การประเมินค่าทางสถิติของคุณสมบัติดินเพื่อหาอัตราส่วนความปลอดภัยสำหรับงานวิศวกรรมธรณีฐานรากในชั้นดินอ่อนกรุงเทพมหานคร

Assessment and Reliability of safety factor in Geotechnical aspects base on Statistic inference of soil strength parameters in soft Bangkok clay

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บทคัดย่อ : งานออกแบบฐานรากและโครงสร้างทางด้านวิศวกรรมปฐพี ยังไม่มีความชัดเจนในเรื่องการกำหนดค่าอัตราส่วนความปลอดภัย โดยปกติทั่วไปมักจะใช้ค่าอัตราส่วนความปลอดภัยระหว่าง 1.2 – 4.0 ในการศึกษาวิจัยนี้มุ่งเน้นหาความสัมพันธ์ของข้อมูลชั้นดินอ่อน บริเวณพื้นที่กรุงเทพมหานคร ซึ่งเป็นองค์ประกอบหลักที่ใช้ในการออกแบบสำหรับงานวิศวกรรมปฐพี โดยหลักการได้นำเอาทฤษฎีความน่าจะเป็นและการวิเคราะห์ข้อมูลพื้นฐาน โดยอาศัยการทดสอบทางด้านสถิติ รวมทั้งศึกษาความแปรปรวนจากปัจจัยต่างๆ,ระดับความเชื่อมั่น ,ตังบ่งชี้ความเชื่อมั่น,การยอมรับความเสี่ยง และโอกาสการเกิดพังทลาย(Probability of Failure)ของโครงสร้างฐานรากในชั้นดินอ่อนในแต่ละระดับความสำคัญ(Individual limit state of performance function) การวิเคราะห์ความแปรปรวน (uncertainties) และ การวิเคราะห์ความเชื่อมั่น (reliabilities approach) โดยวิธี Monte Carlo simulation, FOSM., หรือ FORM., เป็นต้น ให้ผลลัพท์การกระจายตัวของค่าอัตราส่วนความปลอดภัย (a set of the partial safety factor) ในแต่ละ performance functions ผลของการศึกษาสามารถนำข้อมูลที่ได้ทำการวิเคราะห์ไปประยุกต์ใช้ในการออกแบบงานทางด้านวิศวกรรมปฐพี และสามารถควบคุมราคาค่าก่อสร้างได้อย่างมีประสิทธิภาพ

ABSTRACT: Design works in geotechnical engineering have not been clear in the area of safety factor, and the used of overall safety factor is more conservative by engineering judgement, normally, in the range of 1.2 to 4. This research points out that the relationship among the data in soil properties of soft Bangkok clay is the major making decision for design criteria in Geotechnical aspects at depth between 0 – 20 m. below natural ground line. First of all soil data analysis by using the test of statistics inference and probabilistic theory must be clarify, together, concerning about geostatistics in any spatial variation is also not to be avoided. Secondly, "Uncertainties and Reliability Approach ", this research tends to find out all accepted uncertainties and reliability index going along with failure probability in every failure mode of performance functions which refers to individual limit state. The research by product giving a set of safety factors and their distributions using method of Monte Carlo simulation, FOSM,FORM and etc. Consequently , safety factor for each performance functions called "partial safety factor" will be applied to design criteria. Given appropriate safety factor will optimize construction cost and more reliable to geotechnical structures. Finally, the old fashion

overall safety factor has no longer exit and then will be replaced by the term of a set of safety factor as a new design concept to geotechnical engineer.

KEYWORDS: Geostatics, Uncertainties and Reliability Approach, Probability of Failure, Partial Safety Factor

1. Introducton

Thailand, there are many construction projects present in each year and more than 70 percent are presented in Bangkok area. From history background has proved that Bangkok subsoil profile has been governed by soft clay in depth between 0 - 20 m., since it used to be the sedimentation of marine clay. As mention, such a soil characteristic the geotechnical engineer has been faced many problems involving soil data properties and their spatial variation. The uncertainties may be in the form of a lack of information about the subsoil profile or a large scatter in the soil test results and so on (Gordon A. fenton,1997). This research has collected the soil data properties and test results more than thousand boreholes all over Bangkok area (Fig. 1). These soil data will be analyzed by mean of statistics approach and common statistics involving of sample mean, sample variance, sample standard deviation, coefficient of variation (COV.), correlation, distribution types, and probability density function(pdf.). Further more, in term of geostatistics and field modeling, the relationship among the soil properties both in horizon and vertical direction is deeply concern and this refers to the average trend, spatial averaging, autocovariance function, and scale of fluctuation.

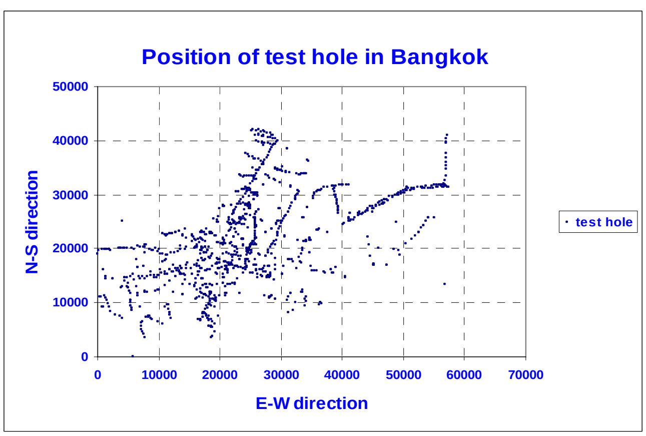

Fig.1 position of test holes in Bangkok area

2. Research Methodology

This research has collected the bore holes data of soil properties all over Bangkok area, providing of 1163 bore holes which categorize to 455 blocks and each block governs the area of one square kilometer. The number of bore hole in each block has varied from 1 to 22 bore holes. Since there have been some different in the number of bore hole, specially in small number of bore hole, the statistical analysis could not be done. Should the data of soil properties in each block has been group more than one. This paper has found out that at least 4 block grouping are more sophisticate than one block alone, with the exception of the large number of bore hole in that one block. Statistical analysis is restricted in the number of samples and can be approached by analytical mean(average) if a large number of sample is available. So statistical treatment of soil data properties will be applied to any single bore hole in each one block or, even by mean of block grouping. This paper strictly concerns the data obtained from field vane shear test and undrain shear strength of a soft Bangkok clay, since most of the soil data properties are continuous random variable, therefore the term of statistical treatment define as follow

- Estimating the mean: The sample mean

$$\hat{\mu}_X = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (1)$$

- Estimating the variance: The sample variance

$$\hat{\sigma}_x^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \hat{\mu}_X)^2 \qquad (2)$$

- The sample standard deviation (σ)

$$\hat{\sigma} = \text{square root of the sample variance} \qquad (3)$$

- The sample coefficient of variance ($COV \cdot \delta$)

$$\hat{\delta}_X = \frac{\hat{\sigma}_X}{\left|\hat{\mu}_X\right|} \quad (4)$$

- The sample correlation coefficient ($\hat{\rho}$)

$$\hat{\rho}_{XY} = \frac{\sum_{i=1}^{n}[\{x_i - \hat{\mu}_X)(y_i - \hat{\mu}_Y)]}{\sqrt{\sum_{i=1}^{n}(x_i - \hat{\mu}_X)^2 \sum_{j=1}^{n}(y_i - \hat{\mu}_y)^2}} \quad (5)$$

In general, soil properties data may be assumed to be normally distribution. The undrain shear strength are fit well and tend toward normal distribution which are common in nature. Normal distribution has a symmetrical distribution with bell-shape curve and its tail decay in an exponential manner. There is a 68-percent chance within ± 1 standard deviation from mean value, 95-percent chance within $\pm 2\sigma$ and 99.7-percent chance within $\pm 3\sigma$. As the Continuous random variables, undrain shear strength Su in this paper, there is an infinite number of possible values within the sample space which any value is greater than Zero. The probability density function(pdf.) describes its probability distribution and can define the probability of that variable value within a very small interval, thus, this probability is proportional to the pdf which denote as $f_x(x)$ for normal distribution

$$f_x(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-1}{2}(\frac{x-\mu}{\sigma})^2} \quad (6)$$

$$-\infty < x < \infty$$

and the cumulative distribution function(cdf.) is the area under the PDF. Describes the probability that the variable takes on a value less than or equal to a given value which denote as $F_x(x)$.

$$F_x(x) = P[X < x] \quad (7)$$

Geostatistics describes the spatial correlation of the data measured at various point in three dimension space and uses of probabilistic model. High variability in space means less dependency in space. Spatial interpolation of close sample tends to be more similar than distant sample and also call spatial autocorrelation. variogram represents the variation between pairs of measurement as function of separated distance(Fig. 2, a, b,c), define as

$$2\gamma(h) = E\{[Z(u) - Z(u+h)]^2\} \quad (8)$$

$$2\gamma(h) = \frac{1}{N(h)} \sum_{N(h)} [Z(u) - Z(u+h)]^2 \quad (9)$$

For semi-variogram

$$\gamma(h) = \frac{1}{2N(h)} \sum_{\alpha=1}^{N(h)} [Z(u_\alpha) - Z(u+h)]^2 \quad (10)$$

where r(h) = semivariogram for lag distance h

N(h) = number of pairs for lag distance

The variogram for lag distance h is defined as the average square different of values separated approximately by h , and lag distance should coincide with data spacing, considerably, the variogram is only valid for a distance one half of the field site.

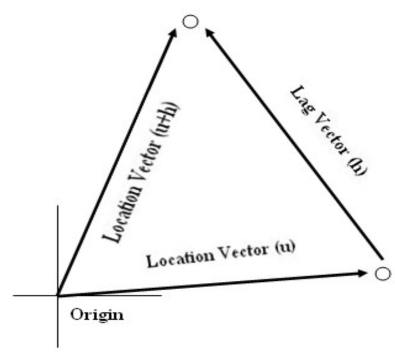

Fig. 2(a) Lag distance h

From: Clayton V. Deutsch and Andre G. Journel, (1992)

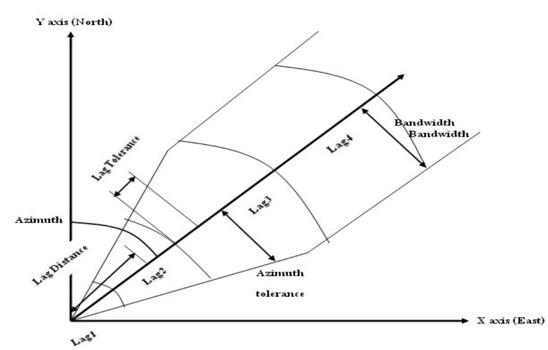

Fig. 2(b) Variogram parameters

From: Clayton V. Deutsch and Andre G. Journel, (1992)

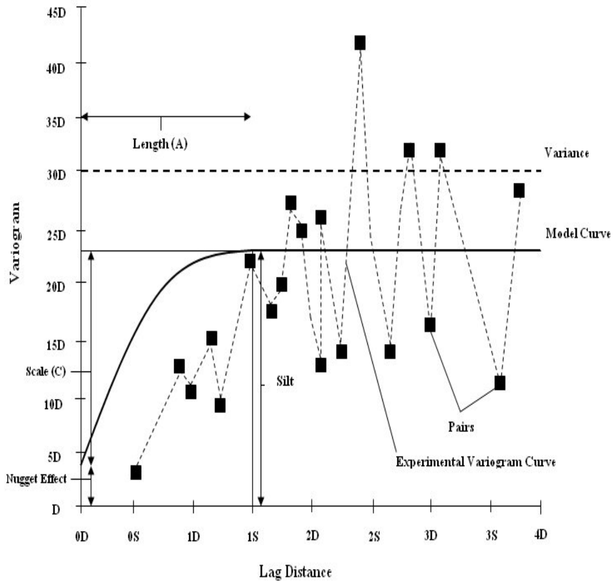

Fig. 2(c) Variogram structure

From: Clayton V. Deutsch and Andre G. Journel, (1992)

Covariance function and Variogram are two converse concept. Variogram is model of spatial variability, but covariance function is model of spatial dependency, both are as function of separating distance. The covariance function will show decreasing of correlation as distance increase, conversely, variogram will show increasing of variability as distance increase. Covariance function define as.

$$C(h) = \frac{1}{n(h)} \sum_{\alpha=1}^{N(h)} Z(u_\alpha) \cdot Z(u_\alpha + h) - m_0 \cdot m_{+h} \qquad (11)$$

Where m_0 and m_{+h} are the means of the tail and head values:

$$m_o = \frac{1}{N(h)} \sum_{\alpha=1}^{N(h)} Z(u_\alpha) \text{ and} \qquad (12)$$

$$m_{+h} = \frac{1}{N(h)} \sum_{\alpha=1}^{N(h)} Z(u_\alpha + h) \qquad (13)$$

and correlation define as

$$\rho(h) = \frac{C(h)}{\sqrt{\sigma_0 \cdot \sigma_{+h}}} \qquad (14)$$

σ_0 and σ_{+h} are the corresponding standard deviations:

$$\sigma_0 = \frac{1}{N(h)} \sum_{\alpha=1} [Z(u_\alpha) - m_0]^2 \qquad (15)$$

$$\sigma_{+h} = \frac{1}{N(h)} \sum_{\alpha=1}^{N(h)} [Z(u_\alpha + h) - m_{+h}]^2 \qquad (16)$$

Random field modeling is the model to characterize continuous spatial fluctuations of a soil property within a soil unit and the proposed of trend analysis is to visualize and predicts the data by using the regression. General form for field modeling is described as

$$P(\underline{x}) = m_p(\underline{x}) + f_p(\underline{x}) \qquad (17)$$

where

$\underline{x}$ = vector of spatial coordinates ; $\underline{x} = (xyz)^T$

$P(\underline{x})$ = soil properties at location $\underline{x}$

$m_p(\underline{x})$ = the average trend

$f_p(\underline{x})$ = zero mean

The statistical method of trend analysis usually presume zero mean and non-zero variance for residual which are random variables. Both simple linear and nonlinear regression analysis are applied for optimum solution. The general equation using in nonlinear regression by Gaussian define as

$$f = a*\exp(-0.5*(((x-x\ )/b)^2+((y-y\ )/c)^2\ )) \qquad (18)$$

3. Discussion

According to this paper, at present, 1163 bore holes of vane shear test and undrain shear strength(Su) have been collected and mapping in to 455 blocks. By using basic statistical analysis which given the average value of Su, variance, standard deviation and its distribution for each bore hole. As mention, each block which governs the area of one square kilometer regarding to the number of bore hole in that block, the number of bore hole has varied from 1 to 22. Since the small number of bore hole in one block has occurred the statistical treatment is difficult, grouping blocks seem to be more convenient and satisfy in term of statistical approach. This paper has chosen one grouping block "group A" (Fig. 3) to be analyzed, the mean value of Su and related statistical parameters and its distribution of very soft clay are shown in Fig. 4.

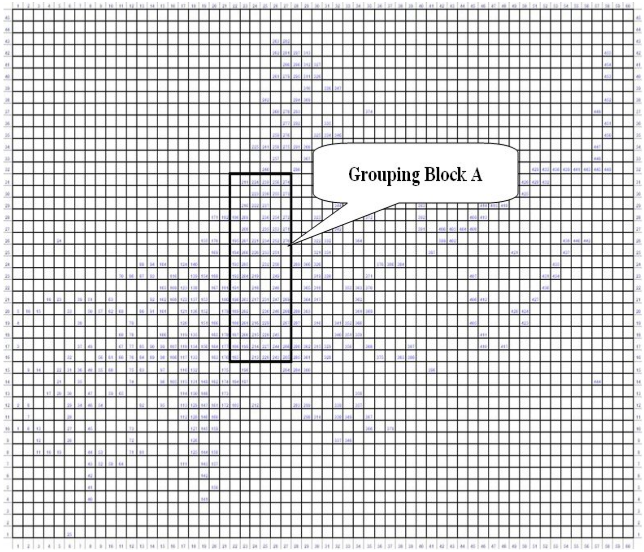

Fig.3 sampling data grouping block A

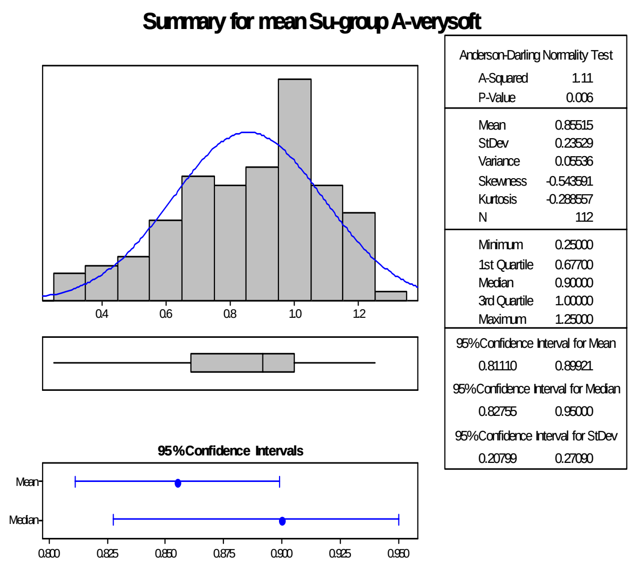

Fig.4 Descriptive statistical parameters grouping block A

This grouping block A has local coordinate 21,000 to 27,000 in east direction and 15,000 to 31,000 in north direction, presenting 96 blocks 112 bore hole in total and to this number 21 blocks lack of data. Geostatistics analysis, after introducing the basic statistical parameters such as mean value of Su, variance, standard deviation and cov. of grouping block A, has accompanied the variogram model to determine the spatial variation as shown in Fig.5. The spatial variation increase as distance move away from the point and covariance function has decreased as increase distance.

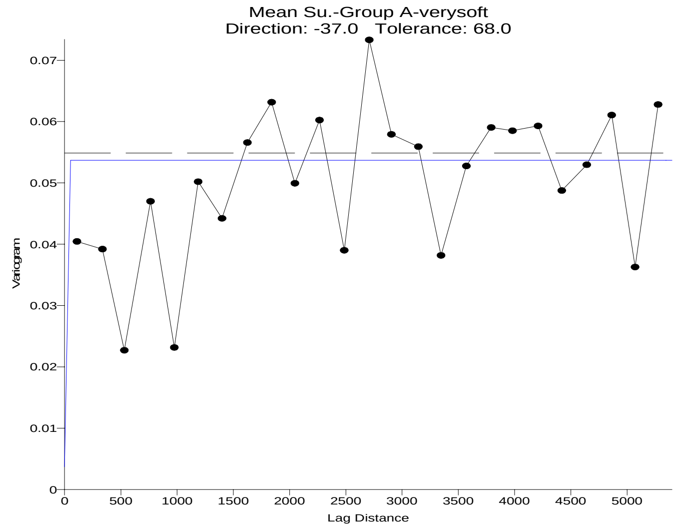

Fig. 5 Variogram mean Su group A - verysoft

In predicting the value of Su (very soft clay) over the area of grouping block A, nonlinear regression by Gaussian method is applied. As shown in Fig. 6(a,b)

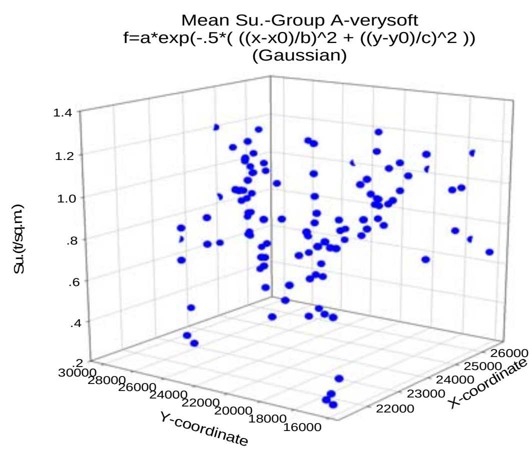

Fig.6 (a) mean Su group A – very soft

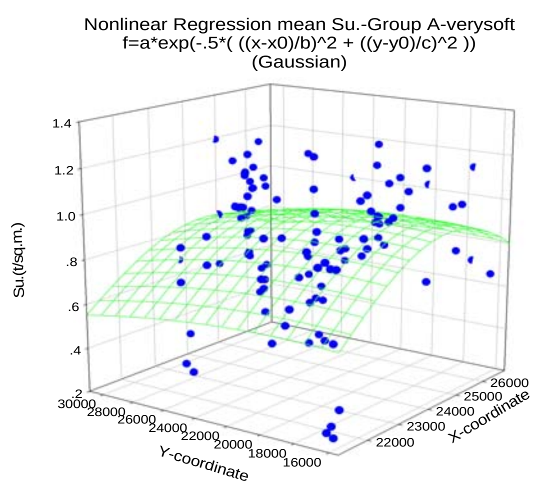

Fig.6 (b) nonlinear regression mean Su group A – very soft

This paper presents the reliability-base design by applying the first-order second moment, first-order reliability method (Ang and Tang, 1984) or using Monte-Carlo simulation etc., and the meaning of reliability will express the probability of success or

reliability = 1- probability of failure and (19)

$$P[\text{failure}] = \int_0^{\alpha} [\int_0^{l} f_r(r)dr] f_L(l)dl \quad (20)$$

However, the reliability index (β) is defined as the difference between the mean value of resistance and the mean value of design load divided by the standard deviation of the difference between resistance and design load. On the other hand, the approximated reliability index is also given by the ratio of the natural logarithm of the mean factor of safety to the COV. of factor safety

reliability index (β) = ln mean FS. / COV. of safety factor (21)

The expression of safety factor, in general, can be define as the ratio of resistance(R),to applied load(L), or

FS. = R/L (22)

the failure event is given by FS. < 1 for all individual performance functions as shown in Fig. 7(a,b)

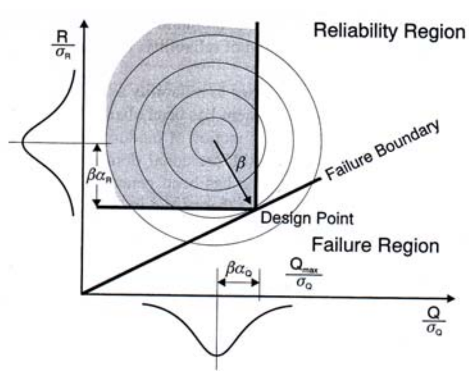

Fig.7 (a) Component of the reliability

From: Pavel Marek, Milan Gustar and Thalia Anagnos, (1996)

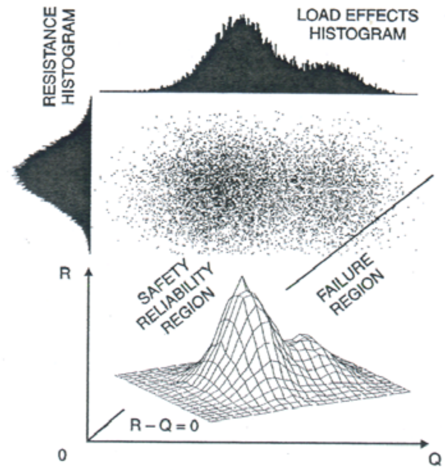

Fig.7 (b) Determination of reliability using the simulation technique

From : Pavel Marek, Milan Gustar and Thalia Anagnos, (1996)

Since the resistance and the load are subjected to uncertainties and define as random variables, thus, safety factor (FS.) should be as random variables and using pdf. The relationship between the probability of failure, the probability distribution of resistance and design load, and the distribution of the safety factor are shown in Fig.8(a,b).

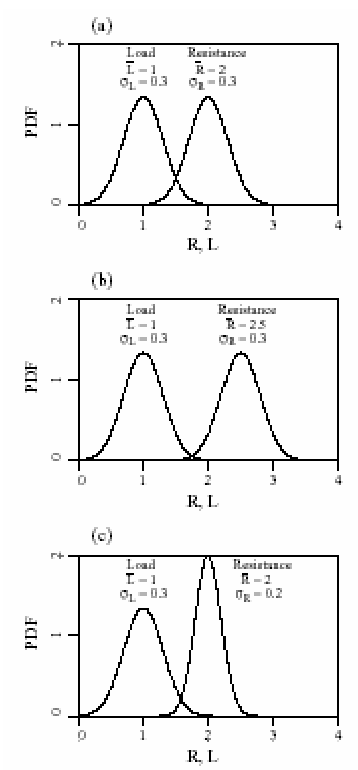

Fig.8 (a) PDF.of load and resistances

From: Gordon A. Fenton, (1997)

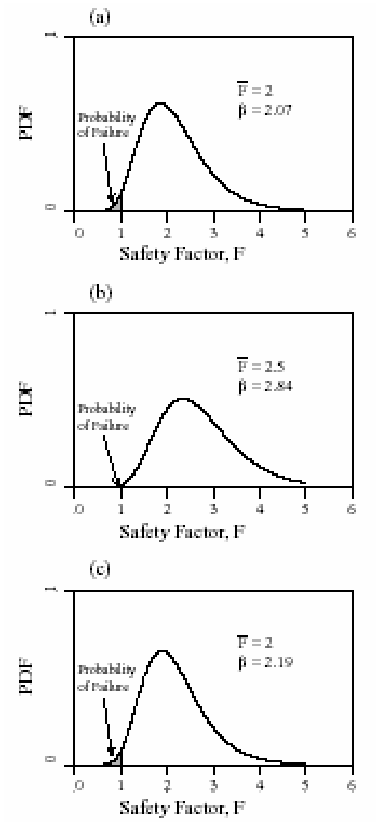

Fig.8 (b) PDF. of safety factor

From: Gordon A. Fenton, (1997)

4. Conclusion

This research reviews a philosophy of safety factors which more uniform level of safety throughout the system. All possible outcome of partial safety factor are applied separately to the load effect and resistance and is benefited to geotechnical engineers for making decision on their works and design criteria. This provides a framework for design practice to new foundation concept, evidently, that is cost saving and more improved reliability.

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