# THE SAFETY FACTOR AND RELIABILITY ANALYSIS FOR THE DEEP MIXING COLUMNS

ILMR, Saga University , Master student, ○ Yassir Jabeur,
ILMR, Saga University, Doctoral student , Toshiyuki Himeno
ILMR, Saga University, Lecturer research fellow , Sailesh Shrestha
ILMR, Saga University, Professor, . Takenori Hino
ILMR, Saga University, Visiting associate professor , Tri Harianto

## 1. INTRODUCTION

Table 1: Characteristic of the execution of the in-situ stabilized columns

| | soil cement column A | soil cement column B | soil cement column C | soil cement column D |
|---|---|---|---|---|
| Type of cement | Cement-based solidifying material | Cement-based solidifying material | Cement-based solidifying material | Cement-based solidifying material |
| water cement ratio (w/c) | 1.5 | 1 | 1.5 | 0.8 |
| Type of blade | Conventional blade. | Improved blade. | Improved blade. | Improved blade. |
| cement content | 110 $kg/m^3$, 170 $kg/m^3$ | 110 $kg/m^3$ , 170 $kg/m^3$ | 150 $kg/m^3$ , 200 $kg/m^3$ | 110 $kg/m^3$ , 170 $kg/m^3$ |

In any civil engineering project, It is obvious that risks are inherent, for this reason the perception of existence of such risks is needed. Additionally, the method of reliability estimation must consider between the economical context (cost) and safety (reliability). For the sake of an adequate estimation risks that consider the uncertainties integrated in the factor of safety, a reliability analysis is justified as very valuable and reasonable mean to assist into taking the safe and appropriate judgment for design parameters. Even though, the choice of the factor of safety relies on the prior experience and engineering judgment. The reliability of the coefficient of the factor of safety strongly depend on the correctness of the design parameters such as strength, loads or characteristic of the material, in which each parameter need to decided as definite values, despite that fact every geotechnical parameter possess a range of variation that can be uncertain.

The laboratory mix test results are used by the design engineer in order to assume and decide the design parameters. In addition, the contractor also work with the same test results to make the planning of the field trial test and obtain representative data for the design procedure. In the field, the reliability and certainty of the unconfined compressive strength of the deep mixing column based on the core samples is depending on the quality of the core sample. For the field trial test, deep mixing columns are performed as representative data, where in each core boring, core samples are seized all over the depth of the columns for the sake of verification of the uniformity of the deep mixing columns, Using the core samples the engineering properties are judged from the unconfined compressive strength on samples at 28 day curing, Kitazume et al. (2013).

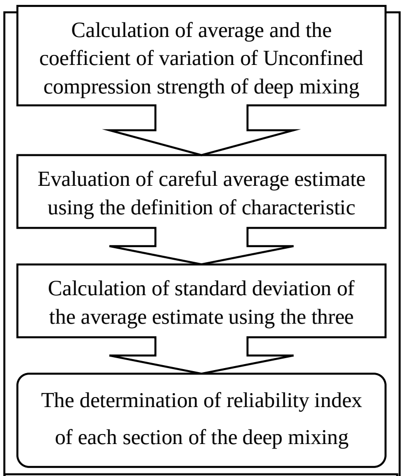


Fig. 1 : Flowchart of calculation of reliability index .

## 2. METHODOLOGY

### 2.1 Three sigma rule

Three-Sigma Rule is a rule of thumb that was defined by Dai and Wang (1992), the rule uses the fact that for a normally distributed parameter, 99.73% of all values lies within three standard deviations of the average. So, between the HCV ( Highest conceivable value) of the parameter, and the LCV (Lowest conceivable value) of the parameter above and below the average value these are approximately three standard deviations. It can be estimated by the Eq. (1), Duncan, (2000):

$$\sigma = (HCV - LCV)/6 \quad (1)$$

### 2.2 The careful average estimate of unconfined compression strength of the deep mixing columns

As stated by the Eurocode 7, the characteristic values of geotechnical parameters should be defined according to the results collected from the field and laboratory tests and inferred values, in the case the geotechnical structure have the ability to transfer loads from a weak soil zone to a stronger one , the careful average estimate is used , Barends, (1999). The characteristic values ($X_k$) of the parameters, can be defined with statistical methods given the consideration of a normal distribution with the Eq. (2), Bond et al. (2006) ; Attila , (2011). Where $X_m$ is the expected value, which can be estimated by the mean of the data; $k_n$ is a statistical parameter depending on the number of samples and confidence level, and $COV_x$ is the coefficient of variation, assumed according to previous knowledge, or calculated from measurement results.

$$X_k = X_m \cdot (1 \pm k_n \cdot COV_x) = X_m \pm k_n \cdot \sigma_x \quad (2)$$

Keywords: Deep mixing method , reliability index , unconfined compressive strength.
Contact address: 1 Honjo, Saga, 840-8502, Institute of Lowland and Marine Research, Saga university, Tel: +81-952-28-8582.

### 2.3 The Reliability Index

The Reliability Index is a coefficient that demonstrates the reliability of an engineering system, this index do not indicate the mechanics of the problem alone, it take into account the uncertainties in the input random variables, Whitman, (1984). The calculation of reliability index assuming a log normal distribution for the factor of safety can be calculated using the Eq. (3) where In the equation $\mu_D$, $\mu_C$are the average and $COV_D$, $COV_C$ are the variation coefficients of the demand and capacity.

Table 2 : The reliability index β of the average estimate

| | soil cement column A | | soil cement column B | | soil cement column C | | soil cement column D | |
|---|---|---|---|---|---|---|---|---|
| cement content (kg/m3) | 110 | 170 | 110 | 170 | 150 | 200 | 110 | 170 |
| COV (D) | 5% | 5% | 5% | 5% | 5% | 5% | 5% | 5% |
| COV (C) | 13% | 11% | 9% | 13% | 13% | 11% | 11% | 9% |
| Factor of safety Fs | 1.08 | 2.41 | 1.38 | 2.42 | 1.49 | 2.06 | 1.57 | 2.68 |
| The reliability index β | 0.57 | 7.53 | 3.11 | 6.23 | 2.42 | 6.09 | 3.53 | 9.73 |

$$\beta\ (\text{lognormal}) = \frac{\ln\left(\frac{\mu_C}{\mu_D}.\sqrt{\frac{(1+(COV_D)^2)}{(1+(COV_C)^2)}}\right)}{\sqrt{\ln((1+(COV_C)^2).(1+(COV_D)^2))}} \qquad (3)$$

Moreover, the Reliability Index permits to make the comparison of the reliability between different structures or modes of performance without the need to calculate the value of the probability and to estimate the probability of unsatisfactory performance of geotechnical structures or system. In the study, the reliability analysis was calculated for the in-situ strength for soil cement columns. In fact, the three sigma rule , it is mostly used when it is difficult to get more data or samples . Since, large number of separated cores from the same column are not available, it is better to use the HCV and LCV as upper and lower characteristic value of the average estimate for a confidence level close to 99.9 % (Fig. 1). Using this index we could compare the reliability and performance level of multiple columns considering the average estimate of the unconfined compression strength of core sample in situ, and the variability of in-situ strength of each column.

## 3 . RESULTS AND DISCUSSION

In this study, the field trial test results as the in situ-test of the representative data are utilized for the analysis, the location where the tests were performed is in Saga lowland for a design strength of 600 (kN/m$^2$).The distance between each column is 4 m. In the columns two kind of cement content were using for the columns, for the upper part 110 kg/m$^3$ and 150 kg/m$^3$. However, for the lower part 170 kg/m3 and 200 kg/m$^3$ was used due to the presence of organic matter (Table 1).. According of the results, in the case of use of 170 kg/m$^3$ for the columns A, B, and D and 200 kg/m$^3$ for the core C, the analysis shows that for the lower part , the reliability index is good. But, for the upper part where 110 kg/m$^3$ for the core A, B, and D and 150 kg/m$^3$ for the core C (Table 2). Only the columns B, and D have reliability index higher than 3 and an above average performance level (Fig. 2).

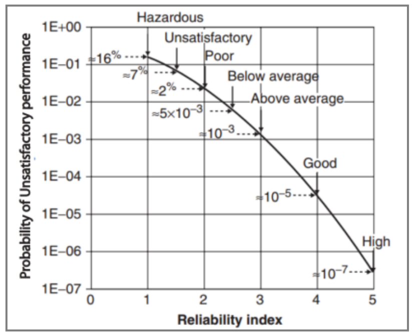


Fig. 2 : Relationship between reliability index and Unsatisfactory performance level (classifications proposed by US Army Corps of Engineers), (Phoon , 2008)

## 4 .CONCLUSION

Considering the results of trail field columns for the process of the design of deep mixing method and in terms of average of in-situ strength and its variability, the conditions of execution of the columns C, and D have higher reliability and they are recommended for the performance of the deep mixing columns for the selected design strength. This method helps us make the correct decision for choosing the execution’ conditions for the deep mixing method based on the trail field columns.

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