Prediction of Axial Load Capacity Based on Texas Cone Penetration Test Data

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ABSTRACT: Texas Cone Penetration (TCP) Test is a dynamic penetration test developed by the Texas Department of Transportation (TxDOT) for the purpose of geotechnical site characterization. The TCP test apparatus consists of a 75mm (3in) diameter hardened steel cone attached to a 45mm (1.75in) O.D. drilling rod. The cone is driven into soil or rock by dropping a 77 kg (170lb) hammer. The number of blows required to penetrate 300mm (12in) is recorded as the TCP blowcount. The TCP profile established by conducting the test at approximately 1.5m (5ft) depth intervals is used by TxDOT engineers when designing driven pile and drilled shaft foundations. This paper describes the development of the TCP test method and presents findings from a research study that compares the axial load capacities predicted by the TCP test method for 29 drilled shaft foundations and 33 driven pile foundations with those obtained from full-scale load tests.

1 INTRODUCTION

The Texas Cone Penetration TCP test method was developed by the Texas Department of Transportation's (TxDOT's) bridge foundations design group in the 1940s as an in-situ test method for evaluating the broad range of geologic materials encountered in foundation construction (TxDOT, 2000). This test method was introduced as a means of evaluating shear strength of soil and rock material in an efficient and a cost effective manner. After further refinement, the test method was introduced into the Department's foundation design practice in 1949 and TCP test data began to appear in construction plans around 1954. The TCP test method consists of recording the number of blows of a 77kg (170lb) hammer dropping 600mm (24in) to force a 75mm (3in) diameter steel cone into a soil or rock formation. The hardened steel cone (also referred to as the conical driving point) is shown in Fig. 1. The TCP test standard (Tex-132-E, 1999) requires penetration to be achieved in three separate increments. The purpose of the first increment is to achieve proper seating. This consists of driving the cone using 12 blows or approximately 150mm (6-in) of penetration, whichever comes first. The TCP blow count (N_{TCP}) is then determined as the sum of the number of blows required to achieve second and third 150mm (6-in) increments. The total blow count corresponding to 300mm (1.0-ft) of penetration is used for design. In hard materials such as rock, the cone is driven using 100 blows and depths of penetration for the first and second 50 blows are recorded.

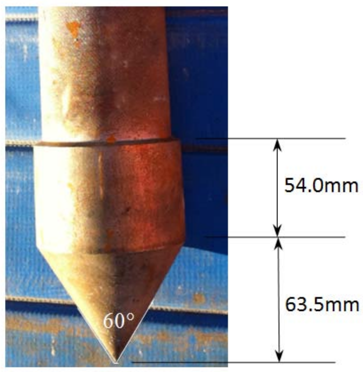

Fig. 1 Conical Driving Point Used in TCP Test

This paper describes the TxDOT deep foundation design procedure based on the data collected from the TCP test. It also describes a research study that evaluated the relibility of the above design method by comparing axial load capacities measured in the field by full scale loads with those predicted by the TCP method. The study examined 29 drilled shaft foundations and 33 driven pile foundations.

2 DEEP FOUNDATION DESIGN USING TCP

It is widely acknowledged that the load carrying capacity of a deep foundation would be governed by the shear strength of the soil or other geologic material supporting the foundation. Accordingly, the TCP based design method relies on correlations between soil shear strength and TCP data to estimate axial load capacity of the foundation. These correlations are presented in the form of two separate design charts. These charts were originally introduced in 1956, but were later modified as evident from the TxDOT Geotechnical Manuals published in 1972, 2000 and 2012. The current version of the design charts used in this research study are presented here. The first design chart, shown in Figs. 2(a) and 2(b), is applicable to soils with TCP blowcounts less than 100 per 300mm (1.0ft). Fig. 2(a) can be used to estimate allowable shaft resistance (skin friction) based on measured TCP blowcounts. Similarly, Fig. 2(b) can be used to determine the allowable base resistance (bearing or tip resistance). The charts shown in Fig. 2 is based on an assumed factor of safety (FOS) of 2.0.

The second design chart, shown in Fig. 3 is applicable to hard soils or other geomaterials with TCP blowcounts greater than 100 blows per 3000mm (1.0ft). It should be noted that, in the design charts shown in Fig. 3, the factor of safety associated with prediction of allowable shaft resistance is given as 3.0 and the FOS for base resistance is given as 2.0+. When using TCP design charts for deep foundation design, the ultimate shaft resistance of driven piles is assumed to be the same as the ultimate shear strength of the surrounding soil material. However, for drilled shafts, the ultimate shaft resistance is considered to be 0.7 times soil shear strength. The reduction factor of 0.7 is used to account for soil disturbance that occurs during drilled shaft installation.

The TCP design charts described above were developed primarily through correlations between TCP blowcounts and laboratory-measured soil shear strengths. There is very limited research that compared actual shaft and base resistance values as measured through instrumented load tests with those estimated using the TCP method. One of the primary objectives of this research was to accomplish that objective.

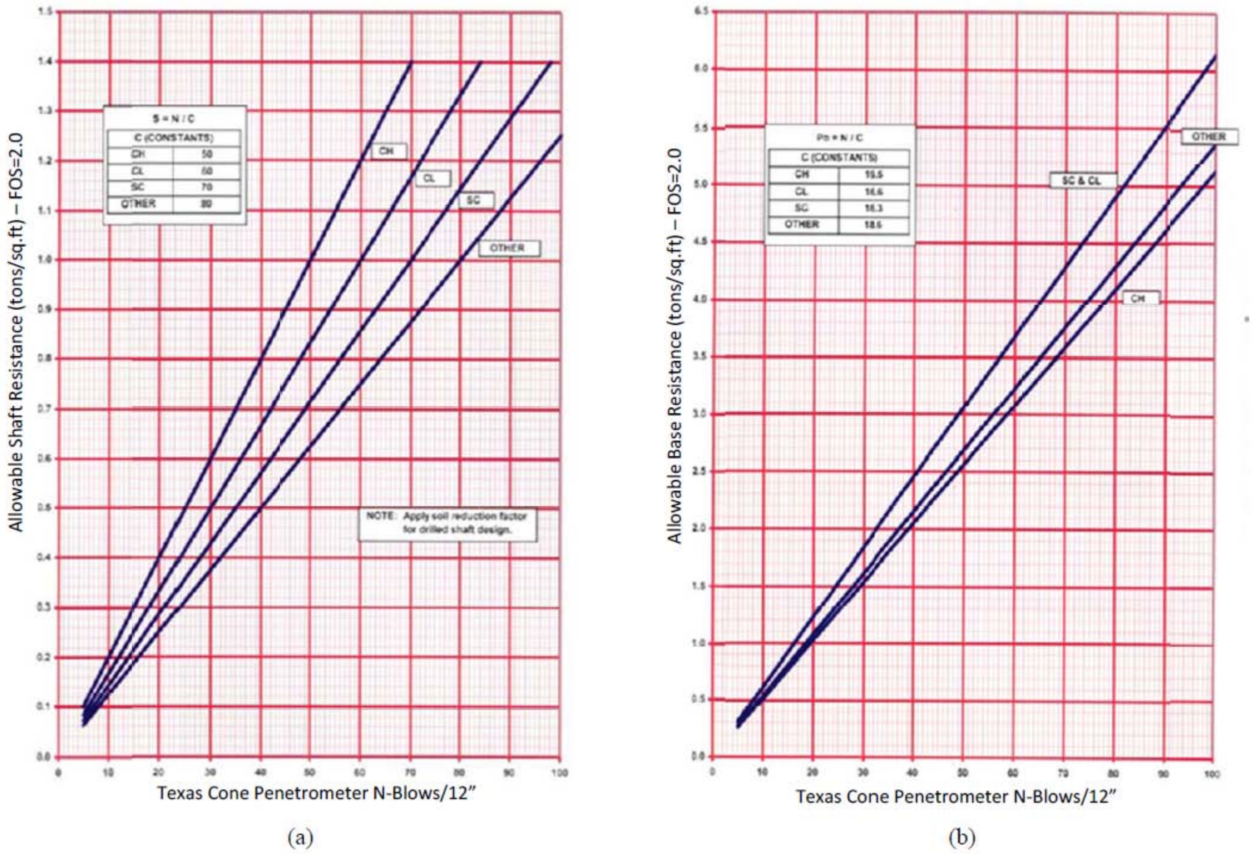

Fig. 2 TCP Design Charts for Soils with Blowcounts <100blows/300mm (1ft) (TxDOT, 2012)

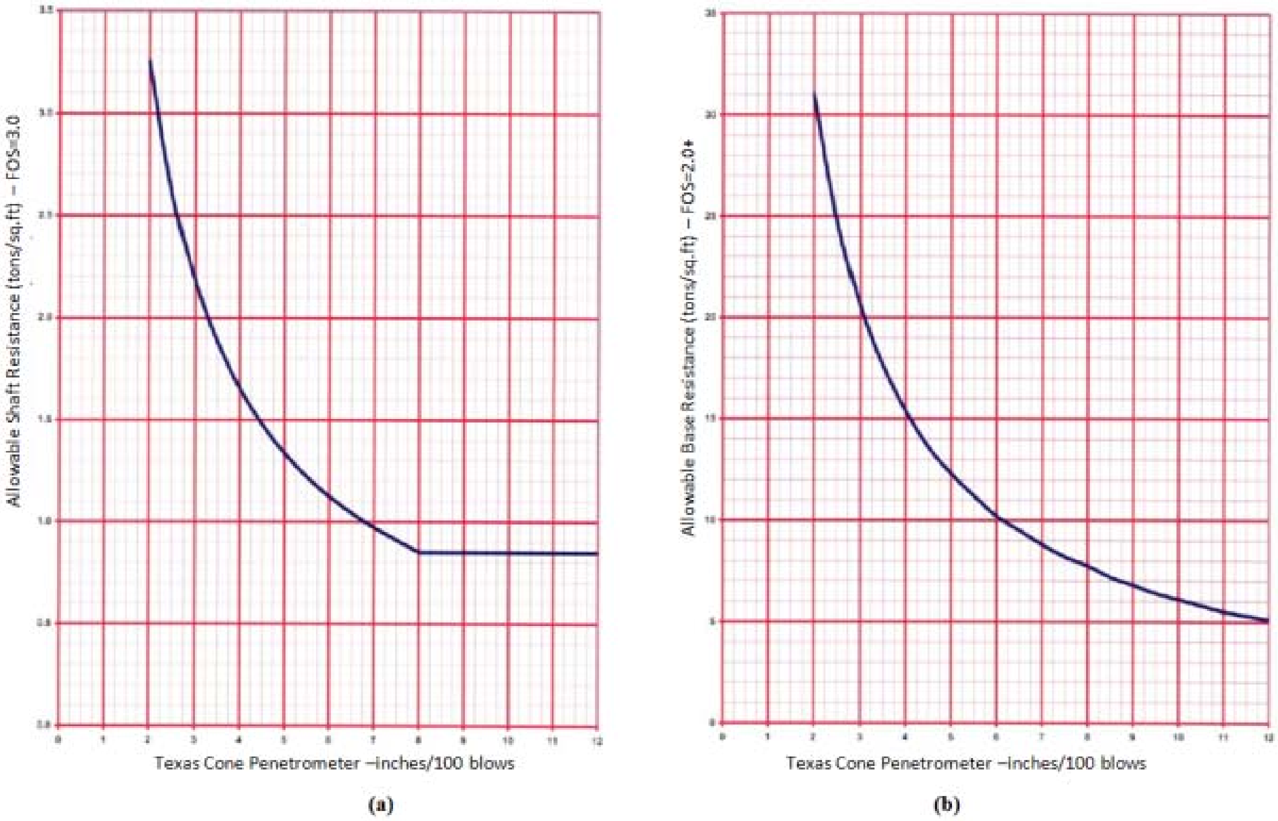

Fig. 3 TCP Design Charts for Soils with Blowcounts >100blows/300mm (1ft) (TxDOT, 2012)

3 EVALUATION OF THE TCP DESIGN METHOD

As mentioned previously, one focus of this research study was to evaluate the performance of the TCP foundation design method. In this research, performance of the TCP design method was evaluated by comapring the actual measured capacity as determined by full scale load tests with the foundation capacities predicted by the TCP Method.

3.1 Load test dataset

The load test data needed for this research were obtained from two separate sources. First, TxDOT possesses an archive of load tests which spans over several decades during which the TCP design method has been used for deep foundation design. However, TxDOT's database archive alone was determined to be inadequate for the purposes of this research. Therefore, the TxDOT data archive was supplemented with load test data available from Texas' neighboring states. In order to leverage these load test data for this research study, new geotechnical borings were drilled and TCP tests conducted at the above load test sites. The dataset compiled in this manner consisted a total of 33 load tests on driven piles and 41 load tests on drilled shafts. The comparison presented in this paper does not include 12 drilled shafts installed in hard materials, i.e. materials with TCP blowcounts >100blows /300mm (1.0ft).

3.2 Measured Capacity

Ultimate capacity of deep foundations is generally defined based on the load-settlement relationship obtained from a full-scale load test. The most widely used settlement-based criteria are Davisson's criterion (Davisson 1972), 5% relative settlement, and 10% relative settlement. In this research, Davisson's criterion was used to determine the ultimate load capacity for both driven piles and drilled shafts.

3.3 Predicted Capacity

The prediction of the axial load capacity of each test pile and drilled shaft was accomplished using the procedure outlined in the TxDOT Geotechnical manual (TxDOT, 2012). It should be noted that the TCP design charts provide *allowable* shaft and base resistances rather than ultimate values. Therefore, allowable resistances were multiplied by the appropriate factors of safety to obtain ultimate shaft and base resistances. A comparison of measured versus predicted axial load capacities for 62 deep foundations is shown in Fig. 4.

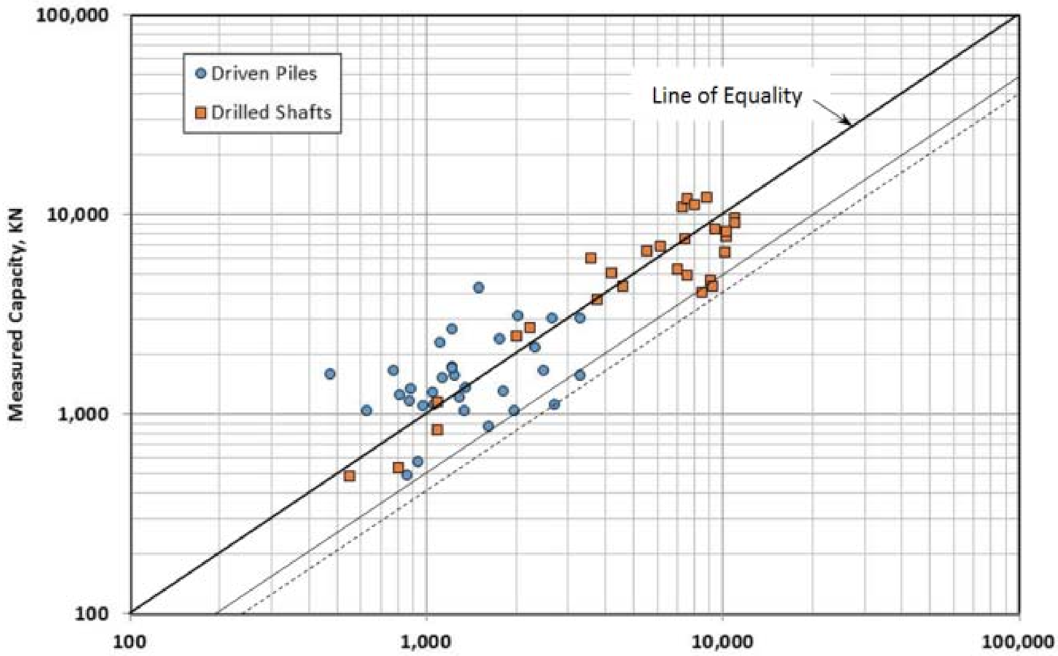

Fig. 4. Measured *vs* Predicted Axial Load Capacity

4 RESULTS AND CONCLUSIONS

Since the data obtained from the drilled shafts installed in hard materials were not included in the above analysis, conclusions presented below will only be applicable to materials with N_{TCP} <100 blows/ft. Data presented in Fig. 4 indicate that the axial load capacities predicted by the TCP method compare favorably with those measured over the complete range of load capacities considered in this study. The coefficient of determination, R^2 corresponding to the correlation between the measured versus predicted capacities is 0.72. Furthermore, it is evident that the data points are evenly distributed above and below the *line of equality*. This observation suggests that the TCP method is equally likely to over-predict the actual load capacity as it is to under-predict it. However, such a conclusion would only be valid for when the measured capacities are determined using the Davisson's criterion. Other widely used criteria, such as 5% and 10% relative settlement generally lead to larger estimates of measured capacities. Therefore, the TCP based predictions would have appeared to be significantly more conservative with respect to measured capacities determined using 5% or 10% relative settlement criteria.

Even though the data provide evidence that the TCP method is capable of predicting load capacities over a broad range of conditions, they also show that significant scatter exists. Some of the observed variability can be attributed to the fact that data used in the study were obtained from archived sources that span several decades. As a result, there was significant uncertainty in load test data as well as site characterization data.

Nevertheless the data can be used to make general assessment of the reliability of the TCP based foundation design method. The fine continuous line shown in the figure represents the relationship between measured load capacities and service loads calculated using a factor of safety (FOS) of 2.0. The vast majority of the data points lie above this line. These data points represent load tests in which the load capacities determined using Davisson's criterion exceeded anticipated service loads. The few data points that fall below this represent load tests that failed to meet the above requirement. On the other hand, all of data points plot above the dotted line which represents service loads calculated using a factor of safety (FOS) of 2.5. Accordingly, it may be inferred that a FOS of about 2.5 will be required with TCP based design method to ensure that actual load capacities determined using Davisson's method will exceed anticipated service loads.

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