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Autor: Kaniraj, S.R.

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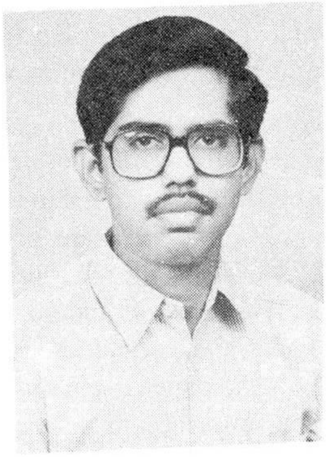
SAFE LOAD FROM DEFICIENT PILE LOAD TEST DATA



S.R. KANIRAJ
Dept. of Civil Engg
IIT, New Delhi, India

Shenbaga R. Kaniraj, born 1946. Graduated in 1967 from Madras University. Obtained doctorate degree from IISc, Bangalore, in 1975. Joined IIT, Delhi, in 1975.

SUMMARY

Initial pile load tests are conducted in major piling projects. The Indian Standard IS:2911 (Part 4)-1985, specifies two criteria for the determination of safe load of a pile. The criteria are in terms of the loads corresponding to total settlements of 12 mm and 10% of the pile diameter. Therefore, to apply both the criteria the settlement of the pile should not be not less than 10% of the pile diameter. When the load-settlement data is deficient, it is desirable to make a reasonably good estimate of the loads corresponding to each criterion by a proper interpretation of the available data. The paper explains the hyperbolic method and the modified hyperbolic method that can be used for this purpose. The paper presents the results of the analyses of data from twnty four pile load tests by using these methods. The results show that for piles transmitting more than 65% of their load through skin friction, the loads corresponding to each criterion of the Indian Standard and the load-settlement curve can be predicted reasonably well by using the hyperbolic method and the modified hyperbolic method, if the load-settlement data is available up to a minimum settlement of 5% of the pile diameter.

1 INTRODUCTION

The Indian Standard Code of Practice IS:2911 (Part 4)-1985 {1} specifies the criteria for the safe load of piles tested in compressive, tensile, and lateral loading. According to the Indian Standard, the safe load of a pile in compression is the smaller of the following two values:

Criterion 1: Two-thirds of the final load at which the total displacement attains a value of 12 mm unless otherwise required in a given case on the basis of the nature and the type of the structure in which case, the safe load should be corresponding to the stated total displacement permissible.

Criterion 2: 50% of the final load at which the total displacement is equal to 10% of the pile diameter in case of uniform diameter piles and 7.5% of bulb diameter in case of under-reamed piles.

For several reasons, often even in the initial load tests, the pile is not subjected to loads that would cause a settlement of 10% of the pile diameter. If the settlement of the pile is more than 12 mm, then the safe load can be estimated by using only the first criterion. When the load-settlement data is deficient, it is desirable to make a reasonably good estimate of the loads corresponding to each criterion by a proper interpretation of the available data. The paper explains analytical procedures which can be used for this purpose. The Australian Standard AS 2159-1995 {2} specifies the acceptance criteria in terms of gross settlement and net settlement. The analytical procedures were used for the Australian Standard criteria also. The paper explains the salient details of the study with respect to the Indian Standard only. For more information, reference can be made to another paper of the author cited at the end {3}.

2 ANALYSIS OF PILE LOAD TEST DATA

To develop analytical procedures, the load-settlement data and other details of pile load tests, in which the settlement exceeded 10% of the pile diameter, were collected from twnty four pile load tests on straight shaft piles. In one test, the pile diameter was 1070 mm, and in other tests it varied from 400 to 800 mm. The pile length varied from 13 to 27 m. Seven of the pile load tests were on driven *cast-in-situ* piles in cohesive soils, nine were on driven *cast-in-situ* piles in noncohesive soils, and six were on bored *cast-in-situ* piles in noncohesive soils. All tests were slow maintained load tests and eight of them were cyclic tests.

Each pile load test data was first scrutinized for consistency and errors. The load-settlement curve is generally a nonlinear curve with the slope - the ratio of incremental settlement to incremental load - increasing continuously with load. A seating error is indicated if at the beginning of the curve there is a decrease in the slope. The initial range of the data was examined. If there was a seating error, the correction in settlement required to make the slope more or less linear in this range was identified. The correction was applied to the raw data. The load-settlement curve was drawn using the corrected data. From this, the loads corresponding to the two criteria of the Indian Standard Code were determined. The loads corresponding to the first and second criteria were designated as Q_{1-IS} and Q_{2-IS}, respectively. In nineteen pile load tests, including the 1070 mm diameter pile, the safe load was governed by the second criterion, that is $Q_{1-IS} > Q_{2-IS}$. This indicates that the safe load estimated from the first criterion alone can be unconservative. The value of the ratio Q_{1-IS}/Q_{2-IS} varied from 0.823 to 1.243 with an average of 1.093. The standard deviation and 95% confidence interval of the ratio were 0.111 and 0.044, respectively.

Different relationships between load and settlement were considered. For each relationship, the expressions for the load corresponding to each criterion were obtained. The data were artificially made deficient by choosing the data only up to a particular value of settlement. From a regression analysis of this data, the parameters of the expressions were obtained. The rigor of the regression analysis was tested from the correlation coefficient, the F-test, and the t-test. The loads corresponding to the two criteria of the Indian Standard were estimated using the corresponding expressions. The load-settlement curve was also predicted. The analysis was repeated for different ranges of the load-settlement data.

An assumed relationship was considered to be satisfactory if the following conditions were satisfied:

a) the load estimated for each criterion compared well with the respective actual load,

b) the estimated values of the safe loads compared well with the actual values,

c) the criteria for the estimated safe loads matched with the criteria that gave the actual safe loads,

d) the predicted and actual load-settlement curves matched well, and

e) the relevant statistical tests were satisfied.

Only the hyperbolic method and the modified hyperbolic method satisfied all these conditions. Therefore, the results of only these two methods are presented in the paper.

3 HYPERBOLIC METHOD

The expressions for the loads corresponding to the Indian Standard criteria are

$$Q_{h1-IS} = \frac{8}{b + 12m} \quad \text{kN} \tag{1}$$

$$Q_{h2-IS} = \frac{0.05D}{b + 0.1mD} \quad \text{kN} \tag{2}$$

$Q_{h1\text{-}IS}$ and $Q_{h2\text{-}IS}$ are the loads given by the hyperbolic method corresponding to the first and second criteria of the Indian Standard, respectively. b and m are constants obtained from linear regression analysis of the data in the (s, s/Q) coordinates system. s is the settlement of pile at pile load Q. The units of s and Q are mm and kN, respectively. D is the pile diameter in mm.

4 MODIFIED HYPERBOLIC METHOD

Rollberg {4} suggested that the load-settlement curve is a hyperbola up to a settlement s_o, beyond which it is a straight line as shown in Fig. 1. s_o is given by an empirical relationship and constants that are dependent on the type of soil and the method of pile installation.

The expressions for the loads corresponding to the Indian Standard criteria are

$$Q_{m1-IS} = \frac{8}{b + 12m} \quad \text{kN} \qquad s_o \geq 12 \text{ mm} \tag{3a}$$

$$Q_{m1-IS} = \frac{2}{3}(c + 12i) \quad \text{kN} \qquad s_o \leq 12 \text{ mm} \tag{3b}$$

$$Q_{m2-IS} = \frac{0.05D}{b + 0.1mD} \quad \text{kN} \qquad s_o \geq 0.1D \text{ mm} \tag{4a}$$

$$Q_{m2-IS} = \frac{1}{2}(c + 0.1iD) \quad \text{kN} \qquad s_o \leq 0.1D \text{ mm} \tag{4b}$$

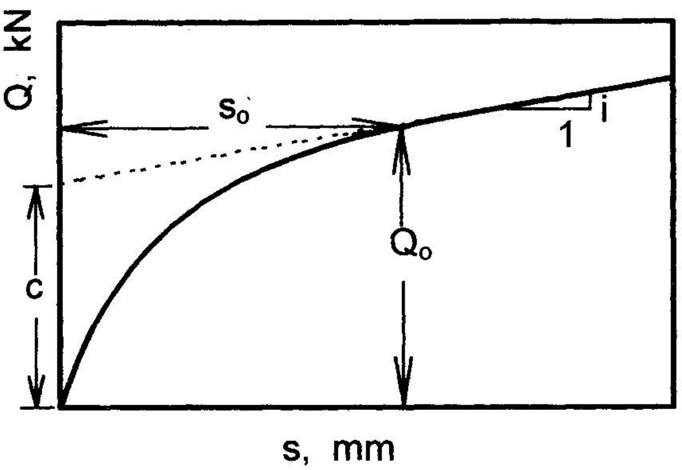


Fig. 1 Modified Hyperbola

$Q_{m1\text{-}IS}$ and $Q_{m2\text{-}IS}$ are the loads given by the modified hyperbolic method corresponding to the first and second criteria of the Indian Standard, respectively. i is the slope of the straight line portion of the load-settlement curve beyond s_o and c is its intercept with the load axis.

5 RESULTS

5.1 Comparison of the Estimated and Actual Loads

The loads estimated by using the hyperbolic method and the modified hyperbolic method were compared with their respective actual loads by computing the ratio of the estimated load to the actual load. The closer the value of this ratio is to unity, better will be the theoretical estimate of the load. The trend of variation of the different ratios with s/D was studied and the upper and lower limits of the variation were determined. Table 1 gives the expressions for the upper and lower limits for the different ratios. The respective ranges of s/D in which the error in the different estimated loads is less than 10% and 5%, and the mean, standard deviation, and 95% confidence interval of the ratios over these ranges of s/D were determined. These results are presented in Table 2. For the same data, the results from the modified hyperbolic method were slightly better than those from the hyperbolic method.

5.2 Load-Settlement Curves

The load-settlement curves predicted from different ranges of deficient data were compared with the actual load-settlement curves. The minimum value of s/D required to predict the load-settlement curve reasonably well ranged from as low as 0.82% to as high as 10%. Still, in majority of piles the required s/D value was very low. In fourteen piles it ranged between 0.82% and 3%, in five piles between 3% and 5%, and in four piles above 5%. The average, standard deviation, and 95% confidence interval of the minimum required s/D value were 3.43%, 2.43%, and 0.97%, respectively. In modified hyperbolic method, it was observed that for bored piles the constants recommended by Rollberg for driven piles instead of bored piles should be used in the analysis.

Table 1: Lower and upper limits for load ratios from the hyperbolic and modified hyperbolic methods

Ratio, y	Limit	Expression
$Q_{h1\text{-}IS}/Q_{1\text{-}IS}$	Lower	$y = -64.4x^2 + 9.1086x + 0.7204$
	Upper	$y = -485494x^5 + 181705x^4 - 26212x^3 + 1808x^2 - 58.472x + 1.7566$
$Q_{h2\text{-}IS}/Q_{2\text{-}IS}$	Lower	$y = -307.05x^4 + 468.83x^3 - 109.9x^2 + 9.9851x + 0.64$
	Upper	$y = 21281x^4 - 7205.8x^3 + 889.62x^2 - 47.092x + 1.8906$
$Q_{m1\text{-}IS}/Q_{1\text{-}IS}$	Lower	$y = -9384.7x^4 + 3115.8x^3 - 367.33x^2 + 17.555x + 0.7062$
	Upper	$y = -688985x^5 + 245552x^4 - 33567x^3 + 2184.9x^2 - 66.395x + 1.7867$
$Q_{m2\text{-}IS}/Q_{2\text{-}IS}$	Lower	$y = 1.2687x^{0.1081}$
	Upper	$y = 154336x^5 - 18178x^4 - 4001.3x^3 + 827.58x^2 - 49.905x + 1.9933$
y = ratio of the estimated load to the actual load; $x = s/D$ (*not* in per cent)		

Table 2: Statistical values for the load ratios from the hyperbolic and modified methods

Quantity	$Q_{h1\text{-}IS}/Q_{1\text{-}IS}$	$Q_{h2\text{-}IS}/Q_{2\text{-}IS}$	$Q_{m1\text{-}IS}/Q_{1\text{-}IS}$	$Q_{m2\text{-}IS}/Q_{2\text{-}IS}$
Over the range of s/D in which the error in the estimated load is within 10%				
Range of s/D%	≥ 2.5	≥ 3.5	≥ 1.7	≥ 2.6
Average	1.002	0.969	1.017	0.980
Standard Deviation	0.0386	0.0511	0.0482	0.0887
95% Conf. Interval	0.0095	0.014	0.012	0.0262
Over the range of s/D in which the error in the estimated load is within 5%				
Range of s/D%	2.5 - 5.5	≈ 10	2.2 - 6	≈ 10
Average	1.013	0.992	1.011	1.006
Standard Deviation	0.0254	0.0106	0.020	0.0156
95% Conf. Interval	0.0085	0.0041	0.0076	0.0074

5.3 Effect of Irregularities and Seating Error in the Actual Load-Settlement Curve

The results obtained from the hyperbolic and modified hyperbolic methods were not sensitive to the irregularities in the actual load-settlement curve. However, the effect of the correction for seating error on the results was significant. Even a small correction, not only improved the predictions significantly but also reduced the amount of data required to do that. The initial range of the observed load-settlement data should therefore be scrutinized carefully to determine the need for any correction to be done in the data.

5.4 Components of Load Transfer

The analysis for the nature of load transfer showed that except for one pile in all the other piles the skin friction was the predominant component. In many piles the skin friction was more than two-thirds of the load acting on the pile.

5.5 Illustrative Example

At Numaligargh, Assam, India, a 500 mm diameter bored cast-in-situ pile of length 19.175 m was subjected to a maximum load of 1207 kN at which the pile settlement was 21.61 mm (s/D = 4.32%). Figure 2 shows the actual load-settlement curve and that predicted by the modified hyperbolic method. The best estimate for the safe load of the pile is obtained by the modified hyperbolic method. According to this method, the safe load is governed by the second criterion and is in the range of 639-665 kN.

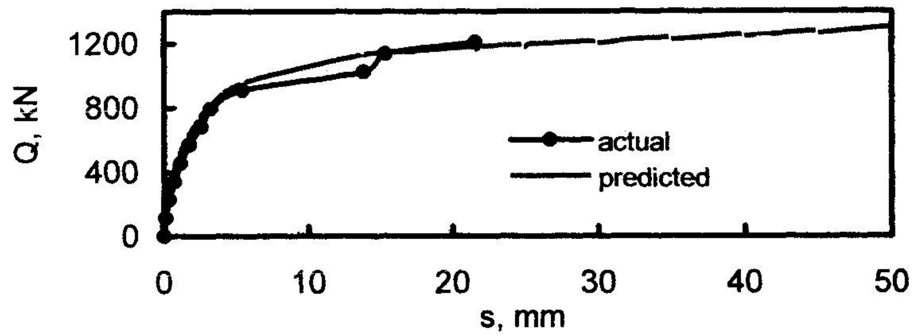


Fig. 2 Actual and predicted load-settlement curves for Numaligargh pile

6 CONCLUSIONS

The loads corresponding to the two criteria of the Indian Standard and the load-settlement curve of piles that transmit more than 65% of their load through skin friction could be predicted reasonably well by the hyperbolic and the modified hyperbolic methods, if the load-settlement data is available up to a minimum settlement of 5% of the pile diameter. For the same data, the modified hyperbolic method gives slightly better results than the hyperbolic method. The results are not sensitive to the irregularities in the actual load-settlement curve but to the correction made for seating error.

7 REFERENCES

1. *IS:2911 (Part 4) Indian standard code of practice for design and construction of pile foundations, Part 4 Load test on piles* (1985). Bureau of Indian Standards, New Delhi, India.
2. *Australian standard : Piling - design and installation AS 2159-1995*, (1995). Standards Association of Australia, Homebush, NSW, Australia.
3. Kaniraj, S.R. (1998). Interpretation of pile acceptance criteria from deficient data, *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, 124, 10, 1035-1040.
4. Rollberg, D. (1977). Determination of the bearing capacity and pile driving resistance of piles using soundings. Institute for Foundation Engineering, Soil Mechanics, Rock Mechanics, and Water Ways Construction, RWTH (University) Aachen, Germany, 3, 43-227.