FORMULATION OF NUMERICAL TECHNIQUE TO DEVELOP t-z CURVE USING LOAD SETTLEMENT DATA FROM PILE LOAD TEST

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ABSTRACT

Until recently very few successful attempts have been made to analyze the behavior of piles and pile systems. This is partly associated with the historical development of piling in that a strong tradition of empiricism has become part of the folklore of piling. When one attempt to take into account aspects such as the effect of pile installation major difficulties apparently arise, but the fact that a complete solution cannot be derived does not preclude the use of analytical approaches based on simple models of soil behavior.

In this paper a simple numerical technique based on load transfer approach is developed to capture the response of the soil to displacement, as experimental technique of instrumenting the pile along the length of pile would have been very costly. This technique uses the available load settlement data from pile load test not instrumented along pile during load testing and back figures the response of soil along pile length.

Once the load settlement response of soil along pile length is known, the curves can be used for the same site to study the effect of different length and/or diameter of the pile on the load settlement curve of pile. In addition, the load settlement curve for other sites can be generated if the soil profile does not vary remarkably from that soil profile from which the load settlement response of soil is developed. This technique is then applied to load settlement data of three pile load tests conducted in various localities of NWFP.

INTRODUCTION

Dynamic and static formulas are presently being used to determine the load-carrying capacity of a pile. A serious limitation in the use of dynamic and static formulas is that these formulas do not yield load-settlement data. Field pile-loading tests are often used to determine load-carrying capacity. Such tests yield load-settlement data but results apply for one site, one pile length, and the tests are expensive1.

In recent years, the increasing demand on the foundation engineer to predict reliably the behaviour of pile designs has stimulated more sophisticated theoretical research into the interaction between a pile or piles and the embedding soil, so that a large volume of empirical knowledge is now balanced by a comparable theoretical understanding. Load transfer method is one of the approaches to model Pile-soil interaction. In this method the elastic response can be assumed to be that of a series of unconnected springs, that is, a Winkler medium or the sub grade reaction assumption. It has the advantage of computational simplicity and perhaps more-ready adaptation to complications such as change in soil type. On the other hand, it can never take into account the important matter of interaction between adjacent piles1. Lymon C. Reese3 presented analytical method to develop load settlement curve. The deep foundation has been replaced by an elastic spring and the soil by a set of nonlinear springs spaced along the shaft with one spring depicting the soil behaviour beneath the tip.

To generate load settlement curve for a pile soil system using load transfer approach requires the t-z curves (shear strength of soil mobilized vs pile movement relative to the adjacent soil called pile slip) and the axial load settlement response of soil at the base of pile. To capture these responses of soil to generate load settlement curve require considerable instrumentation along the length of pile. This technique is costly and requires sensitive equipment. So far no pile is instrumented during load testing to obtain t-z curve in Pakistan. Therefore, in this

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115
research, a numerical technique is developed to obtain t-z curve. The formulation of this numerical technique is primarily based upon load transfer approach but is used in modified way to obtain t-z curves using load settlement data from pile load tests instead of its conventional use to generate load settlement curve with known t-z curves. This approach is then used on the available pile load test data of the following three localities of NWFP to obtain site-specific t-z curves.

1) Barikab Bridge site, Mardan.
2) Kanair Kass Nullah Bridge site on Basion Krurd Berot Road, Mardan.
3) Kabul Bridge CH. 1394+403, Islamabad-Peshawar Motorway Project (M1).

These t-z curves give an average response of soil along the pile shaft. With these curves available for a site, the load settlement behaviour of pile of different length and/or diameter can be predicted for the same site or for different sites with approximately same soil properties.

NUMERICAL TECHNIQUE TO OBTAIN t-z CURVE

To capture the average response of side soil (i.e. to develop t-z curve) with the known P-Δ curve obtained from the pile load test, following steps are followed:

1. Find modulus of Elasticity of the soil using equation 1 given by Poulos and Davis.

\[ \Delta = \frac{P}{E} \times \frac{1}{d} \quad (1) \]

\[ P = \text{Applied axial load at top of the pile} \]
\[ \Delta = \text{Settlement of pile head due to load P.} \]
\[ E = \text{Average modulus of elasticity of soil} \]
\[ d = \text{Diameter of pile} \]

For Floating pile

\[ I = I_{e}R_{s}R_{v} \]

For End-Bearing Pile on stiffer stratum

\[ I = I_{e}R_{s}R_{v} \]

where

\[ R_{e} = \text{Correction factor for pile compressibility} \]
\[ R_{s} = \text{Correction factor for finite depth of layer on a rigid base} \]
\[ R_{v} = \text{Correction for soil Poisson’s ratio} \]
\[ I_{o} = \text{Settlement influence factor for incompressible pile in semi-infinite mass, for} \ v = 0.5 \]

2. Assign a base spring at the base of pile with stiffness calculated from boussinesq equation.

\[ K_{b} = 2 \times E \times d(1-v^{2}) \]

\[ K_{b} = \text{Spring constant of soil at base of Pile} \]
\[ E = \text{Modulus of elasticity of soil} \]
\[ d = \text{Diameter of pile} \]
\[ v = \text{Poisson’s ratio of soil} \]

3. Start with a small base movement of pile yb1, say equal to \( Y_{b1} \) = (top settlement of pile at 10 tons load)/100.

4. Assume arbitrary initial slope of t-z curve to 0.00025 kg/mm²/mm.

5. Perform the load transfer analysis. Find the load, P, and settlement Δ at the top of the pile for the base movement assumed in step 1.

6. For this P, read the corresponding Δ (actual) from the actual P-Δ curve.

7. Let Error = (Δ-Actual). If absolute of (Error) < 0.009 mm then the slope assumed for t-z curve is acceptable. If Error >0.009 then increment the slope by 0.00025 Kg/mm²/mm. If Error > 0.009 then decrement the slope by 0.00025 Kg/mm²/mm. Return to step # 3. The rationale of allowing error of 0.009 mm is that the accuracy of micrometers used to find settlement in the pile load test should be 0.01mm. And the rationale of using increments of 0.00025 Kg/mm²/mm is that this much slope does not miss to locate the point on actual t-z curve.
Pile Movement

Fig. 1. t-z Curve

which gives settlement at top of pile within the acceptable error of 0.009 mm, Fig. 1.

8. Once the initial slope of t-z curve is established for small base movement yb1, note the side soil movement ys1 (movement of the mid point of the top most pile element in contact with soil). Now using the slope a and the side soil movement ys1, calculate the corresponding shear strength mobilized ts1 and this establishes one point on t-z curve i.e.

\[ ts1 = a \ast ys1 \]

9. Increment the base movement twice the first one and return to step # 4. Since the slip or pile movement at the mid of pile element increases up the pile, those pile segments which have side movement less than ys1, will read shear strength mobilized from the 1st linear-segment (which is established) on t-z curve, and, those side movement which are greater than ys1, the shear strength mobilized is read from the next linear segment of t-z curve to be established from trial slope Fig. 2.

10. Return to step # 5.

11. Assume as many base movements as the actual load-settlement curve allows and establish t-z curve.

This method is conveniently applicable to load settlement curves, which are linear or smoothly non-linear. For load settlement curves with sharp

Fig. 2. Stages of development of t-z curve

Fig. 3. Load settlement curve
brake Fig. 3, indicating the initiation of the second stage, this approach sometimes give numerical locking beyond the break point. In such cases, the t-z curve can be accurately established to the point corresponding to the break in the load-settlement curve Fig. 4. Practically speaking, this portion of the t-z curve is of interest since at this point the skin resistance is fully mobilized and the soil beyond the break point exhibits a plastic behaviour Fig. 4.

APPLICATION OF THE TECHNIQUE

The technique developed to generate t-z curve is applied to load settlement data collected from three localities of NWFP. The t-z curves for the three sites mentioned above are shown in figures 5, 6, and 7.

CONCLUSION

The numerical technique presented in this paper is used to develop t-z curves for pile load test data for a particular site. Using these curves for that site or for other site of nearly same soil characteristics, the load settlement behaviour can be predicted for piles of different pile geometry (diameter and length) and compressibility (modulus of elasticity of pile material).

After the pile load test, the t-z curve should be generated using the load settlement data of the actual test and parametric study should be carried out to determine the optimum pile geometry.

REFERENCES