Ⅲ－B13 Statistical Analysis on Factors controlling a Dynamic Evaluation Formula for Bearing Capacity of Driven Piles

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1. Introduction

Paikowsky, Regan and Mcdonnell(1994) have build up a database to evaluate various dynamic analysis for bearing capacity of driven piles. The main part of this database is called PD/LT, and contains 208 dynamic measurement cases on 120 piles monitored during driving, followed by a static load test to failure.

In this study, the energy approach method, which is a simple dynamic pile bearing capacity evaluation formula proposed by Paikowsky(1982) is studied by regression analysis on this database. . Only EOD (end of driving) data is introduced in the analysis in this study. Physical interpretation of the statistical analysis results are presented. Finally, a few recommendations are made to improve the energy approach method.

2. The Energy Approach

The energy approach is based on energy balance between the total energy delivered to the pile and the work done by the pile/soil system. The total work done by each hammer blow is calculated as follows:

$$W = R_u\ (S + \frac{Q}{2}) \tag{1}$$

where R_u : yield resistance

S : pile set, denoting permanent displacement of pile

Q : quake, denoting elastic deformation of pile/soil system

The problems relating this evaluation of Ru based on Eq.(1) are (1) the energy transferee from a hammer to a pile is difficult to evaluate, and (2) there is difference between the static and dynamic soil resistance.

In the energy approach method proposed by Paikowsky(1982) has overcome these problems by following means:

(1) The energy derived to the pile is calculated directory from the measurements of acceleration and force during driving:

$$E_n = \int V(t)F(t)dt \tag{2}$$

where F(t) : force signal at the pile top for the analyzed blow.

V(t) : velocity signal at the pile top for the analyzed blow

$$V(t) = \int a_{cc}(t)\,dt \tag{3}$$

where $a_{cc}(t)$: acceleration measurement at the pile top for the analyzed blow.

The maximum displacement of pile, D_{max}, is also obtained from the measurement by double integration of the acceleration measurement at the pile top. The pile set, the permanent displacement, however, is not obtained from the measurement, but estimated from empirical relation as set= 1/BPI, where BPI is blow counts per 1 inch of penetration of the pile. Thus Eq.(1) is replaced as:

$$R_u = \frac{E_u}{Set + \frac{(D_{max} - Set)}{2}} \tag{4}$$

This dynamic resistance, R_u, need to be corrected to the static resistance, P_u, by a correction factor K_{sp} as:

$$P_u = K_{sp} \cdot R_u \tag{5}$$

K_{sp} may be corrected for soil types as well as pile types.

In this study, this correlation factor is calibrated based on the PD/LT database mentioned earlier.

3. Data and Method of Analysis

Many factors on each observation case are presented in the database. By carrying out some preliminary analysis, however, it is determined to limit the factor only to side and tip soil types and pile type in the present analysis. number of data for each case is presented in **Table 1**.

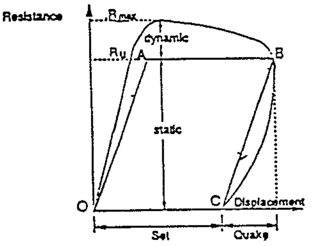

Fig. 1 Resistance vs. displacement at the top of the pile

Table 1 Number of data for each Tip Soil Type category

Tip Soil Type	LDP	SDP	Side Soil Type	LDP	SDP
Clay	5	7	Clay	25	4
Silt	5	1	Silt	6	11
Sand	37	9	Sand	31	11
Gravel	1	4	Gravel	4	1
Rock & Till	21	8	Rock & Till	3	2
Total	69	29	Total	69	29

note: LDP=large disp. pile, SDP=small disp. pile

Regression analysis is performed to select the significant parameters by AIC and other statistical measures such as t-value and correlation coefficient. The significant parameters are added in stepwise fashion, and final models are chosen based on both statistical indices and engineering considerations.

4. Results of analysis and considerations

Paikowsky et.al (1994) have classified piles into two groups: large displacement piles (LDP) and small displacement piles (SDP). The classification is based on the area ratio:

(area of pile's surface in contact with soil) / (pile tip area);

and piles this ratio less than 350 are LDP, and SDP otherwise. This classification is followed in this analysis as well.

(1) Large Displacement Piles (LDP)

The best model selected for this case is presented in Table 2. Since all the variables finally selected are concerning tip soil type, one can directly present mean K_{sp} values with their standard deviation. One data was discarded from the analysis, because of its extremely different behavior compared to other data.

First of all, no side soil effect was judged as significant. Furthermore, it turns out that K_{sp} is lager for softer pile tip soil like clay and silt, and is smaller for harder pile tip layer like rock.

As mentioned earlier, LDP have relatively larger tip area compared to SDP, it may be natural that their behavior is more controlled by pile tip soil than pile side soil.(see also the result on SDP below).

For the second point, it is speculated that K_{sp} is lager for softer pile tip soil probably because 'Set' in Eq.(4) is over estimated for soft soil. Since 'Set' is estimated by an empirical formula, 1/BPI , this can be overestimated for softer soil, and vise versa for the harder soils. Better estimation of R_u could be obtained by improving the estimation procedure of 'Set'.

(2) Small Displacement Pile (SDP)

The result obtained for SDP is not as clearcut as for LDP: tip-rock and side-clay are selected as the significant parameters.

The sign for tip rock is minus meaning Ksp for tip-rock pile should be 0.274 less than the other tip soils. This result exactly coincides with the LDP case; thus it is speculated that estimation of 'Set' has the same problem of under estimation.

Side-clay is also significant. Since SDP has relatively lager pile side area in contact with soil, side-clay may be picked up as significant parameter.

Note that number of data employed in this SDP case is only 29, and not much can be stated from the result. However, the result is a rational one.

5. Concluding Remarks

The result shown in this paper is only preliminary result. More analysis is necessary to come up with final statement on the correction of K_{sp} used in the energy approach.

Table 2 The optimum model for LDP (N=68)

Item	mean K_{sp} value	stand. div.
tip- silt & clay	1.30	0.175
tip-sand	1.08	0.221
tip-rock	0.878	0.100
AIC		-125.4
Multi-correlation coefficient		0.471

Table 3 The optimum model for SDP (N=29)

Item	Reg. Coeff.	stand. div.
tip- rock	-0.274	0.115
side-clay	0.200	0.208
intercept	1.01	
AIC		-7.08
Multi-correlation coefficient		0.602

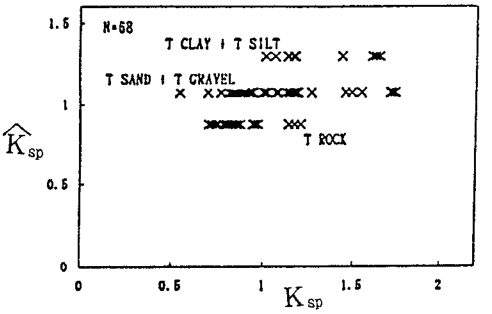

Fig.2 Observed and predicted Ksp for LDP

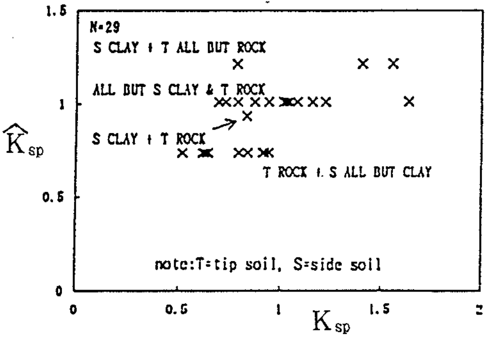

Fig. 3 Observed and predicted Ksp for SDP

References

Paikowsky, S., J.E.Regan and J.J. Mcdonnel (1994) A simple filed method for capacity evaluation of driven piles, Publiction N0. FHWA-RD-94-042, US Department of transportation

Paikowsky, S.(1982) Use of dynamic mesurements to predict pile capacity under local conditions, M.Sc thesis, Technion-Israel Institute of Technology