BEARING CAPACITY ANALYSIS OF RAFT FOUNDATION BASED ON PROBABILITY METHOD

ANALISIS KAPASITAS DUKUNG PONDASI RAKIT DENGAN METODE PROBABILITAS

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ABSTRACT
Variability on CPT test on Anugerah Palace Hotel site has been evaluated in this paper. As CPT data tends to be varied, the deterministic method is not longer appropriate anymore. The probability analysis is conducted to tackle this phenomenon, in the form of Monte Carlo method. This recent method has been developed to calculate raft foundation design on the site at the depth of 4.5 m below soil surface. The analysis starts by fitting tip resistance, qc taken from 4 CPTs data on the Anugerah Palace Hotel site using Normal, Log-normal, Beta, and Gamma distribution by ready program written in MATLAB. As statistics parameters come out, the analysis of raft foundation can be started to determine the safety factor against the total vertical load of the structures, by computer aid of Crystal Ball. The results show that all sites produce the safety factor larger than 1.0 totally, and there will no chance for failure. As the minimum factor of safety increases up to 2.5, the percentage of the structure for having safety factor laeger than 2.5 are only 5% maximum..
Keywords: CPT, Monte Carlo, Probabilistiy, MATLAB, Crystal Ball, Raft Foundation

ABSTRAK
Variasi data CPT atau sondir di pembangunan Hotel Anugerah Palace telah dievaluasi pada penelitian ini. Karena data sondir yang sangat bervariasi, maka metoda perhitungan secara deterministik atau konvensional tidak mampu mengakomodasi kondisi tanah yang sebenarnya di lapangan. Analisis probabilitas merupakan metoda yang banyak digunakan para peneliti untuk menyelesaikan problem data lapangan yang bervariasi dengan Monte Cartlo analisis. Cara terakhir ini dipakai untuk menghitung desain Pondasi Rakit di lokasi pembangunan Hotel Anugerah Palace pada kedalaman 4,5 m. Analisis dimulai dengan mencari distribusi frekuensi yang paling mewakili data tahanan ujung, qc, pada 4 data sondir yang ada di lapangan dalam bentuk Normal, Log-normal, Beta, dan Gamma. Selanjutnya parameter statistik dari analisis Matlab dan data distribusi yang telah dipilih digunakan untuk perhitungan Pondasi Rakit dengan menggunakan Crystal Ball. Hasil pnenlitian menunjukkan bahwa angka keamanan pada semua tempat menghasilkan angka lebih dari 1,0 seluruhnya, yang berarti, struktur tanah di bawah pondasi tidak runtuh. Ketika angka aman minimum 2,5 diberikan sebagai prasyarat analisis, dari empat lokasi sondir menunjukkan hasil bahwa prosentase angka aman yang melebihi 2,5 tidak lebih dari 5%
Kata-kata kunci : CPT, Monte Carlo, probabilitas, MATLAB, Crystal Ball, Pondasi Rakit

INTRODUCTION

In the era of 90' there was quite a lot of analysis designing geotechnical project were based on analysis of the deterministic models. Although the approach in deterministic method has been carried out extensively, in fact almost all soil properties varies and the possibility of homogeneous extremely rare (Listyawan, 2006). So the concept of probability analysis is better solutions to handle the less precision of deterministic methods.

The deterministic way uses only one value of certain soil properties which considered representtative, the concept of probability of soil properties uses all the data existing to accommodate any variant that occurs. One of the soil properties that show high variation in the data are the results of cone penetration test (CPT), which in Indonesian is better known as 'sondir'. The high variation of data can be seen in the value of tip resistance (q_c) and sleeve friction (f_s) from the CPT. Processing data to be used in the analysis of probability models then used for raft foundation stability analysis.

Hotel Anugerah Palace is built on area of 1100 m^2, consists of 9 floors and 1 Basement. The projects are scheduled to finish in June 2013. Due to the construction of this hotel located in the city center access is very easy to get there, let alone the town solo is a destination city for trade. Besides, the position of the

town as a solo 3-way intersection of the east of the area east of Java, north of the area and the coast road west of the city of Yogyakarta. Not only as a trade center, a solo also serves as a transit town to the big cities so that means no lodging to be a highly promising.

In first design the Hotel Anugerah Palace will construct using bore pile foundation, but after testing using sondir the value of tight soil is too far, so bore pile foundation method can not be applied for this construction. Consolidation in soil also in different descent which different area, if using bore pile foundation that make building consolidate with different velocity. These difficulties brought to the implementtation of raft foundation. Raft foundation is constructed like a mat that covering all area of building, not only around of column.

In previous research, Murdhiyanto (2012) represent the manually calculation (fellinius method) and the Crystal Ball program analysis, the value of the safety factor the most variation happened to the field of landslides III that is 1.2885 (for manual) and the percentage of the value of F> 1 for 87.770% (Crystal Ball). Variations performed on Fellinius method allows the slope will be stable or not eroding as more security value of 1. While the results of the program Crystal Ball can be concluded that the slope it probably persist > 80.

Based on the problems that have been described above, the research is focused on computing the stability of raft foundation on areas that have a high building and finding the value of safety factors for raft foundation using variets CPT data that to obtain the smallest value of the safety.

Background Theory

In the high building structures need a strong foundation to support the load of building that detained by the foundation. Many foundation methods are used in the construction of high building, such as the method with foot plate foundation, pile group foundation, bore pile foundation and raft foundation. Generally, the foundation is used based on the soil types that will support a building with variets data from Cone Penetration Test (CPT) or commonly known as 'sondir'. Variation data can be seen from the tip resistance (q_c) and sleeve friction (f_s) from the CPT. This research uses raft foundation as research material. Analysis stability of raft foundation is a rare thing to do in the implementation of multi-storey building construction, because the use of this method is only performed in a state that does not allowed to use conventional methods.

Raft foundation

A raft foundation is a large concrete slab, which is used to connect (interface) of one or more columns in a few lines with the soil. The foundation may include all or only a part of the foundation area. A raft foundation may be used to support storage tanks or industrial equipment. Raft foundation is usually used for chimneys, and various tower constructions. By definition, the spread foot plate is called a raft (mat). Illustrate some raft configurations that possible to use for buildings. These configurations include the entire building, but it is not really necessary.

A raft foundation may be used where the ground soil has a low bearing capacity and load of columns bigger than 50% of the area, covered by large conventional foot plate. Depend on own financing and consideration that a raft foundation require steel for reinforce both positive moments and negative moments., so it may be more economical to use the foot plate foundation even if all the area are covered. This action has done to avoid the steel that used to reinforce for negative moment and can be changed with foot plate foundation, to avoid transformation forms.

Raft foundation is supported by the driven pile, in certain situation such as a high the ground water (to control floating force) or where the soil easily affected by a high consolidation. It should be noted that some tension of foot plate foundation will penetrate the soil to a higher depth or have a higher intensity at shallow depths.

Design of raft commonly consist of a flat concrete slab with thickness from 0.75 to 2 m, with base and with two sides reinforcement top and bottom constantly. Sometimes, this type of foot plate foundation is designed very excessive, because three main reasons: additional fee and effects of uncertainty in the analysis; the extra cost of an excessive design of the construction, in general will be looked like cheap cost for excessive design and relatively fair according to total project financing; extras safety factor that provided for the additional cost.

Bearing Capacity of Raft Foundation

A raft foundation should be stable against a high consolidation that may occur in the long period (consolidation) or short period (elastic or soon), and that happens in the long period and short period. Allowable compression pressure obtained by using an appropriate safety factor can be seen in Table 1.

Table 1. Safety factor for each type of failure

Type of Failure	Type of Foundation	F
Shear	Work soil, dam, embankment and etc.	1.2-1.6
Shear	Retaining wall construction.	1.5-2.0
Shear	Sheet pile wall	1.2-1.6
	Cutting that sustained (braced)(temporary)	1.2-1.5
Shear	Foot plate foundation	
	Local foundation	2-3
	Raft	1.7-2.5
	Upwards tension	1.7-2.5
Seepage	upwards tension	1.5-2.5
	Erotion under ground.	3-5

A raft foundation must be stable against depth shear failure that can affect rotation failure [for example, neither failure elevators Transcona (white, 1953) nor the failure vertical or blow. A failure blow vertical which evenly not will so serious, because of this effect is only high consolidation which the possibility can be estimated. However, consolidation possibility it will spread evenly, then the varieties must be treated with same attention such as for shear failure that set inside. Addition for bearing capacity of raft foundation can be seen at Figure 1.

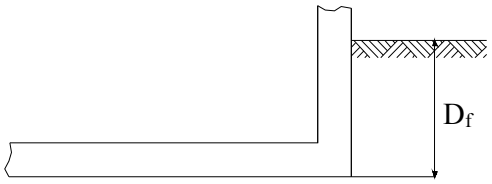

Figure 1. Raft Foundation

Bearing capacity formula for the raft foundation:

$$q_u = \frac{q_c}{20} \cdot K_d \qquad (1)$$

Where :

q_c = Tip resistance (kg/m^2)

K_d = 1+0,33.D_f/B

D_f = Depth of foundation (m)

B = width of foundation (m)

The value of K_d must be lower than 1.33 ($K_d \leq 1.33$).

Statistics and Probability Density Function

Statistics always deal with data collection and solving the real problems by analyzing all of them. Data sets have to be organized, summarized, and displayed before any interpretation can be attempted. Graphical displays are often become the well known method to represent the data. The obvious and very useful measures on data set are mean and standard deviation

Probability distribution is divided into discrete and continuous distribution. A discrete distribution means each of its values with a certain probability that often represented in the form of bar graphics. A continuous distribution has a probability of zero of assuming exactly any of its values and consequently, its probability cannot be given in tabular form. It can be stated as a formula that would necessarily be a function of numerical values of a continuous variable *X* and as such will be represented by the functional notation *f(x)*. In dealing with continuous variables, *f(x)* is usually called the probability density function. The most important continuous probability distribution in the entire field of statistics is the normal distribution. Its graph, called the normal curve, is the bell-shaped curve. The normal distribution is often referred to as the Gaussian distribution. The density function of a normal variable *X*, μ and standard deviation σ, is :

$$n(x;\mu;\sigma) = \frac{1}{\sqrt{2\pi}\sigma} e^{-(1/2)[x-\mu)/\sigma]^2} \qquad (2)$$

Although the normal distribution can be used to solve many problems in engineering and science, there are still numerous situations that require different types of density functions, such as the gamma distribution. Its name was derived from the well-known gamma function (Walpole *et al*. 1998). The probability density function of the gamma distribution can be expressed in terms of the gamma function:

$$f(x;k;\theta) = x^{k-1} \frac{e^{-x/\theta}}{\theta^k \Gamma(k)} \qquad \text{for } x > 0 \qquad (3)$$

Alternatively, the gamma distribution can be parameterized in terms of a shape parameter $\alpha = k$ and an inverse scale parameter $\beta = 1 / \theta$, called a rate parameter:

$$g(x;\alpha;\beta) = x^{\alpha-1} \frac{\beta^\alpha e^{-\beta x}}{\Gamma(\alpha)} \text{ for } x > 0 \qquad (4)$$

In probability theory and statistics, the beta distribution is a continuous probability distribution with the probability density function (pdf) defined on the interval [0,1]:

$$f(x;\alpha;\beta) = x^{\alpha-1}(1-x)^{\beta-1} \frac{1}{B(\alpha,\beta)} \qquad (5)$$

where α and β are parameters that must be greater than zero and *B* is the beta function (Farrington *et al*. 1999).

The Log-normal distribution is used for wide variety of applications. The distribution applies in cases where a natural log transformation results in normal distribution (Limpert *et al*. 2001). The log-normal distribution has probability density function (pdf):

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma x} e^{-[\ln(x)-\mu]^2/(2\sigma^2)} \text{ for } x > 0 \qquad (6)$$

Chi Square Goodness-of-fit Test

One of the testing methods of statistical hypotheses of a data set that has a specified theoretical distribution is chi square test. The test is based on how good a fit between the frequency of occurrence of observations in an observed sample and the expected frequencies obtained from the hypothesized distribution (Walpole *et al*. 1998). A goodness-of-fit test between observed and expected frequencies is based on the quantity:

$$\chi^2 = \sum_{i=1}^{k} \frac{(o_i - e_i)^2}{e_i} \qquad (7)$$

Where χ^2 is a value of a random variable whose sampling distribution is approximated very closely by the chi-square distribution with $v = k - 1$ degrees of freedom. The symbols o_i and e_i represent the observed and expected frequencies, respectively, for the *i*th cell. If the observed frequencies are close to the corresponding expected frequencies, the χ^2-value will be small, indicating a good fit. If the observed frequencies differ considerably from the expected frequencies, the χ^2-value will be large and the fit is poor.

Available Raw CPT Data

The cone penetration test (CPT) is becoming increaseingly more popular as an in-situ test for site investigation and geotechnical design. As a logging tool this technique is unequalled with respect to the delineation of stratigraphy and the continuous rapid measurement of parameter like bearing and friction (Robertson & Campanella. 1983). Be in opposition to the use of SPT, the CPT has an advantage that is provides a continuous data record together with excellent repeatability and accuracy at relatively low cost. Some experiences around the world, CPT have confirmed a repeatability of tip resistance that is better than $\pm$2% (Jefferies *et al*. 1988a). According to Robertson (1986), the CPT is perfect for investigating loose deposits, since the pushing force is small; hence, this test has become a major asset in evaluating the liquefaction potential of soils. The CPT data from the Anugerah Palace Hotel soil were obtained from 4 locations to the depth up to 17 m.

Introduction Program MATLAB

MATLAB (Matrix Labolatory) is a program for the analysis and numerical computation and an advanced mathematical programming language that created with the idea to use eel and matrix form. MATLAB is also a high-level programming language based on a matrix that is often used for numerical computation techniques, which is used to solve problems involving mathematical operations element, matrix, optimization, approximation and others.

MATLAB has evolved into a sophisticated programming and contains functions “built-in” to do the signal processing tasks, linear algebra and other mathematical calculations. MATLAB also contains a toolbox which contains additional functions for application courses. MATLAB is extensible, which mean that a user can write new functions to be added to the library when the functions “built-in” that available can not perform certain tasks. Programming capability required is not too difficult if you have the experience and other programming languages such as C, PASCAL or FORTRAN.

Introduction Program Crystal Ball

Crystal Ball is software that is used to do the Monte Carlo simulations in Ms Excel spreadsheet. Crystal Ball calculates thousands of cases of "what if” automatically, save the input and the results of each calculation as self scenarios. Analysis of each scenarios will provide an explanation of limitation of posibility‘outcome’, where the input section has the maximum result and where the focus of attention.

METHOD OF WORK

CPT Analysis

Time consuming and complex process is desirable to examine the CPT data statistically. In this present study, the Author uses a set Fortran 90 computer program built by Wong (2004), which has been customized by Gitman (2006) by adding the Matlab computer program to characterize the probability density function and performing the best fit distribution for each profile. These programs make the possibility of investigating several CPT profiles within a reasonably short time period.

Post CPT Analysis

Once the probability density function has been derived, a Monntecarlo computation can be started using Crystal Ball by assigns some equations of bearing capacity of raft foundation onto worksheet on the program. A 100,000 trialls have been developed to reach convergence of the plot. Finally, the result of Crystal Ball analysis is compared to the one from manual calculation. Figure 2 shows a flowchart for all steps.

In this current study, the four types of distribution (i.e. normal, gamma, beta and log-normal) have been analyzed to get the best fit distribution for both tip resistance and state parameter. The probability density function is defined by subdividing the

range of data values into classes of equal width as following formula:

$$(PDF)_i = \left(\frac{f_i}{\sum_{i=1}^{n_c} f_i} \right) \left(\frac{1}{bw} \right) \quad (10)$$

Where f_i is the sampling class frequency for the class reference number i, n_c is the total number of classes and bw is the class width. In the automated rogram, 6 classes have been used for all profiles. Thus, each profile has a different class width as the range of data is differ from one profile to another. By considering the four types of distribution, the best fit distribution has been calculated using the chi square goodness-fit method. The best fit distribution is the distribution that has the lowest value of chi square. For every CPT profile, the point statistics (i.e. the mean, μ, and standard deviation, σ) are calculated.

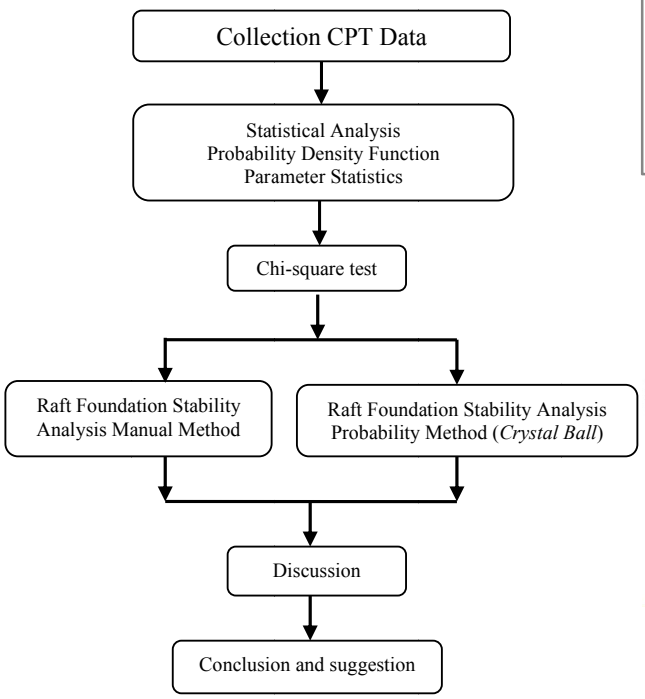

Figure 2. Summary flowchart of CPT evaluation process

RESULT AND DISCUSSION

General Representation of CPT Evaluation Data on Anugerah Palace Hotel

4 CPT data of Anugerah Palace Hotel Soil have been assessed in the present investigation. Typical sheets illustration of the CPT data can be seen in Figure 3. For each profile, a typical sheet encompasses: (a) the raw CPT profiles; (b) a summary of point statistics for tip resistance; (c) the best fit distribution for tip resistance. In general, the tip resistance of Anugerah Palace Hotel Soil starts with the lower value up to 0.20 m depth and then increases slightly to the depth of 15 – 17 m.

Point Statistics	*Qc*
μ (kg/cm^2)	66.78
σ (kg/cm^2)	40
v	0.60

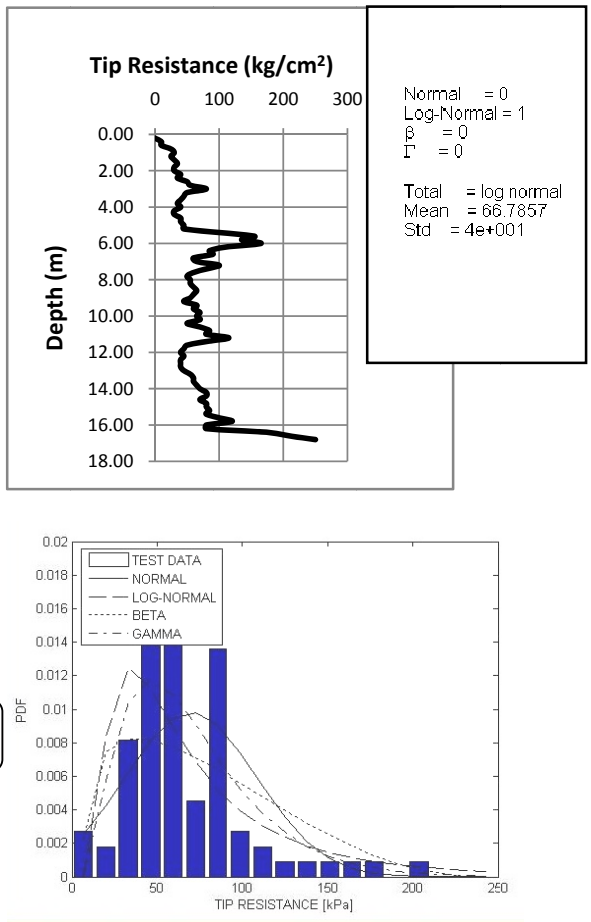

Figure 3. CPT 2 sheet evaluation

Probability Density Function

In general, the probability distribution functions of tip resistance appearances a different type of distribution in terms of the number of peak arises. The mono-modal or bimodal distribution can be identified across the profiles as assessed in a natural deposit (Listyawan, 2006). Definitely, it is detected across the profiles in Anugerah Palace Hotel soil that the mono-modal or bimodal distribution of tip resistance can be identified.

Best fit distribution

A different best fit distribution arises for each profile, as tabulated in Table 2.

The chi-square values of the normal, log-normal, beta and gamma distribution for tip resistance of CPT 2 are tabulated in Table 3. It can be seen that the χ^2 value of normal distribution for both tip resistance 0.069 respectively, whereas less than $\chi^2_{\upsilon,\alpha}$ = 7.815 (for the significance level of 0.95). It means that there is no objection to the hypothesis of normality.

Table 2. Best fit distribution

Profile number	Best fit distribution
1	Normal
2	Log-normal
3	Beta
4	Gamma

Table 3. Chi-square value of CPT 2

Distribution	Chi-square
Normal	0.069
Log-normal	0.035
Beta	0.045
Gamma	0.63

Probability analysis on Bearing Capacity of Raft Foundation

Data available taken from the Anugerah Palace Hotel site are as follows:

- Width of foundation : 24.812 m
- Area of foundation : 1,041.856 m^2
- Depth of foundation : 4.5 m
- Total vertical load : 10,012.450 tones

The CPT data used in the bearing capacity of raft foundation are only the data up to depth of foundation (i.e. 4.5 m). Safety factor for each CPT data has been calculated using Crystal Ball by comparing the load that can be handled by the foundation and the actual vertical load that subjected to the structures. Figure 4, 5, 6, dan 7 are the out put from Crystal Ball analysis.

It can be observed from Figure 4, 5, 6, and 7, factor of safety of raft foundation earn completely larger than 1.0. The probability failure of the structures tend to be zero as there is no chance for getting safety factor less than 1.0. The results show that using each CPT data up to 4.5 m depth, the raft foundation will still stay on its position, there is no failure on the soil below the foundation.

But, in some foundations, the conventional method gives the requirement that the minimum safety factor is more than 1.0, or even reaches 2.5. In this recent study, the safety factor of 2.5 minimum have been assigned to the Crystal Ball analysis, as can be seen in Figure 8, 9,10, and 11 for CPT 1, CPT 2, CPT 3, and CPT 4 respectively.

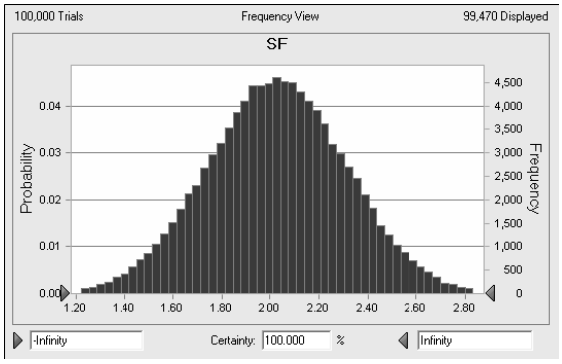

Figure 4. Safety factor for CPT 1

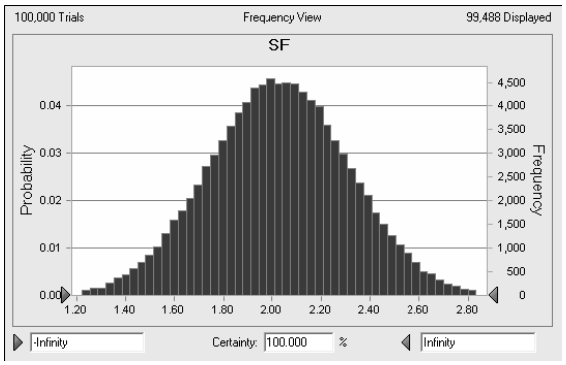

Figure 5. Safety factor for CPT 2

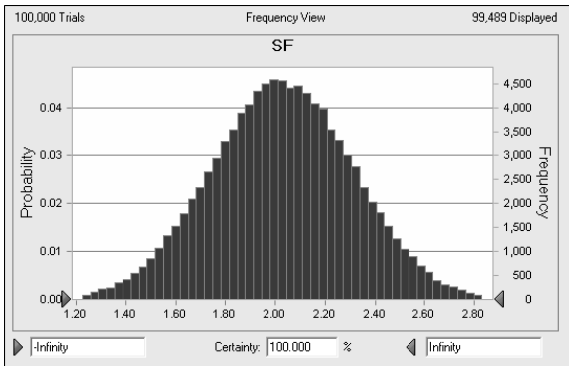

Figure 6. Safety factor for CPT 3

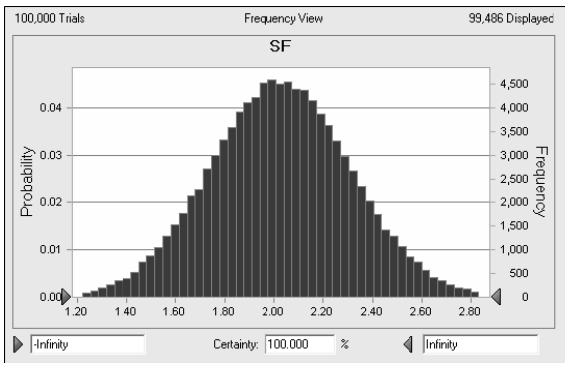

Figure 7. Safety factor for CPT 7

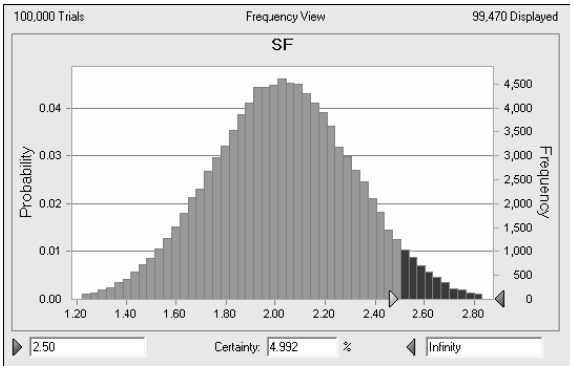

Figure 8. Safety factor > 2.5 for CPT 1

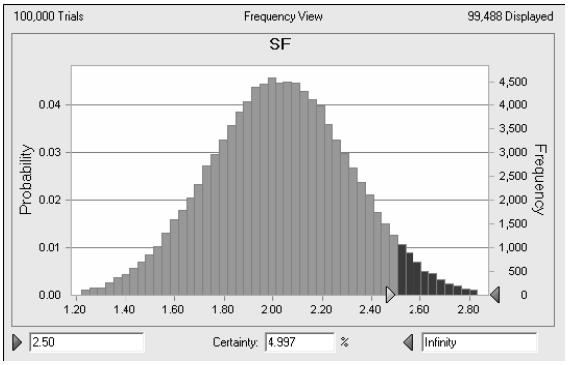

Figure 9. Safety factor > 2.5 for CPT 2

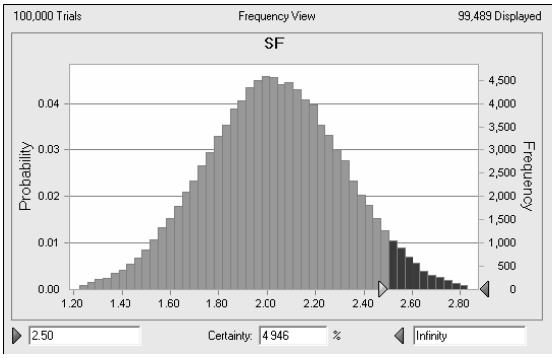

Figure 10. Safety factor > 2.5 for CPT 3

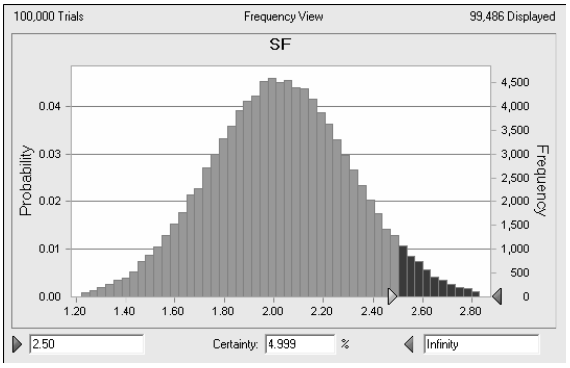

Figure 11. Safety factor > 2.5 for CPT 4

Figure 12 shows the percentage of safety factor larger than 2.5. In general, all CPT come out the result that the percentage for getting safety factor larger than 2.5 are less than 5%. The smallest percentage occurs in CPT 3, which is 4.946%, and the largest occurs in CPT 4, which is 4.999%. These results agree with the data of CPT mean on tip resistance value, which give the fact that mean of tip resistance for CPT 3 is the smallest (i.e. 38.441 kg/cm^2), and mean of tip resistance for CPT 4 is the largest (i.e. 40.354 kg/cm^2)

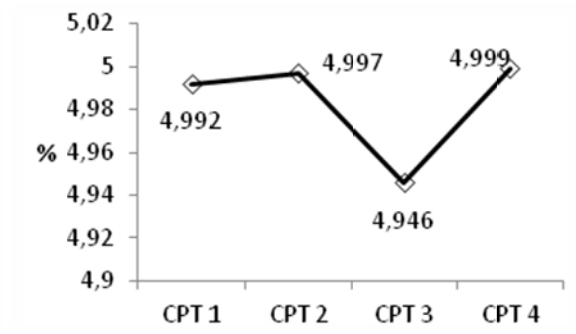

Figure 12. Percentage safety factor > 2.5

CONCLUSSION

The probability analysis of raft foundation has been investigated on this recent study. The result shows that all CPT data on Anugrah Palace Hotel site give the fact that the data can be fited using normal distribution. The Crystal Ball analysis shows that all the foundation structures will still stable as 100% safety factor are larger than 1.0. But as the minimum safety factor, which is 2.5 assign on the structures, the percentage of safety factor > 2.5 is only 5% maximum, whereas does not meet the design requirement in conventional method.

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