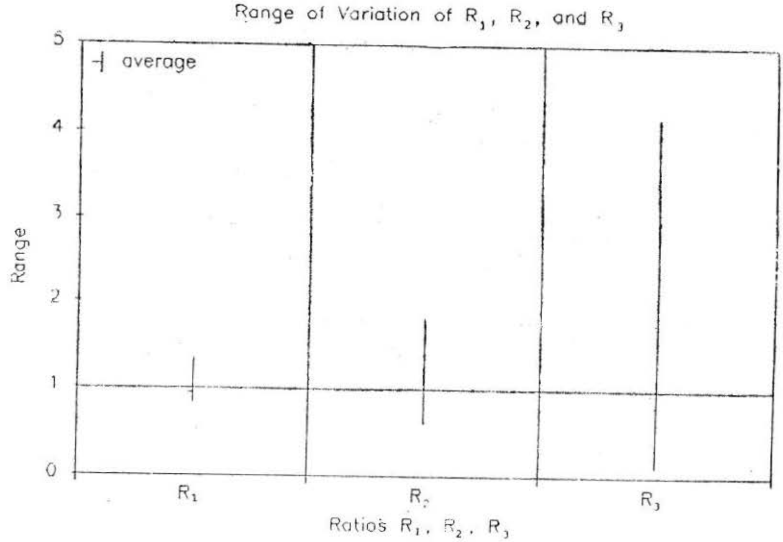


FIGURE 4 Range of variation of ratios R_1, R_2, and R_3

Mazurkiewicz's method (Mazurkiewicz 1972), Davisson's method (Davisson 1973), Carroll's creep method (Carroll 1987) and the modified hyperbolic method (Rollberg 1976, Chakraborty 1989). Of these methods the Davisson's method was originally suggested for quick maintained load tests but was later found to give good estimates of the ultimate load for slow maintained load tests as well (Canadian Foundation Engineering Manual 1985).

The safe load of each pile is determined as follows. The ultimate load of a pile is first determined using the different methods. The probable ultimate load Q_{max} of a pile is determined iteratively by calculating the average of the ultimate load values determined by using the different methods, eliminating the extreme values, and recalculating the average value, and so on as explained before for the determination of the average of the ratio R_1. 50% of the probable ultimate load is considered to be the safe load of the pile. Let this value be denoted as Q_{s3}. To compare Q_{s3} with the safe load obtained by using the IS code criteria, the ratio R_2 defined by Eq. 2 is computed.

$$R_2 = \frac{Q_{s3}}{Q_{s1}} \tag{2}$$

Figure 2 shows the distribution of R_2. Most of the values lie within the range of 0.7 to 1. Of the 24 values in this range, 14 are in the range from 0.8 to 0.9, 5 are in the range from 0.7 to 0.8, and 5 are in the range from 0.9 to 1. The average value of R_2 is calculated in the same manner as explained for R_1. Figure 4 shows the range of variation of R_2 and the average value. R_2 ranges from 0.59 to 1.84 and has an everage value of 0.83.

Figures 2 and 4, and the average value of R_2 imply that the methods of predicting the ultimate load are conservative. In general, they give a safe load which is 20% lower than that given by the 12 mm total settlement criterion. This conclusion, however, is not valid for all the methods if the safe load from each method is considered separately as some methods generally predict higher ultimate loads than others.

To get an idea about the order of settlement at the safe load, the ratio R_3 is computed for each pile and the average of R_3 is calculated in the same manner as explained for the ratio R_1. R_3 is defined as

$$R_3 = \frac{\text{settlement at safe load}}{\text{pile diameter}} \times 100 \tag{3}$$

Figure 4 shows the range and the average of R_3 obtained for the 12 mm total settlement criterion and for the methods of interpretation of the load-settlement curve. The comparative safe load from the methods of interpretaion is lower than that from the 12 mm total settlement criterion. Evidently, the IS code criterion gives higer R_3 values. The range of R_3 for the IS code criterion varies from 0.11 to 1.4%, with the exception of one pile which has R_3 = 4.2%. The average value of R_3 is 0.8%. The distribution of R_3 is shown in Fig. 3. It is evident that most of the values are less than 1.2% and are nearly uniformly spread in the range of 0.4 to 1.2%. These values may therfore be considered as the limits for R_3. The average of R_3 is 0.99% for piles less than 400 mm diameter, 0.84% for piles of diameter 400 to 500 mm, and 0.47% for piles more than 500 mm diameter. The R_3 value, therefore, appears to decrease with increasing pile diameter.

Illustration of the Use of R_3

The use of the ratio R_3 to estimate the safe load is illustrated with the load test data on 4 piles. The details of the location, diameter, and length of these piles are given in columns 2 to 4 of Table 2. The load test data were collected in such a manner that during the load test the pile should have undergone a total settlement more than 12 mm but less than 10% of the Pile diameter. Further, the loading should have been carried out in a monotonically increasing pattern, *i.e.* without releasing of load in a cyclic pattern. The load-settlement curve of each pile was drawn.

The average value of R_3 of each pile is shown in column 5 of Table 2. The settlement at safe load is obtained by multiplying R_3 by the pile diameter and given in column 6. From the load-settlement curve the load corresponding to this settlement was estimated as the safe load and reported in column 7.

TABLE 2

Determination of safe load using R_3 and 12 mm total settlement criterion

Sl. No.	Project and Location	Diameter (mm)	Length (m)	R_3 %	$R_3 \times D$ mm	$Q_{(R3)}$ kN	$Q_{(12)}$ kN	$0.67 \times Q_{(12)}$ (kN)	Error %
1	2	3	4	5	6	7	8	9	10
1	Officers quarters, Delhi Cantontment	450	16.34	0.84	3.78	932	1361	907	2.75
2	Captains' quarters, Delhi Cantontment	450	15.75	0.84	3.78	1000	1540	1026	-2.53
3	Captains' quarters, Delhi Cantontment	500	16.15	0.84	4.20	981	1716	1144	-14.25
4	Thermal power station, Panipat	530	—	0.47	2.49	1687	2815	1876	-10.07

$Q_{(R3)}$ = safe load from R_3

$Q_{(12)}$ = load at 12 mm settlement

Error = [(col. 7—col.9) × 100]/col.9

Since the recommended R_3 value are based on a relatively small number of piles, 29 in all covering different range of pile diameters, it is considered appropriate to compare the safe load obtained from R_3 with the safe load obtained by the 12 mm settlement criterion. For this sake, the load at 12 mm settlement and two-thirds of this load are obtained. These values are given in columns 8 and 9 of the table. The error in the prediction using R_3 is calculated by using Eq. 4 and reported in column 10.

$$\text{error} = \frac{\text{load in col. 7} - \text{load in col. 9}}{\text{load in col. 9}} \times 100 \quad (4)$$

For the two 450 mm diameter piles the use of R_3 has resulted in a very good estimate of the safe load. In the case of 500 and 530 mm diameter piles the prediction is somewhat conservative. However, the trend is encouraging. With a large database of pile load test results it might be possible to further refine the values of R_3.

The load test data on a 500 mm diameter, 17.11 m long pile tested at Tanda Power Project was also analysed. This pile was subjected to a cyclic load test. The safe load obtained by using R_3 is very conservative in this case being 1216 kN against 1608 kN obtained by the 12 mm criterion (about 24% less). Evidently more investigation is required in the case of cyclic load tests.

Conclusions

The data from load tests on 29 piles have been analysed to evaluate the Indian standards code criteria for the determination of safe load on piles, and to evaluate the nature of prediction of the ultimate load and hence the safe load by the several methods proposed for this purpose. The following are the conclusions of the study.

The two criteria of the Indian standards code, namely, 12 mm total settlement criterion and the 10% pile diameter total settlement criterion give nearly the same safe load. Often in practice the safe load is obtained by using the 12 mm total settlement criterion alone. This appears to be satisfactory. But, for large diameter piles (diameter $>$ 1m or so) or where the end bearing component is predominant it is expected that the 12 mm total settlement criterion is likely to give smaller safe load than the 10% pile diameter total settlement criterion. However, in such cases it is either the permissible settlement or the permissible stress on the pile material which may govern the safe load on the pile.

Considering the average of the ultimate loads determined by the different methods of interpretation of the load-settlement curve, these methods appear to be conservative. The average safe load is 20% lower than that given by the Indian standards code criterion. This conclusion, however, cannot be extended to each method separately.

The ratio of settlement at safe load according to the IS code criterion to pile diameter is in the range of 0.4 to 1.2%. The ratio decreases with increasing pile diameter. For piles with diameter greater than 500 mm the safe load is the load corresponding to a settlement of 0.47% of the pile diameter. For piles having a diameter between 400 and 500 mm, the load corresponding to a settlement of 0.84% of the pile diameter can be considered as the safe load. For safe loads on smaller diameter piles (diameter $<$ 400 mm) the ratio of settlement to pile diameter is 0.99%. These values are required to be refined further using a large database of pile load test results.

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