Pile Settlement Uncertainty in Jakarta, Indonesia.

Bondan Satria[1] and Widjojo A. Prakoso[2]
[1]*Department of Civil Engineering, Universitas Indonesia, Depok, Indonesia*
[2]*Department of Civil Engineering, Universitas Indonesia, Depok, Indonesia*
E-mail: *bondansatria.isaktil@gmail.com*

ABSTRACT: Geotechnical engineering is one of the oldest branch of civil engineering, which continues to evolve along with the level of human civilization. In the practice there are much uncertainty in the geotechnical field, both in terms of design and the inherent variability of the soil material. This uncertainty, coupled with the limited soil data available, makes the geotechnical engineer assumed over estimates or under estimate the soil parameter. The safety factor (SF) assumptions is one method to reduce the risk of such design error, but the FS can be misleading as it is usually recommended or used without specific reference. One of the alternative approaches is the Reliability Based Design (RBD), RBD is a design methodology that summarizes and incorporates key factors of uncertainty. RBD incorporates the cause and effect of every variable and hence the possible consequences, making the eventual results more accurate. In this study the authors will discuss about uncertainty analysis of pile settlement based on soil investigation data. The result is calibrated with the data of static axial loading test based on existing projects in Jakarta. The use of RBD results in a more optimal and economical design, while maintaining the required safety design consideration.

Keywords: Uncertainty, inherent variability, safety factor, reliability, pile settlement.

1. INTRODUCTION

Geotechnical engineering is one of the oldest branch of civil engineering, which continues to evolve along with the level of human civilization. Before the 18th century the period of geotechnical engineering development was divided into 4 main phase, they are pre-classical, classical soil mechanic phase 1, classical soil mechani phase 2 and modern soil mechanic (Skempton, 1985). In the practice, soil as heterogeneous material have much uncertainty in terms of design, the inherent variability of the soil and also other factor such as design method, variations of loads occurring, variations in the strength of the soil material, inaccuracies in designing, variations in method analysis, the quality of the soil investigation, land degradation, soil expansion and shrinkage and the use of construction methods . This uncertainty, coupled with the limited soil data available, makes the geotechnical engineer assumed over estimates or under estimate the soil parameter. Uncertainty in geotechnics has long been recognized (ENR, 1963; Casagrande, 1965). Engineers understand directly or indirectly that there is always the possibility of failure to achieve design objectives during the design life time. Therefore the safety factor (FS) is used in the design as a solution to reduce the risk of design failure, Safety factor (SF) generally used 2 ~ 3, this value is generally adequately assumed in most foundation designs (Focht and O'neil, 1985). Safety factor serves as a solution to reduce design failure, but (FS) can be misleading as it is usually recommended or used without reference and is very subjective

One of the alternative approaches is Reliability Based Design (RBD), RBD incorporates the cause and effect of every variable, key factor of uncertainty and hence the possible consequences, making the eventual results more accurate. In this paper, the authors will discuss about uncertainty analysis of pile settlement based on soil investigation data and the result will be calibrated with the data of static axial loading test based on some projects in Jakarta, it is expected by using the key factors of uncertainty which is the initial step of the RBD will make the result more optimal and economical design while maintaining the safety of design.

The paper will discuss the first step of RBD that is about the analysis of the uncertainty of the elastic settlement of pile foundation based on the soil data of field investigation and pile static loading result as calibration on several projects in Jakarta, random number method and statistic and probabilistic method will use to develop the data. When pile is loaded the settlement will increased. The settlement increase in the pile is caused by 2 (two) factors, the compression due to the structure of the pile itself and the settlement of the surrounding soil around pile and also the bottom of the pile. In this study is assumed that the soil around the pile skin perimeter is bound or moped perfectly on the surface of the pile through friction and adhesion, each settlement of the pile is assumed by the settlement of the soil around and at the bottom of pile. Based on classical soil mechanic "*Poulus HG, Davis EH. Pile foundation analysis and design. New York: John Wiley & Sons; 1980,"* soil can be assumed to be linear elastic, the decline that occurs will be able to return to its original position with a force that is proportional to the modulus of soil elasticity and decreased magnitude

2. METHODOLOGY

The purpose of this paper to find the coefficient of uncertainty factors and determine the empirical relationship between one variable with other variables, key and factor so it is expected to provide a coefficient factors that can make the calculation method of pile settlement is more accurate. The field information and data such as soil investigation data (SPT) and the pile static axial test of three projects in Jakarta will be used as input, parameter and boundary in analysing the pile settlement in compression with spring stiffness method and elastic settlement analysis by Poulos & Davis, then to develop distribution data and uncertainty analyzes were analyzed using random variable with 100x iteration and lognormal distribution for 50%, 100%, 150% and 200% from loading plan.

2.1 Pile Settlement Analysis

Spring Method

The pile settlement formula with spring stiffness method is calculated based refer to *Skempton* formula below :

Pile Stiffness :

$$K_{pile} = \frac{EA}{L} \quad (1)$$

Soil Stiffness :

$$f_{friction} = A_{skin} \times S_u \quad (2)$$

$$f_{tip} = A_{tip} \times 9 \times S_u \quad (3)$$

$$K = f/L \quad (4)$$

Where :

K = Stiffness of material
E = Modulus of elasticscity
A = Area of element
L = Length of element
f = Soil resistance

A_{skin} = Parameter area of pile
A_{tip} = Tip area
S_u = Shear undrained
L = Pile settlement, use 1%d for friction and 4%d for tip

Where rigid local coordinate matrices are used as below:

$$\begin{Bmatrix} f_{x1} \\ f_{x2} \end{Bmatrix} = \begin{bmatrix} \frac{EA}{L} & -\frac{EA}{L} \\ -\frac{EA}{L} & \frac{EA}{L} \end{bmatrix} \begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix} \quad (5)$$

Which then assembled into global coordinates K system which is the sum of Kpile and Ksoil with the following equation:

$$\{f_{system}\} = [K_{system}] \times \{U_{system}\} \quad (6)$$

$$\{U_{system}\} = [K_{system}]^{-1} \times \{f_{system}\} \quad (7)$$

Poulos and Davis

Estimation of pile settlement on homogeneous soil will be used in this study based on the following formula:

$$L = \frac{F}{E_s d} I_p \quad (8)$$

Where :

L = Settlement at the top of pile
F = Loading on the pile
Es = Modulus of soil elasticity
d = Pile diameter
Ip = Settlement influence factor based on *soil poison ratio*

Random Variable

Random variable is a variable that has a probable value or chance is a numerical result of a random phenomenon. The probability characteristics of the random variable have a probability distribution, which determines the possibilities occurring in the intervals determined by the key factors and the key descriptions specified. Random variable can analysis by formula below, but for this paper author use excel formula that refer to algoritma Mersenne Twister to generate radom variable.

$$X_n = (a_{x-1} + b) \bmod m \quad (9)$$

Where :

α = Multiplier
b = Increment
m = Modulus

Statistics and Probability

Statistics is a collection of data, information or results of application of statistical algorithms in the form of numbers arranged in the form of tables or lists and or diagrams that describe or relate to a particular problem, while probability is an opportunity or being probable or something to happen or be is a way of expressing knowledge or believing that an event will take effect or has occurred.
This paper will used lognormal distribution, where the distribution of lognormal associated with the normal distribution. Lognormal distribution in the simplest form is a density function of a random change whose logarithm follows the normal distribution law. The basis for calculating variant and standard deviation is the desire to know the diversity of a group data.

$$\log\bar{X} = \frac{\sum \log x_i}{n-1} \quad (10)$$

$$s \log X = \frac{\sqrt{\sum(\log x_i - \log\bar{x})^2}}{n-1} \quad (11)$$

$$COV = \frac{s}{\bar{x}} \times 100\% \quad (12)$$

Where:
s = Standard Deviation
x_i = X value at-i
n = Sample size
$\bar{x}$ = Mean

Number of Iteration Cycle

The number of samples is plays an important rule to provide accurate data. To obtain accurate analysis results in a statistical and probabilistic method, a minimum size of the repetition or sample process is adequate and can represent the model to be analyzed.

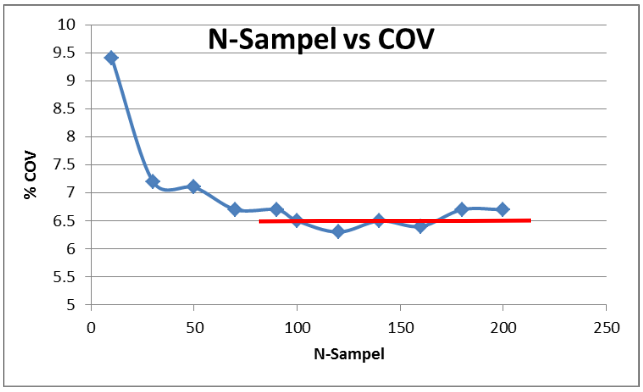

Figure 1 N-Sample vs COV

3. RESULT AND DISCUSSION

Spring Method

Based on the analysis from the spring method, there is has graphic correlation between Su and N-SPT value for the three projects reviewed based on 50%, 100%, 150% and 200% from loading plan, the analysis result have been verified using pile static axial loading test result.

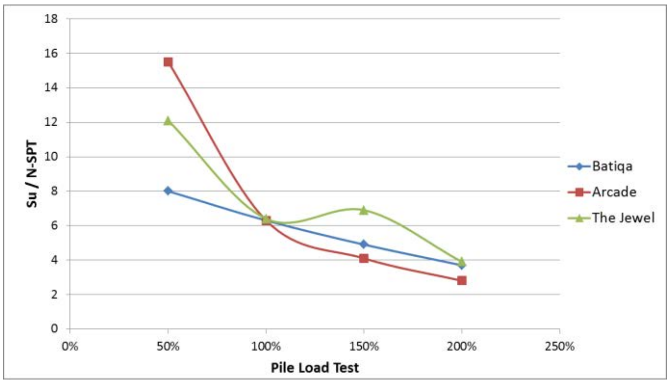

Figure 2 Pile Load Test vs Su/N-SPT (Spring Method)

Based on the figure 2 above, author have the data below :

Table 1 Correlation Value of N-SPT vs Su for Spring Method

Loading	50%	100%	150%	200%
Mean	11.87	6.33	5.30	3.47
STDV	3.76	0.06	1.44	0.59
COV	31.65%	0.91%	27.217%	16.90%

Poulos & David Method

Based on the analysis result from Poulus & Davis formula (Figure 3), provide the correlation between Es and N-SPT values for the three projects reviewed for 50%, 100%, 150% and 200% from loading plan and the analysis result have been verified using pile static axial loading test result :

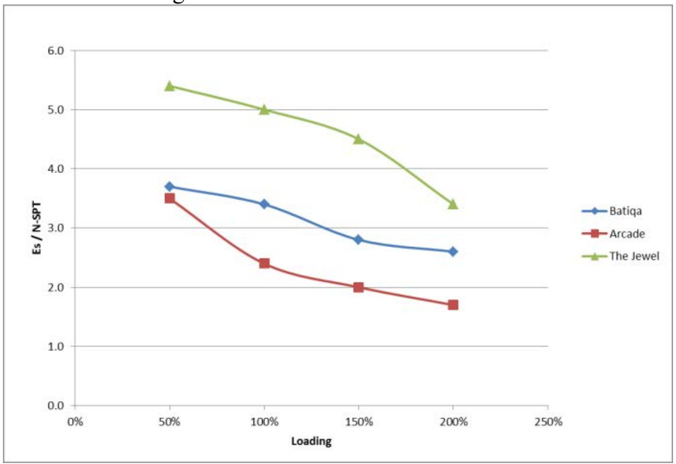

Figure 3 Pile Load Test vs Es/N-SPT (Poulos & Davis)

Based on figure 3 above, author have the data below :

Table 2 Correlation Value of N-SPT vs Es for Poulos & Davis

Loading	50%	100%	150%	200%
Mean	4.20	3.60	3.10	2.57
STDV	1.04	1.31	1.28	0.85
COV	24.86%	36.43%	41.18%	33.14%

Resume for Data Analysis
The results of analysis from two different methods, soil data and pile loading test will be evaluated use statistic and probabilistic methods for every phase of loading 50%, 100%, 150% and 200%, the result is resume in Table 3.

Table 3 Mean, Standard Deviation and COV Resume analysis

LOADING – 50%				
Project		Arcade	Batiqa	The Jewel
Spring Method	Mean	1.71	1.31	1.47
	STDV	0.09	0.07	0.07
	COV	5.00%	5.70%	4.80%
Poulos & Davis	Mean	1.63	1.36	1.78
	STDV	0.22	0.33	0.25
	COV	13.70%	24.10%	14.30%
Pile Loading Test	Mean	1.75	1.39	1.75
	STDV	0.17	0.38	0.83
	COV	9.90%	27.37%	47.68%
Soil Investigation	COV	30.25%	41.55%	35.27%
LOADING – 100%				
Spring Method	Mean	4.74	3.03	4.12
	STDV	0.28	0.18	0.24
	COV	5.80%	6.10%	5.90%
Poulos & Davis	Mean	4.76	2.97	3.85
	STDV	0.65	0.72	0.55
	COV	13.70%	24.10%	14.30%
Pile Loading Test	Mean	4.77	2.99	4.25
	STDV	1.16	0.56	1.53
	COV	24.27%	18.67%	35.94%
Soil Investigation	COV	30.25%	41.55%	35.27%
LOADING – 150%				
Spring Method	Mean	8.70	5.35	6.29
	STDV	0.58	0.35	0.37
	COV	6.60%	6.60%	6.00%
Poulos & Davis	Mean	8.56	5.4	6.41
	STDV	1.18	1.3	0.92
	COV	13.70%	24.10%	14.30%
Pile Loading Test	Mean	8.72	5.46	6.15
	STDV	1.67	1.59	1.56
	COV	19.19%	29.19%	25.43%
Soil Investigation	COV	30.25%	41.55%	35.27%
LOADING – 200%				
Spring Method	Mean	14.32	8.69	11.03
	STDV	1.08	0.62	0.80
	COV	7.50%	7.10%	7.30%
Poulos & Davis	Mean	13.43	7.76	11.31
	STDV	1.84	1.87	1.62
	COV	13.70%	24.10%	14.30%
Pile Loading Test	Mean	14.39	7.87	9.86
	STDV	2.75	2.07	2.15
	COV	19.10%	26.28%	21.80%
Soil Investigation	COV	30.25%	41.55%	35.27%

Uncertainty Factor
Based on the results of the design analysis, both using the method of spring method and the elastic settlement formula by Poulos & Davis obtained a value of COV smaller than the results of pile loading test, it is caused by the limited data of pile static axial test results. Therefore need an uncertainty factor that is incorporated into the analysis or formula in order to obtain the results of the analysis that can cover the actual conditions on the field. Therefore author use a constable X, where the constable X has an average value equal to 1 with a certain COV value so that it can cover the pile settlement conditions based on the actual conditions.

Thus, the value of X constant for loading phase 50%, 100%, 150% and 200% from loading plan below :

$\bar{X}_{Spring}$ = 1
$X_{spring\ COV}$ = 21.21% ~ 27.69%
$\bar{X}_{p\&d}$ = 1
$X_{p\&d\ COV}$ = 13.50% ~ 22.75%

4. CONCLUSION

Based on the information from the field data both soil investigation data (SPT) and the static pile loading test of three projects in Jakarta as an inputs in analyzing the reduction of the pile settlement with the spring method and the elastic settlement by Poulos and Davis and using the random variable probability method with 100x iteration and lognormal distribution it can be made the following conclusion:

1. The results of the analysis in this study have similar results with pile loading test, but to obtain better results, is require more data and distribution of samples are evenly distributed in Jakarta (both ground investigation data and pile testing).
2. The result of the analysis using spring method increased COV along with increasing loading, whereas in Poulos and Davis method got uniform COV for each loading with the quantity ranged between 2 ~ 3 times from COV value with spring method. This result explains that using the assumption by the soil along the pole as homogeneous soil in poulos & davis will increase the value of variability.
3. The correlation value of N-SPT with Su (undrained shear strength) using spring method with 100 times cycle in this study shows that the greatest variability occurs when the load condition is 50%, and the smallest variability value occurs at 100%. With variation values ranging between N-SPT = 2.80 ~ 15.50 Su, for loads of 50%, 100%, 150% and 200% from the loading plan.
4. The value of N-SPT correlation of Es (elastic modulus) using Poulos & Davis formula with 100 times cycle in this study shows that the greatest variability occurs when the load condition is 150%, and the smallest variability value occurs at 100%. With variations in value ranging between N-SPT = 1.70 ~ 5.40 Es, for the load of 50%, 100%, 150% and 200% from the loading plan.

5. REFERENCES

Ang Alfredo H. S., and Tang Wilson H. (1975). Probability Concepts in Engineering Planning and Design, Volume I & II Basic Principles. Willey.

Kulhawy Fred H., Kok Kwang Phoon, Prakoso Widjojo A. and Hirany Anwar. (2006). *Reliability-Based Design of Foundation for Transmission Line Structures*. Cornell University, Hollister Hall, Ithaca, NY, The 2006 Electrical Transmission Conference.

Naghibi Farzaneh, Fenton Gordon A. and Griffiths D.V. (2014). *Prediction of pile settlement in an elastic soil*. Elsevier – Computer and Geotechnic.

Poulos H.G., Davis E.H. (1980*). Pile Foundation Analysis and Design*. John Wiley & Sons.

Prakoso Widjojo A. (2016). *Case Study on Variability in Soils and Driven Pile Performance*. Universitas Indonesia, Depok, Indonesia.

Vesic A.F. (1977). *Design of Pile Foundation*. National Cooperative Highway Research Program, Synthesis of Practice No. 42, Transportation Research Board, Washington, D.C.F

Yudhi Lastiasih, Irsyam Masyhur dan Sidi Indra Djati. (2013). *Reabilitas Daya Dukung Pondasi Tiang Bor Berdasarkan Formula Reese & Wright dan Usulan Load Resistance Factor Design dalam Perencanaan Pondasi Tiang Bor Studi Kasus Proyek Jakarta*. Jurnal Ilmu dan Terapan Bidang Teknik Sipil Badan Kejuruan Sipil Persatuan Insinyur Indonesia.

Bondan Satria, Widjojo A. Prakoso. (2017). Analisis Ketidakpastian Penurunan Pondasi Tiang Pancang Berdasarkan Beberapa Studi Kasus Di Jakarta, Indonesia. Tesis Departemen Teknik Sipil Universitas Indonesia.