A CASE STUDY ON NEGATIVE SKIN FRICTION

ZA-CHIEH MOH

CHIN-DER OU

SIU-MUN WOO

Moh and Associates (S) Pte. Ltd.

Reprinted from

Proceedings, 1st International Geotechnical Seminar

Construction Problems in Soft Soils,

Singapore, 1-3 Dec. 1983

Nanyang Technological Institute, Singapore

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by

Za-Chieh Moh, Sc.D., P.Eng.
Chin-Der Ou , Ph.D. and
Siu-Mun Woo , D.Eng.

MOH AND ASSOCIATES (S) PTE LTD
Singapore

Summary

The potential development of negative skin friction is one of the major concerns to geotechnical engineers in designing pile foundations at sites where ground subsidence due to long term consolidation of compressible subsoils is anticipated. A full scale testing program and theoretical study was carried out to evaluate the effectiveness of a special asphalt coated pile (NF pile) in reducing the magnitude of potential negative skin friction.

Loading tests were carried out on a special coated steel pipe pile and an uncoated plain pipe pile. From instrumentation installed on the piles, distribution of stresses and therefore skin friction along the pile shafts under loading were determined. It was found that NF pile was effective in reducing the potential negative skin friction by as high as 90 percent.

1. INTRODUCTION

In many parts of Singapore, particularly in the reclaimed land along the coastal areas such as Marina Centre, East Coast and Changi, the ground is normally covered with a thick layer of soft marine deposit consisting of peat, very soft marine clay and other types of very compressible materials (Ref. 1). The ground in these areas will undergo substantial amount of subsidence due to long term consolidation of the very compressible marine deposits under the surcharge load of reclamation and any other imposed load. Most buildings and constructed facilities located in the reclaimed land have to be supported by deep foundation which penetrates through the soft marine deposit and rests on the underlying hard stratum.

When a downward displacement occurs in the surrounding soil of a pile or any other type of deep foundation, a downdrag force, or the so-called "negative skin friction" will exert an additional load on the pile. This downdrag force will produce adverse effect on the structure system supported by the pile if it were not properly taken into consideration in the design. Numerous methods have been proposed for predicting the magnitude of negative skin friction on piles (for example, Ref. 2, 3, 4, 5, 6, 7 and 8).

A number of measures could be adopted to counteract or to reduce the negative skin friction when it occurs. The measures include increasing the number of piles in a group or the strength of the pile material, using double tubing pile, or providing special coating on the pile surface. Coating the pile with bituminous material is often the most economical method for reducing downdrag (for example, Ref. 4, 9, 10, 11 and 12).

This paper describes a full scale investigation on the effectiveness of a special asphalt coated pile (Trade name NF pile) in reduction of the negative skin friction. In the study, a special asphalt coated pile produced by the Nippon Kokan K.K. of Japan was tested by a series of full scale loading tests along with a plain uncoated pipe pile in a piece of reclaimed land in Singapore. Methods and accuracy of predicting residual negative skin friction on coated piles are also discussed.

2. TESTING PROGRAM

2.1 Site and Subsoil Condition

For the purpose of evaluating the effectiveness of NF pile in reducing negative skin friction, a full scale loading test program was carried out at a selected site with potential of large subsidence in Singapore. The site selected is located on the recent reclaimed land along the south-western seafront, off the mouth of the Singapore River. The area is known as the Marina Centre, which covers a land area of about 92,000 sq.m. The tests were performed within the project area of the SL Marina Centre Development. At the time of the tests, the site area was completely vacant with no occupant or any type of structure.

The subsoil conditions at the Marina Centre Project site was investigated by Moh and Associates (S) Pte Ltd (Ref. 13). A total of 42 boreholes had been drilled within the site area. In-situ testing including borehole pressuremeter tests and laboratory testing were carried out to evaluate the subsurface conditions and characteristics for foundation design. At the particular test site, an additional check borehole was drilled prior to the pile tests. Based on the borehole records and soil test data, the subsoils underlying the site can be divided into four main strata. From the ground surface extending to a depth of about 3.7 m is a layer of loose sandy fill which is the reclaim land fill. Underlying the fill is a relatively thick layer, about 15 m, of loose to medium dense sand deposit containing shell fragments. From the depth of 19.4 m extending to 32.1 m below the existing ground surface is the soft marine clay layer whose high compressibility is the main source contributing to the potential downdrag problem. Below the depth of 32.1 m is a layer of slightly cemented silty sand which is the bearing stratum for the test piles.

2.2 Test Piles

The piles used in the testing program were manufactured by Nippon Kokan K.K. of Japan. Table 1 presents the properties of the piles used for the loading test. The test piles, approximately 33 m long each, were driven open-ended with an IDH-45 diesel hammer until they rested in the dense silty sand stratum.

For measuring stress transfer through the pile section, resistant-wire type strain gauges manufactured by OYO Corporation (HS-10C high rigidity type) were mounted on the inside surface of the pipe piles. The strain gauges were protected from possible damage due to driving by a steel channel welded on the inner surface of the piles. A total number of 18 gauges were installed on the NF test pile and 12 gauges on the uncoated plain test pile. Settlements of the piles during loading test were measured by means of displacement dial gauges. A reaction frame with concrete blocks was used for loading purpose.

2.3 Testing Procedures

Pile loading tests were carried out on the uncoated plain and NF piles at seven days after installation. For each test, five loading-unloading cycles* were arranged to be placed on the pile. The loading cycles were 100 t, 200 t, 300 t, 400 t and up to a maximum of 450 t. The rates of loading and unloading used during the tests were 15 t/min and 30 t/min respectively. For loading stages, each load was maintained for a period of minimum of one hour. The maximum load of 450 t was however maintained for a period of 20 hours.

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* During the actual loading test, six cycles were applied to the NF pile. The fourth and fifth cycles were of the same loading.

Table 1: Properties of Test Piles

Type of Pile	Uncoated Plain Pile	NF Pile
Outside diameter	610.35 mm	610.2 mm
Thickness	12.33 mm	12.6 mm
Total length	32.4 m in 3 pieces (10.9m + 12m + 9.5m)	33.85 m in 4 pieces (0.35m + 12m + 12m + *9.5m) * uncoated portion
Cross-sect. area	Pipe : 231.65 cm^2 C-channel: 77.3 cm^2 TOTAL : 308.95 cm^2	Pipe : 236.38 cm^2 C-channel: 77.3 cm^2 TOTAL : 313.68 cm^2
Length of Sliding Area	-	22.4 m in 2 pieces (11.2m + 11.2m ea.)
Thickness of Sliding Area	-	Average 1.5mm or more
Thickness of Protective Layer	-	Average 3.0mm or more
Pile Spec.	JIS G3444 Class 2	JIS G3444 Class 2
Pile Tip Condition	Open End	Open End

3. RESULTS AND ANALYSES

3.1 Bearing Capacity of Piles Under Loading Test

The maximum test load of 450 t imposed on the two test piles was selected on the basis of the strength of the steel material. The load-settlement records of the two test piles are presented in Figs. 1 and 2. Figure 3 shows the relationship between test load and settlement of piles in logarithmic scale. The test results indicate that for both the NF pile and the uncoated plain pile, the applied load did not cause any significant amount of settlement and no indication of failure was observed. This implies that the maximum test load was still less than the ultimate bearing capacity of the subsoil. The selection or determination of allowable pile bearing capacity in this site is governed by the strength of the pile material rather than the subsoil. Table 2 compares the bearing capacity values of the uncoated plain pile and NF pile as interpreted from the loading tests and that estimated from the theoretical formula proposed by Meyerhof (Ref. 14).

Table 2: Allowable Bearing Capacity of Piles*

Pile Type	Allowable Bearing Capacity, tons		
	From Loading Test	Estimated by using Meyerhof's Formula	Based on Pile Material Strength
Uncoated Plain Pile	Over 220	198	167
NF Pile	210	200	170

* With Factor of Safety of 2.0

3.2 Residual Skin Friction on NF Pile

Figure 4 presents the driving records and the axial load distribution results as measured from the strain gauges for the two test piles. It is interesting to note that despite the presence of asphalt coating on the NF pile, the driving resistance, as shown by the number of blows required, of the coated pile was practically the same as that of the uncoated plain pile. The axial load distribution along the pile shaft was, however, quite different. The presence of the asphalt coating on the NF pile has significantly reduced the amount of skin friction as shown in Fig. 5, which compares the distribution of skin friction along the two pile shafts under the maximum test load as well as the working load conditions. This figure clearly demonstrates the effectiveness of NF pile in reduction of skin friction.

Table 3 presents a comparison of the measured and theoretical average values of residual skin friction along the NF pile on the coated and uncoated portions of the pile. The theoretical values were calculated by using (i) formula proposed by Claessen and Horvat (Ref. 10) based on visco-elastic theory, and (ii) an empirical method proposed by Baligh et al (Ref. 9). Since the NF pile was not entirely coated, the average value of the skin friction was adjusted by considering the contribution of skin friction due to the uncoated length. The results shown in the Table indicate that the theoretical values calculated on the basis of visco-elastic theory are fairly close to the values interpreted from the test results when the applied load on the test pile is above the allowable bearing capacity. For loadings in the working load range, the observed skin friction values varied from about 40 percent to over 150 percent higher than the theoretically calculated values.

Table 3: Measured and Theoretical Average Residual Skin Friction Along NF Pile

Cycle	I Averaged Observed Skin Friction	II Average Calculated skin friction by Visco-Elastic Theory t/m^2	III Average Calculated skin friction by Baligh et al Empirical Method t/m^2	$\frac{I}{II}$	$\frac{I}{III}$
1	0.76	0.27	0.13	2.81	5.85
2	1.11	0.82	0.26	1.35	4.27
3	1.54	1.59	0.36	0.97	4.28
4	2.13	2.03	0.44	1.05	4.84
6	2.06	1.93	0.51	1.07	4.04

3.3 Prediction of Long-Term Residual Negative Skin Friction on NF Pile

From the test results presented in Section 3,2, it can be concluded that the skin friction along a steel pile can be significantly reduced by asphalt coating. The residual skin friction o; an NF pile under load can be reasonably estimated by using visco-elastic theory. For practical application, however, due to the fact that the rate of ground subsidence is generally very slow, estimation of the values of the residual negative skin friction must be adjusted by taking into consideration of the rate of settlement which is expected to occur at the particular project site.

For the site conditions at the Marina Centre, if a factor of safety of 2 is applied, the residual negative skin friction on NF pile estimated on the basis of visco-elastic theory is approximately equal to 0.45 t/m^2 for a ground subsidence rate as high as 30 cm/year. The total value of the negative skin friction of the test NF pile is therefore equal to 24.2 t. For the uncoated plain pile, the total value of the negative skin friction is estimated to be approximately equal to 241.1 t. It appears that the NF pile is quite effective in reducing the potential negative skin friction along piles due to ground subsidence.

4. CONCLUSIONS

Full scale field tests and theoretical studies have demonstrated that negative skin friction on piles due to ground subsidence can be significantly reduced if NF piles were used. For long term settlement, if the settlement rate is less than 30 cm/year, the reduction of negative skin friction of NF pile as compared to uncoated plain pile can be as high as 90 percent for a site subsoil condition similar to the Marina Centre in Singapore. Only a small value of redisual negative skin friction needs to be considered in the design of pile foundation if NF piles are used.

The magnitude of residual negative skin friction acting on NF piles can be predicted by using visco-elastic theory with acceptable accuracy as demonstrated by the test results.

5. ACKNOWLEDGEMENTS

The full scale pile loading test program described in this paper was carried out by Moh and Associates (S) Pte Ltd under the sponsorship of Messrs. Okura & Co., Ltd and Nippon Kokan Kabushiki Kaisha.

The authors gratefully acknowledge assistance rendered by the staff of the two sponsors. Acknowledgements are due to the Marina Centre Development Pte Ltd for permission to carry out the field tests on their site. Thanks are due to Messrs. Kong Sio-Keong and Ngo Chi-Phuong, Geotechnical Engineers of Moh and Associates, who have supervised the work and assisted in the analysis.

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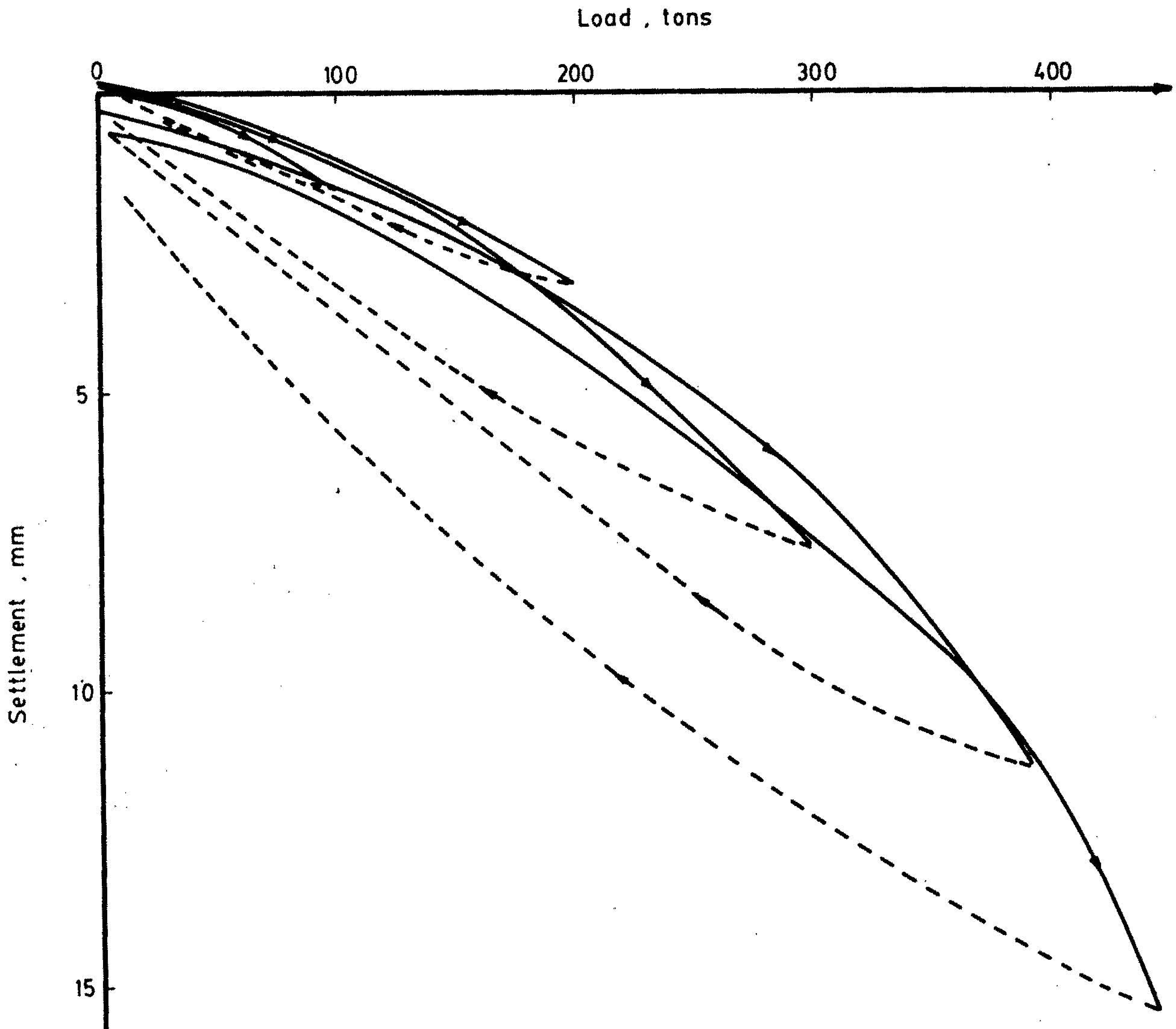

Fig. 1 Load-Settlement Curve of Loading Test on Plain Pile

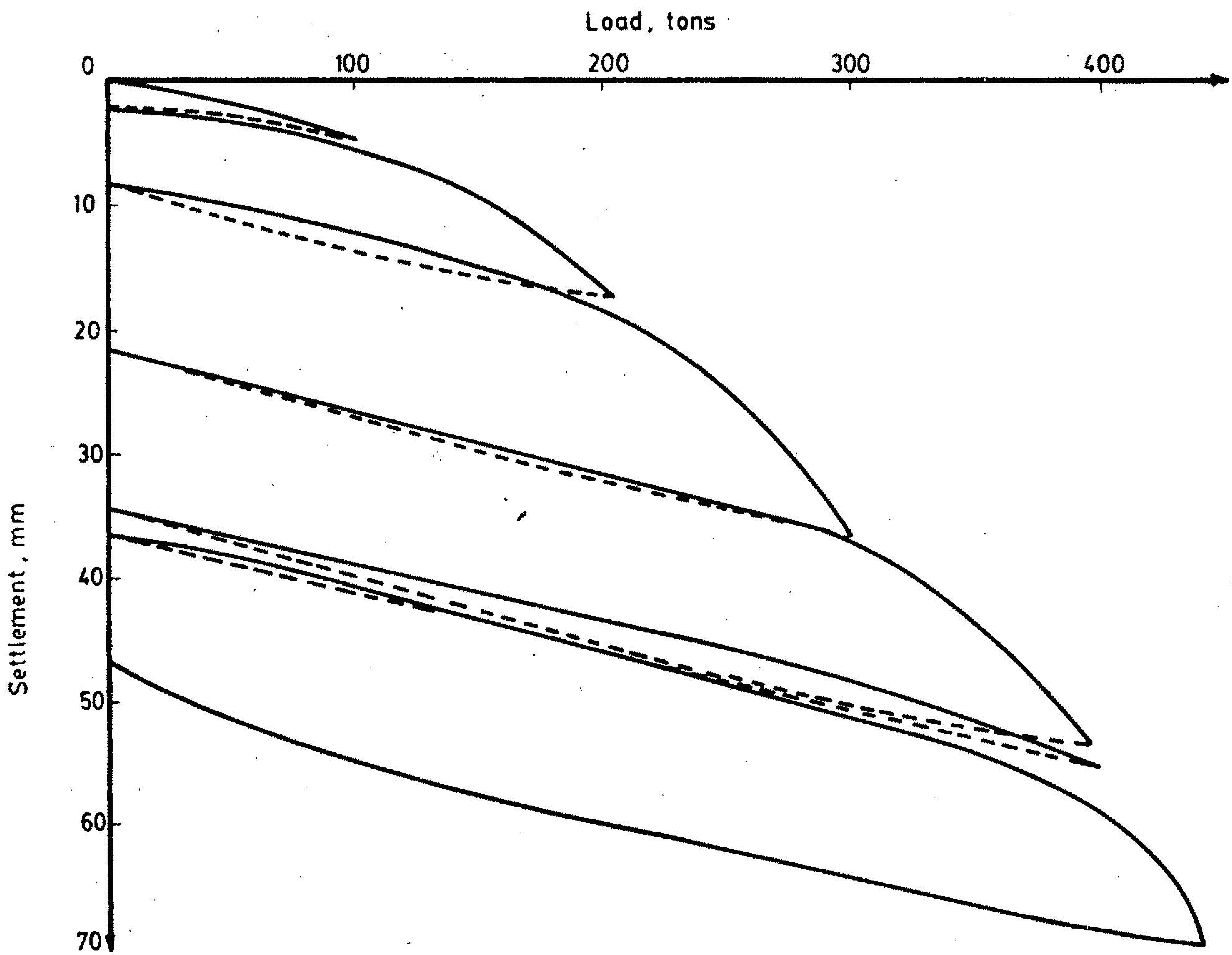

Fig. 2 Load-Settlement Curve of Loading Test on NF Pile

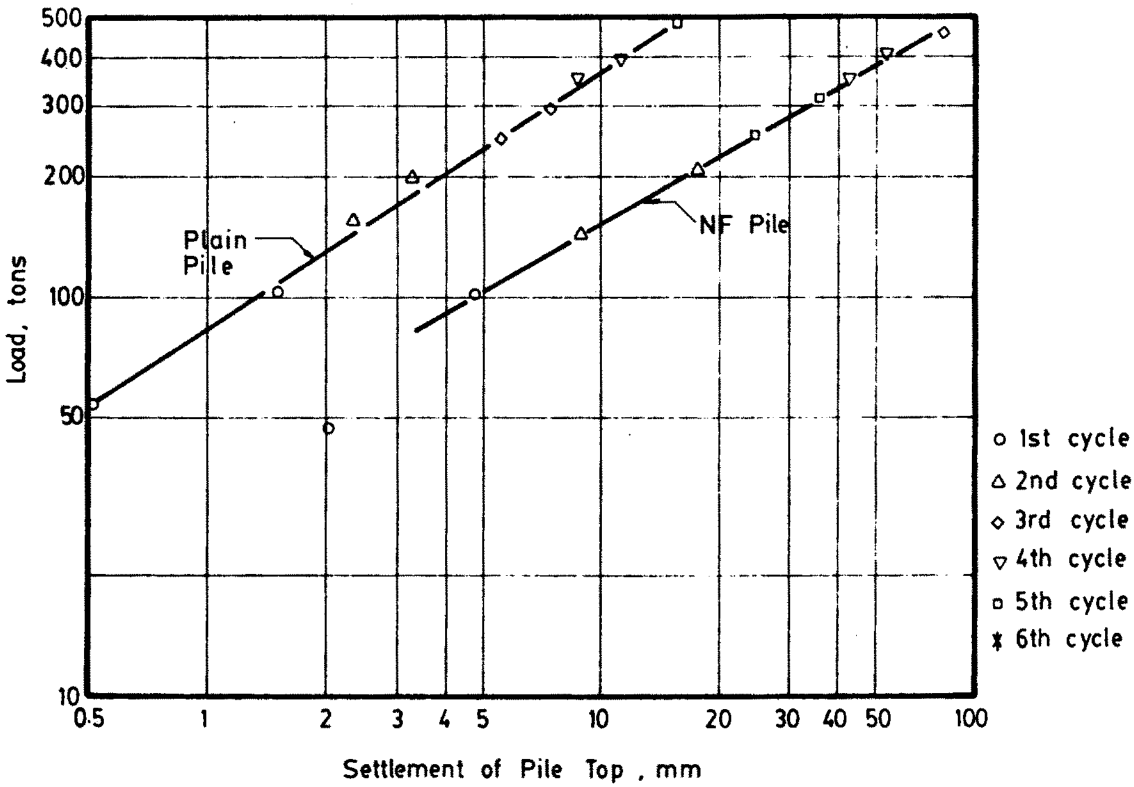

Fig. 3 Relationship of Load and Settlement in Log Scale

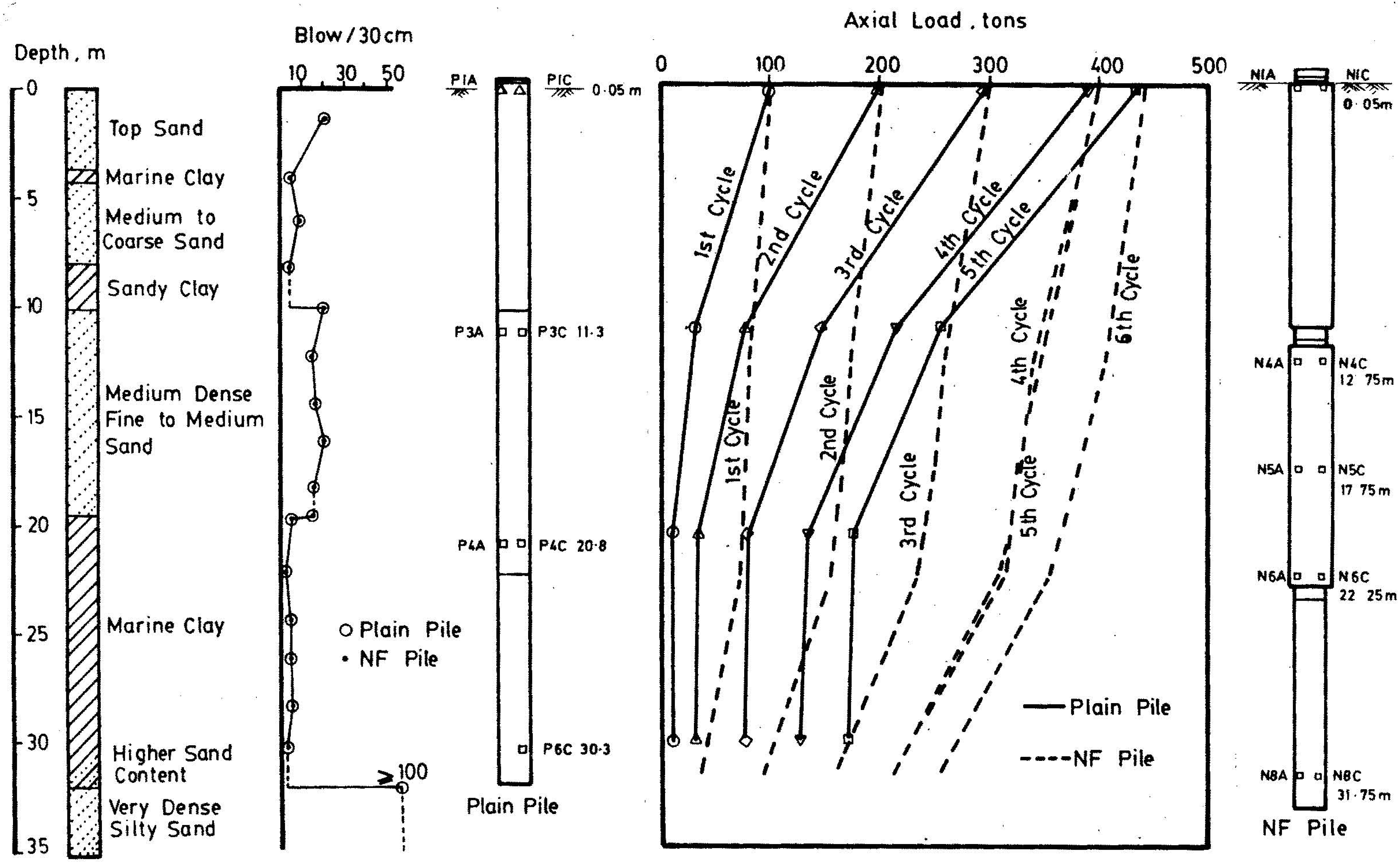

Fig. 4 Distribution of Axial Load Along Piles During Load Test

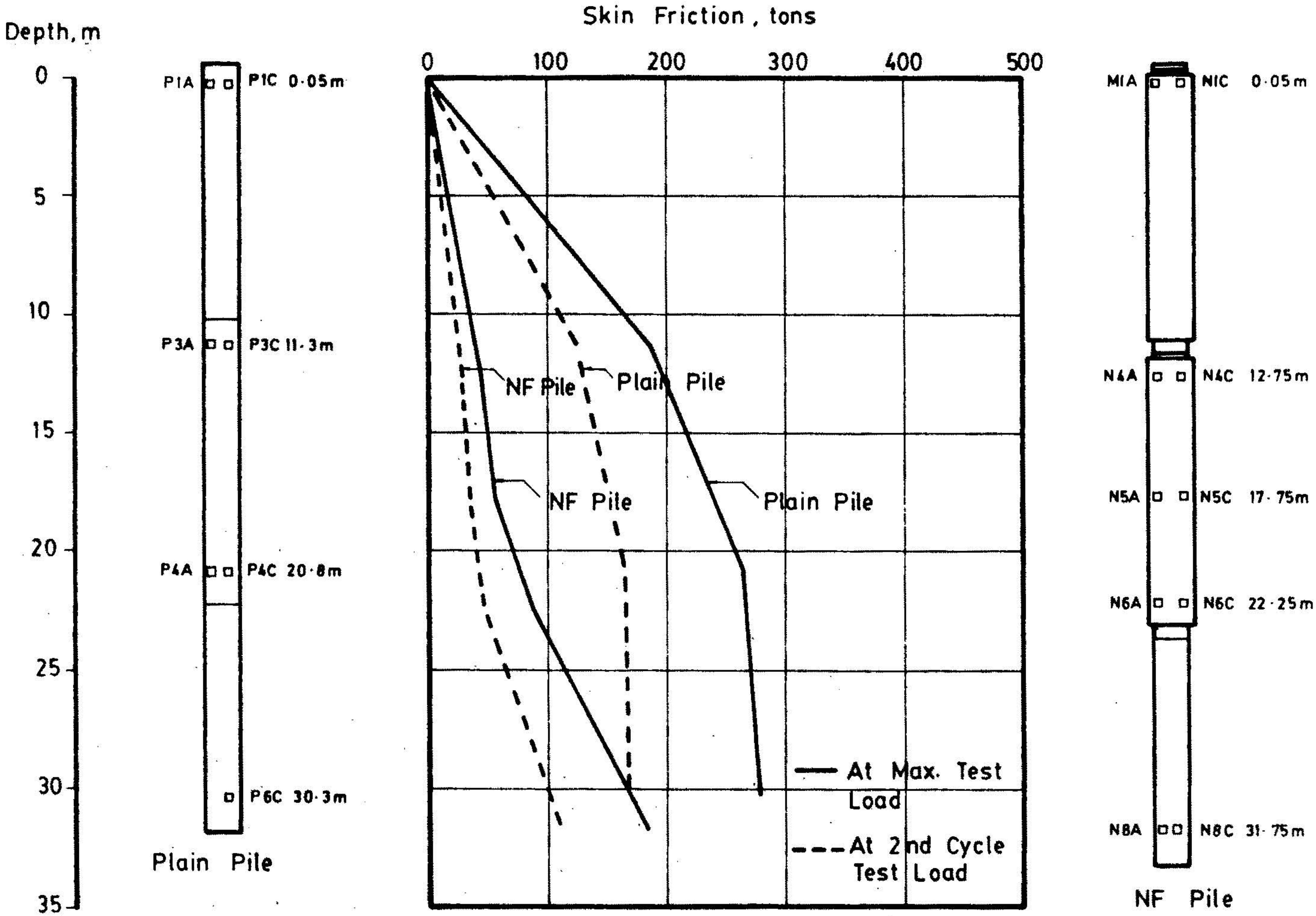

Fig. 5 Comparison of Skin Friction Distribution Along Uncoated Plain Pile and NF Pile

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