Proceedings of 12th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2022 Month: October Volume: 12

Routine Pile Load Test: A Case Study of Bagdwar Khola Bridge

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Abstract
The use of bored cast in situ piles for supporting bridge foundations is becoming popular among the designers in Nepal. Whereas, proper judgement and experience is very important in declaring the ultimate capacity of bored piles as the calculations are based on the empirical formulas which were generated elsewhere. Hence, appropriate load tests must be carried out to verify and substantiate the designed capacity of Pile. Large scale static pile load test on bored piles of bridges are rarely conducted in Nepal as it is costly, time consuming and requires high capacity loading arrangements and reaction mechanisms. Hence, Routine pile load tests are carried out to verify the load bearing capacity of working piles at service loads. Routine pile load tests for bored piles were carried out for one test pile in each foundation of Bagdwar Khola Bridge and settlements were noted using dial gauges. The Ultimate pile capacity was extrapolated using Chin, Davission & latest technique suggested by Giovanni Dalerci and Rossella Bovolenta. The proposed technique was also applied to estimate ultimate loads of two of the piles on which Initial Pile Load Test were performed and the result found are in good agreement with the method proposed by Hirany and Kulhawy. The Load-Setlement Curve from the Routine Pile Load Test is extrapolated upto the ultimate capacity and the shaft, base and total load curves are also generated. The method proposed can be used to estimate the ultimate capacity of bored piles provided the pile displacement is at least 0.5% the pile diameter and there are at least five loading steps.

Keywords
Bored Pile, Routine Pile Load Test, Extrapolation, Load-Settlement Curves

1. Introduction

It has become normal, and in many cases necessary, to carry out a set number of full-scale pile load tests at the site of more significant projects due to the numerous uncertainties inherent in the analysis of pile foundations. These tests' main goal is to experimentally confirm that the pile's actual response to load, as shown by its load displacement relationships, corresponds to the designer's assumed response and that the pile's actual ultimate load is equal to or greater than the computed ultimate load used as the basis for foundation design. Such conventional tests include the axial compressive, axial tensile and the lateral load tests.

There are two types of static load test on pile which are Initial Test and Routine Test [1]. Initial Test which is done in case of important and/or major projects helps to verify the ultimate capacities of piles and the number of tests is relatively small whereas Routine Test which is conducted in at least one test pile in each foundation helps to verify the safe load capacity of pile.

Bridges are considered to be the important projects, whereas in Nepal Initial Pile Load testing of the Cast in-situ bored piles are rarely or not even conducted to verify the designed ultimate loads. Generally Indian Codes (IRC Codes) are used in the design of bored pile in Nepal. Initial load test is to be conducted which is a part of design process for conforming the expected properties of bearing strata and the pile capacity [2]. But the pile designs are not properly substantiated by Initial load tests. With this the actual ultimate capacity of the pile remains unknown. Only routine tests on axial load capacity of piles are performed in the construction stage to determine whether the pile is sufficient or not in taking the service loads.

Executing full-scale load tests that accurately depict the actual pile behavior, which is typically represented in terms of a load-deformation relationship, is the most accurate method for evaluating the pile capacity. The drawbacks of this direct procedure, however, include the considerable time and expense involved in carrying out such experiments. Additionally, doing pile load testing during the project development phase would not be practical. They are often conducted during the construction phase on production piles which cannot be loaded to failure [3]. The approach is frequently substituted for applying a load that is 1.5–2 times the design load because full scale load test is costly and time-consuming. In reality only proof load tests are performed and ultimate capacity and the actual factor of safety remains unknown. This process leads to an uneconomical foundation solution, unclear capacity when alterations are needed, and an engineer's inability to understand the governing mechanism for better design.

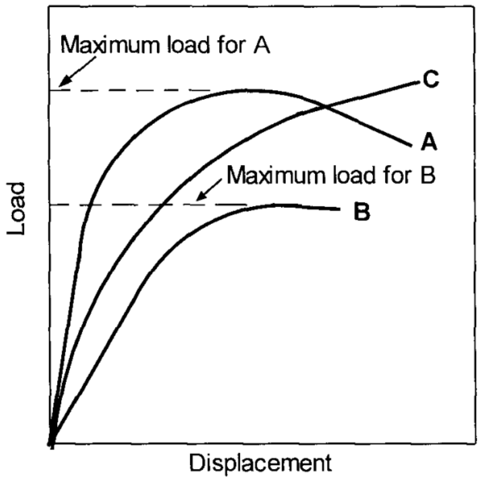

Figure 1: Typical Load-Displacement Curves for Drilled Foundations (Hirany A. and Kulhawy F. H.)

2. Interpretation of Ultimate Load

The load that causes a pile to plunge or quickly settle under a sustained load is known as the ultimate failure load. However, plunging can necessitate substantial settlement that go beyond the permissible limit. The load-displacement curves produced by axial compression and uplift tests on deep foundations can result any one of the three patterns seen in Figure 1. The peak of A and the asymptote of B clearly identify the pile's maximum capacity. However, the maximum pile capacity is not precisely determined if the load-displacement curve resembles C. Curve C best describes the load-displacement curves for drilled foundations [4].

Various literatures are available for estimating the ultimate capacity of pile from non-failed load tests which are based on a) mathematical modeling; b) pile settlement limitation and c) graphical construction.

Mathematical modeling consists of various methods such as Van der Veen and Chin methods [3]. Pile settlement limitation consists of methods such as Tomlinson, Vesic , Hansen's 90% Criteria, Fuller Hoy and De Beer [3]. Similarly Graphical construction consists of methods such as Davisson and modified later by O'Rourke and Kulhawy and the L1-L2 method developed by Hirany and Kulhawy [3]. All these methods of ultimate load representation have their own way of interpretation. Some methods are used for the interpretation of failure load using available load-settlement curve from full scale load tests while other are used in the extrapolation of the load-settlement curves using available load-settlement curve of non-failed tests.

Hirany and Kulhawy [5] developed the L1-L2 method for the interpretation of ultimate loads for drilled shafts. They revealed that the ultimate load (QL2) lies on an average pile displacement of 4% the diameter of pile in compression. They found this interpretation criteria may be appropriate across the full range of drilled foundations. They also concluded that QL2/QD = 1.15 to 1.20 can be useful in the interpretation of load tests conducted only to limited displacements.

From the evaluation of the ultimate load carrying capacity of large scale bored piles statically loaded to failure measured directly and obtained from selected methods of load test data interpretation based on different failure criteria revealed that the shaft friction component was fully mobilized at displacements of 0.2 to 0.6% of pile diameter and the ultimate load was fully mobilized at displacements of 1.34 to 2.7% of pile diameter [3]. The performance evaluation of the interpretation methods on the basis on statistical and cumulative probability criteria indicated the approaches of Hirany and Kulhawy L1-L2 and Fuller and Hoy produced the best overall results and produced very close agreement between interpreted and measured pile capacities. The analysis also revealed that the Chin's method produced the worst performance assessment of all because it grossly overestimated the ultimate pile capacity [3].

Using load tests that are not carried out to failure, Giovanni Dalerci and Rossella Bovolenta [6] suggested a new technique for determining the ultimate load of piles. Using this technique, the total, shaft, and base load-settlement curves can be assessed and complete analysis of pile behavior can be done.

3. Routine Pile Load Test

In current research an attempt has been made in extrapolating the load-settlement curve from routine pile load test conducted for working piles of Bagdwar Khola Bridge. For extrapolating, Chin's Method, Davisson's Method, Hirany and Kulhawy L1-L2 method and the recent technique proposed by Giovanni Dalerci and Rossella Bovolenta are used and Shaft load-settlement curve, Base load-settlement curve and Total load-settlement curve are generated.

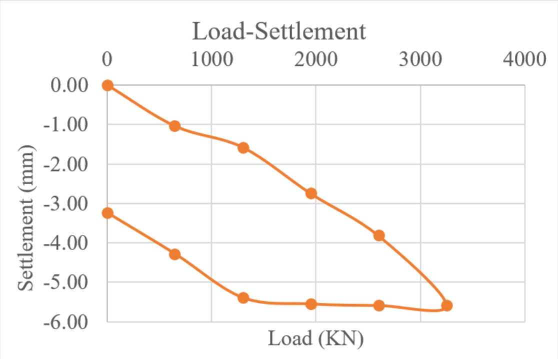

Figure 2: Load-Settlement plot of Left Abutment Pile.

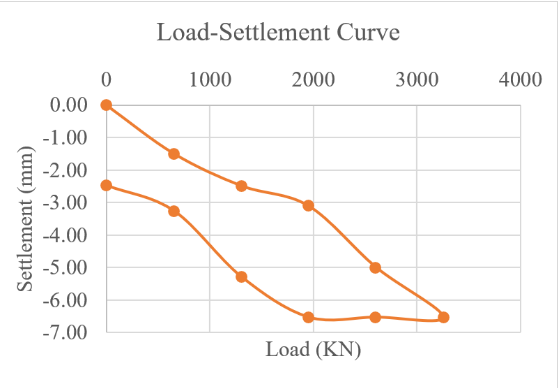

Figure 3: Load-Settlement plot of Right Abutment

Bagdwar Khola Bridge is the one located in Chulachuli area of Ilam District just below the foothills of chure region, Nepal. The stratigraphy of the bridge location consists of poorly graded sandy soil. The Bridge foundation consists of bored cast in situ pile with 1200mm diameter, 20m length and grade of concrete M35. The designed allowable pile capacity was 2160 KN. Routine pile load test were conducted for left and right abutment piles for maximum load upto 1.5 times the allowable load (3250 KN). The load-settlement curve for both the piles are as shown in Figure 2 and Figure 3.

4. Extrapolation of Load-Settlement Curve

Only the loading curve from the test is considered for the extrapolation. The loading curves are at first smoothened using best fitting curves and the settlement values obtained after smoothening the curve are used for further calculations. The curves thus obtained are shown in Figure 4 and Figure 5. Using new obtained settlement values Chin's Plot were constructed for both the piles and the Ultimate load as extrapolated from Chin's Plot was found to be 10000 KN and 20000 KN respectively for left and right abutment pile. Chin's Plot are as shown in Figure 6 and Figure 7.

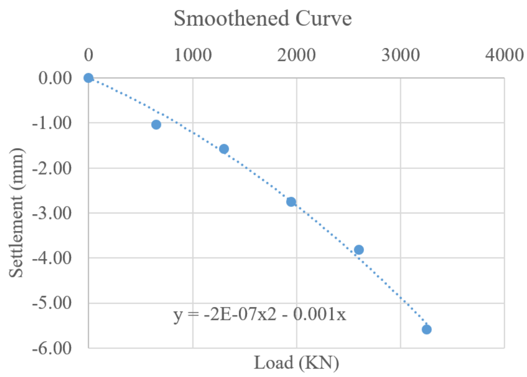

Figure 4: Load-settlement curve after smoothening (Left Abutment Pile)

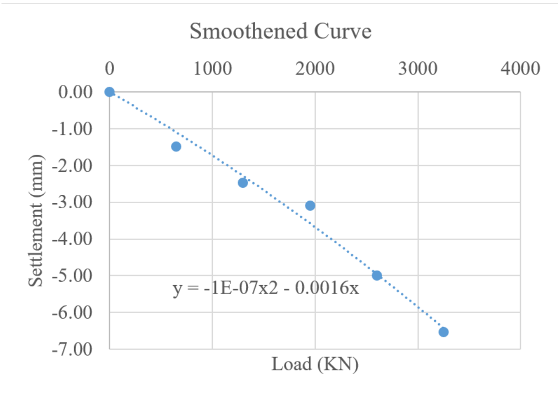

Figure 5: Load-settlement curve after smoothening (Right Abutment Pile)

Using the ultimate load as determined from Chin's Method, the Total load curves were generated using the new techniques as suggested by Giovanni Dalerci, Rossella Bovolenta [6]. Various trials were performed to adjust the required parameters in the proposed method so as to match the settlement values with previously smoothened curves. As the literatures suggest that the ultimate load from Chin's method is generally overestimated, thus obtained Load-Settlement plot is then used to estimate ultimate load using Davisson's Method as suggested by Hirany and Kulhawy [5]. The ratio of QL2 and QD is taken as 1.2. From Davisson's interpretations QD is determined as 6500 KN and 7000 KN respectively and using 1.2 factor results QL2 as 7800 KN and 8400 KN respectively for left and right abutment as ultimate load interpreted by L1-L2 method [4] as shown in Figure 8 and Figure 9 .

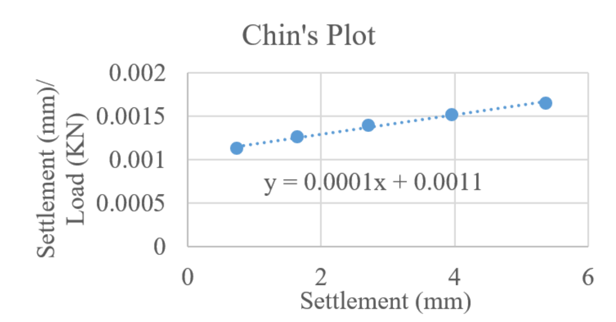

Figure 6: Chin's Plot for Left Abutment Pile

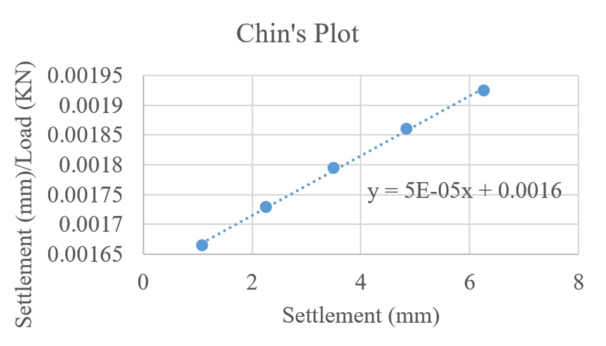

Figure 7: Chin's Plot for Right Abutment Pile

Figure 8: Davisson's Plot for Left Abutment Pile

Figure 9: Davisson's Plot for Right Abutment Pile

The detailed methodology for Extrapolation of Ultimate Load from Routine Pile Load Test are described stepwise as follows:

- The load-settlement plot obtained in field is smoothened if necessary from which refined settlement values are obtained.
- Using the original/refined settlement Chin's Plot (s Vs s/Q) is prepared. A straight line in the form y=mx+c is obtained. The inverse of the slope of the line is Chin's ultimate load.
- Using Chin's ultimate load the load-settlement plot using the technique suggested by Giovanni Dalerci & Rossella Bovolenta is prepared.
  - Since the load-settlement datas are limited, some trial and error are needed to find ultimate shaft load first adjusting values of β, ψ, δ and s_{avcr}. δ is generally taken as 0.95. Trials have been performed using solver in microsoft excel program.
  - Since the settlement data are limited (skin friction is not fully mobilized), the settlement values obtained are used as input in the load-settlement data to determine ultimate shaft load and check whether the shaft load-settlement plot is smooth or not. This can be clear from Figure 10 & Figure 11. The kinks in the shaft load-settlement plot indicate further trials needed.
- After knowing value of ultimate shaft load Q_{su}, ultimate base load Q_{bu} is taken as Q_{bu} =Q-Q_{su}.
- The load settlement plot is refined matching the initially refined settlement values. In doing so,

parameters such as β, ψ, and s_{avcr} and even Q_{su} may change in small range.

- After generating load-settlement plot since literatures have suggested that the Chin's method generally overestimates the ultimate load, Davisson's method is applied in the generated plot to determine Davisson's ultimate load Q_D.
- This Davisson's ultimate load is multiplied by a factor of 1.2 to obtain the actual ultimate load as suggested by Hirany & Kulhway.
- Thus obtained ultimate load is used to plot the final load-settlement curve. Using the obtained ultimate load, previous techniques (steps 3 to 4) are applied to generate new load-settlement plot. For the first trial already calculated values of β, ψ, and s_{avcr} may be used.
- The load settlement plot is again refined matching the initially refined settlement values. In doing so, parameters such as β, ψ, and s_{avcr} and even Q_{su} may change in small range.
- Finally, the load-settlement plots for the Total Load, Shaft Load & Base Load are generated. (Please refer [6] for notations)

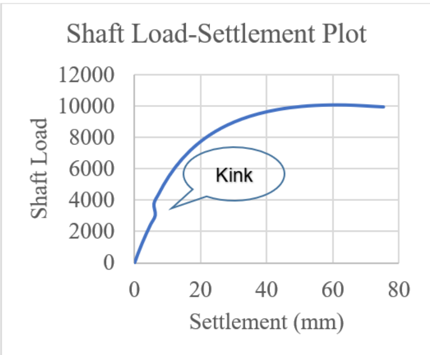

Figure 10: Shaft Load-Original refined settlement curve during trial

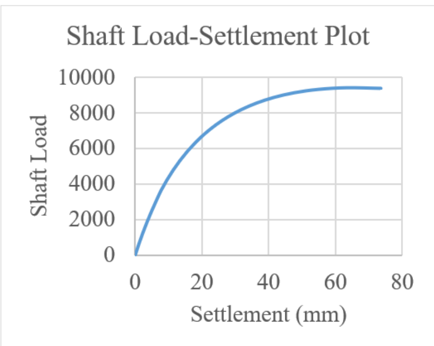

Figure 11: Shaft Load-Initial refined settlement curve after trials

5. Load-Settlement Curve Generation

After evaluation of ultimate loads from above method, the ultimate shaft load and ultimate base load for pile can be ascertained and the Shaft, Base and Total Load curves can be generated as described above using new technique suggested by Giovanni Dalerci, Rossella Bovolenta [6]. The generated curves are shown in Figure 10 and Figure 11. From the plotted curves it can be noted that both the piles are working as both friction and end bearing. The ultimate shaft loads are 4120 KN and 4420 KN for left abutment and right abutment pile respectively. Similarly, the ultimate base loads are 2840KN and 4340 KN for left abutment and right abutment pile respectively. The load shared by shaft and base is found to be 59% and 41% for left abutment pile and 50% and 50% for right abutment pile.

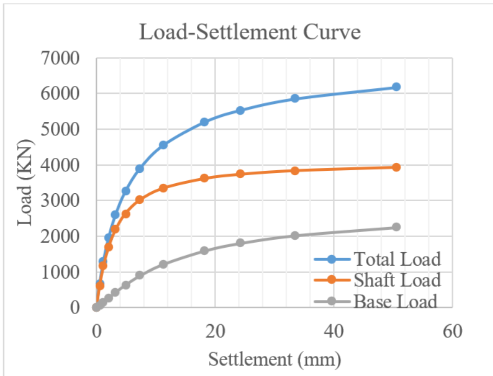

Figure 12: Load-Settlement Curve for left Abutment Pile

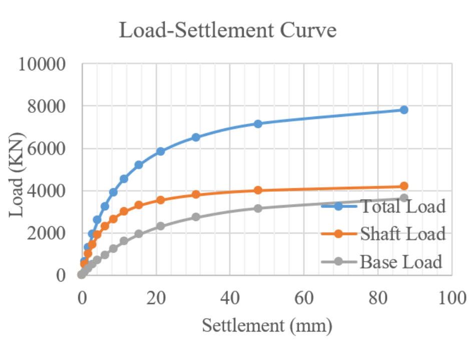

Figure 13: Load-Settlement Curve for Right Abutment Pile

6. Comparison with Initial Pile Load Test

To determine whether the proposed method predict the ultimate loads good enough or not, it has been compared with the initial pile load test results of two bridges Dudhela and Khando Bridge along Kamala-Kanchanpur section of Mahendra Highway. The piles were of 1000 mm diameter and 20 m in length and they were loaded to 200% of their allowable loads (1606.2 KN & 1357.4 KN. Respectively for Dudhela & Khando). The load-settlement plots are shown in Figure 14 & Figure 15.

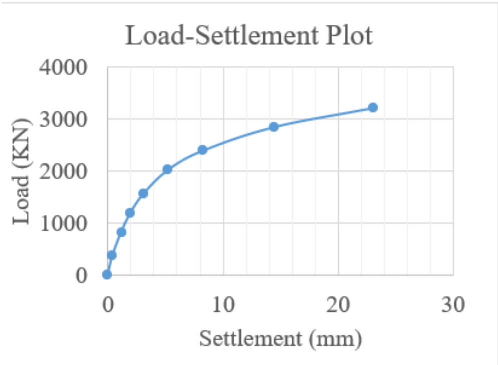

Figure 14: Load -Settlement Plot of Dudhela Khola Bridge

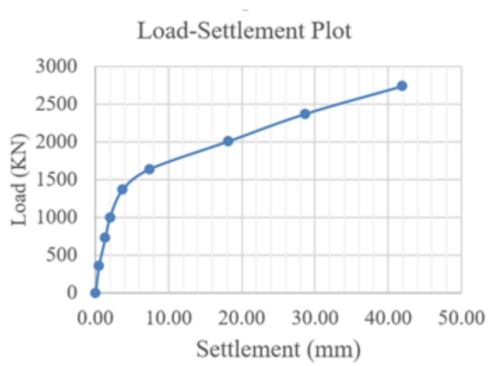

Figure 15: Load-Settlement plot of Khando Khola Bridge

The limited data (upto 0.4% displacement) were taken from the initial pile load test data and the ultimate load was extrapolated using the proposed method which were found to be 3240 KN for Dudhela Khola Bridge & 2520 KN for Khando Khola Bridge. Again Hirany & Kulhway L1-L2 method (Ultimate load occur at 4% of pile diameter displacement) was applied to both the plots and the ultimate loads were found to be 3500 KN for Dudhela & 2700 KN for Khando Khola Bridge. The estimated ultimate load from the proposed method were only 7.14% and 6.67% less than the ultimate load interpreted by Hirany & Kulhway respectively for Dudhela & Khando Khola Bridge. The load-settlement plot generated by the proposed method and that obtained in field are shown in Figure 16 & Figure 17.

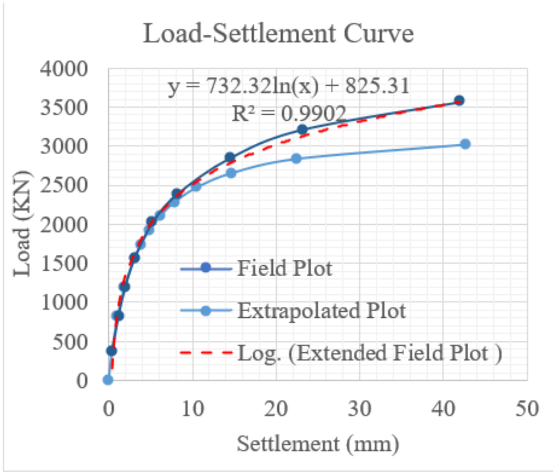

Figure 16: Field & Extrapolated Load-Settlement Plot of Dudhela Khola Bridge

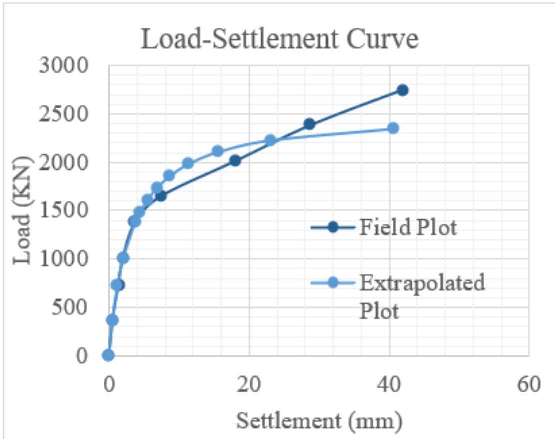

Figure 17: Field & Extrapolated Load-Settlement Plot of Khando Khola Bridge

7. Conclusion

The routine pile load test was performed on either abutment foundations of Bagdwar Khola Bridge with predominantly sandy soil. The ultimate loads were estimated and load-settlement curves were extrapolated to obtain Shaft load, Base load and Total Load curves and following conclusions were made.

- From the comparison with two initial pile load test results it was found that this method can be used to estimate ultimate load from routine pile load test provided the pile displacement is at least 0.5% of pile diameter and there are at least five loading steps.
- The projected load-settlement curve can be used in the analysis of pile behaviors using

numerical modeling. There is also additional benefit that the Young's Modulus of Elasticity for the soil is revealed which can be used in numerical modeling for further studies.

- In this research only attempt has been made to estimate ultimate capacity of bored piles using Routine Pile load tests. Since Pile is loaded only up to 1.5 times the designed allowable load, load-settlement data available are limited, it can be used for preliminary analysis of bored piles. Complete behavior of bored piles could be ascertained from full scale pile load tests with instrumentation.

8. Acknowledgement

The authors are thankful to Er. Ratna Laxmi Bajracharya (Department of Roads, Project Directorate (ADB)) for providing pile load test reports of the bridges. The authors are also thankful to Er. Rajan K.C. for support in typesetting the manuscript.

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