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Reliability Analysis of Bearing Capacity of Soil of Combined Pile Raft Foundation (CPRF) of Historic Dharahara

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ABSTRACT: When the raft foundation alone does not fulfil the design requirement, it may be possible to enhance the performance of the raft by economical addition of piles to transfer the heavy load to soft soil with a rather low total or differential settlement called a combined pile raft foundation (CPRF). The proposed twenty-one storey Dharahara tower at Sundhara, Kathmandu is being constructed with CPRF.This paper focuses on the reliability index, the probability of failure and reliability of Dharahara. Statistical analysis is carried out to determine the mean and variance of log-normally distributed geotechnical uncertainty parameters cohesion, unit weight, friction angle and the normally distributed loading on the foundation. First, the limit equilibrium performance function equation of bearing capacity is prepared using a First Order Reliability Method (FORM) and then solving the value of reliability index by coding on C Programming Language. Obtained value is validated with Euro Code-Basis of Structural Design. The results show that the reliability of the designed foundation system of Dharahara is 0.99999872% and the probability of failure is 0.00000128%. Sensitivity analysis is performed by varying uncertainty parameters and the result shows that friction angle is more sensitive than the other three parameters.

KEYWORDS: Combined pile raft foundation, Historic Dharahara, Reliability Index, Sensitivity Analysis, Performance function, Uncertainty parameters

1. INTRODUCTION

To carry out the excessive loads that come from the superstructures like high-rise buildings, towers, bridges, power plants or other civil structures and to reduce excessive total and differential settlement, only pile or raft foundation is not feasible because of the load shearing mechanism of the pile-raft-soil (Ayuluri and Krishna, 2017). Therefore, the combination of two separate foundation systems, namely Combined Piled Raft Foundations (short CPRF) has been developed (Clancy and Randolph, 1993). However, the standards and design rules for CPRF are not available up to now (Ahner, 1998). The problem in the design of Combined Piled-Raft Foundations has becomes more and more important in the recent past years.

Geotechnical design can be done either by deterministic or Probabilistic approach. A deterministic approach is the conventional one in which the available equation and charts are used to assess the allowable bearing capacity. Reliability is the ability of a structure to comply with given requirements under specified conditions during the intended life, for which it was designed. The same definition as in ISO 2394 is provided in Euro code EN 1990 (BS EN 1990:2002) that the reliability covers the load bearing capacity, serviceability as well as the durability of a structure. The purpose of the investigation is to elaborate on the safety concept for the CPRF.

2. MATERIAL AND METHODS

2.1 Variation of soil and loading parameters

To carry out a reliability analysis, a detailed study of the related uncertainties is essential. In regards to the bearing capacity of CPRF foundations, there are many By means of this equation, safe domains are separated from unsafe domains. The safe domain is characterized by $g > 0$ and failure

2.2 Reliability Methods

Reliability of the system is expressed in the form of reliability index (β) which is related to the probability of failure of the system (P_f). In this study, Reliability analysis performed for bearing capacity of pile raft foundation using the First Order second level Reliability Method (FORM II). FORM II modelled uncertain parameter by the mean values and the standard deviations and by the correlation coefficients between stochastic variables.

2.3 Limit state function

On the basis of a mechanical model, the selected limit state is represented by the function:

$$g = Q - S, \qquad (1)$$

Q is the capacity of the structure and S is the supply on a structure. The performance function g(X) is a function of capacity and demand variables (X_1, X_2, …,X_n) which are

$$g(X_1, X_2, \cdots\cdots\cdots, X_n)\begin{cases} > 0 & \textit{safe state} \\ = 0 & \text{limit state} \\ < 0 & \textit{failure state} \end{cases}$$

basic random variables for both Q and S such By means of this equation, safe domains are separated from unsafe domains.

The safe domain is characterized by $g > 0$ and failure occur if $g \leq 0$.

2.4 Reliability Index

i. Reduced Variables

It is convenient to convert all random variables to their standard form, which is a non-dimensional form of the variables. For the basic variables Q and S, the standard forms can be expressed as:

$$Z_Q = \frac{R-\mu_Q}{\sigma_Q}, \quad Z_S = \frac{R-\mu_S}{\sigma_S}$$

The variables Z_Q and Z_S, are sometimes called reduced variables. By rearranging Equation, the capacity Q and the supply S can be expressed in terms of the reduced variables as follows:

$R=\mu_Q+Z_Q\sigma_Q$, $R=\mu_S+Z_S\sigma_S$

The limit state function g(Q, S) = Q-S can be expressed in terms of the reduced variables by using the above equation. The result is

$g(Z_Q, Z_S) = \mu_Q+Z_Q\sigma_Q-\mu_S - Z_S\sigma_S = (\mu_Q-\mu_S) + Z_Q\sigma_Q - Z_S\sigma_S$

For any specific value of g (Z_Q, Z_S), this equation represents a straight line in the space reduced variables Z_Q and Z_S. The line corresponding to g (Z_Q, Z_S) =0 separates the safe and failure domain in the space of reduced variables.

The reliability index is the shortest distance from the origin of reduced variables to a hyper plane is also illustrated in Figure 1. Using geometry, we can calculate the reliability index (shortest distance) from the following formula.

$$\beta = \frac{\mu_Q - \mu_S}{\sqrt{\sigma_Q^2+\sigma_S^2}}$$

where β is the inverse of the coefficient of variation of the function g (Q, S) = Q-S When Q and S are uncorrelated for normally distributed random variables, it can be shown that the reliability index is related to the probability of failure by

$\beta = -\Phi^{-1}(P_f)$ or $P_f = \Phi(-\beta)$

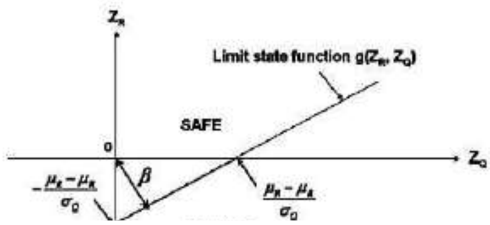

Figure 1 - Reliability index defined as the shortest distance in the space of reduced variables (Xue and Nag, 2011).

Where, ϕ is the cumulative distribution function of the standardized normal distribution. The relation between ϕ and β is given in Table 1.

Table 1- Relation of Reliability index β with the probability of failure Pf, (EN 1990:2002)

Reliability index (β)	1.28	2.32	3.09	3.72	4.27	4.75	5.2
Probability of failure (Pf)	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}

Analysis, Result and Discussion

In this study, the behaviour of the piled raft foundation systems under axial loads and properties of soil is taken from the real case of Dharahara to prepare the limit equilibrium equation of performance function computed in C Programming language coding.

Performance Function

The Combined Piled-Raft Foundations consist of two elements: raft and piles. Thus, the resistance of the CPRF can be shown as follows:

$Q_{CPRF} = Q_{raft} + Q_{piles}$

Q_{raft} is the capacity of the raft and Q_{piles} is the capacity of the piles. All variables are random

$Q_u=A_{Raft}.q_{Raft}+A_{Base}.q_{Base}+A_{Friction}.q_{Friction}$

$q_{Raft}=C' N_c F_{cs} F_{cd}+q(N_q-1)F_{qs}F_{qd}+0.5\gamma B N_\gamma F_{\gamma s}F_{\gamma d}$

Where,

$N_q=\tan^2(45+Ø'/2)\,e^{\pi\tan Ø'}\cdot N_c=(N_q-1)\cot Ø'=\{\tan^2(45+Ø'/2)\,e^{\pi\tan Ø'}-1\}\cot Ø'$

$N_\gamma=2(N_q+1)\tan Ø'=2\{\tan^2(45+Ø'/2)\,e^{\pi\tan Ø'}+1\}\tan Ø'$

Raft Capacity

Shape and depth factor of designed Dharahara of raft dimension 35.89m x 33.61m x 2m is calculated from these formulas (Arora, 7th edition)

$F_{cs}=1+0.2B/L$, $F_{qs}=1+0.2B/L$, $F_{\gamma s}=1-0.4B/L$

$F_{cd}=1+0.35(D_f/B)$, $F_{qd}=1+0.35(D_f/B)$, $F_{\gamma d}=1$

$q_{Raft}= C' N_c *1.18*1.02+\gamma*2*(N_q-1)*1.18*1.02+0.5*\gamma*33.61*N_\gamma*0.625$

$Q_{Raft}= A_{Raft}.q_{Raft}=1451.85\,C' N_c+2903.71\gamma(N_q-1)+12669.53\gamma N_\gamma$

Pile Capacity

For the case of a pile, 98 numbers of a 21m and 80 numbers of 30 m piles of 750mm diameter section are designed.

Base Resistance of Pile Group (98 nos of 21m pile+80 nos of 30m pile)

$Q_{Base}=NE\,(q_{Base}.A_{Base})_{21mPile}+NE\,(q_{Base}.A_{base})_{30mPile}$

$= 98*0.79*\pi*0.75^2/4*(C' N_c F_{cs} F_{cd}+\gamma D_f N_q F_{qs} F_{qd})_{21mPile}+80*0.63*\pi*0.75^2/4*(C' N_c F_{cs} F_{cd}+\gamma D_f N_q F_{qs} F_{qd})_{30mPile}$

$=843.91\,C' N_c+21328.27\gamma N_q$

Similarly, for friction resistance of pile is calculated as,

$Q_{Friction}=NE\,(q_{Friction}.A_{Friction})_{21mPile}+NE\,(q_{Friction}.A_{Friction})_{30mPile}$

$=98*0.79*\pi*0.75(K\sigma'_o\tan\delta')_{21mPile}+80*0.63*\pi*0.75(K\sigma'_o\tan\delta')_{30mPile}$

$K=1.8(1-\sin Ø')$ and $\delta'=0.8Ø'$ (Das, 7th edition)

[for Z=0 to 15D, $f_{15D}=K\sigma'_o\tan\delta'$, and for z=15D to L, $f=f_{15D}$] (Das, 7th edition)

$=262323.46(1-\sin Ø')\,\gamma\tan 0.8Ø'$

(Kumar and Choudhury, 2018) proposed prediction method to estimate both pile-raft and raft-pile interaction factors.

$Q_u=\alpha_{rp}Q_{Raft}+\alpha_{pr}(Q_{Base}+Q_{friction})$

Where, $\alpha_{rp}=0.57$= raft-pile interaction factor and $\alpha_{pr}=0.86$= pile-raft interaction factor.

$=1553.32C'\{\tan^2(45+Ø'/2)e^{\pi\tan Ø'}-1\}\cot Ø'+19997.43\gamma\{\tan^2(45+Ø'/2)e^{\pi\tan Ø'}\}-1655.11\gamma+7221.63\gamma[2\{\tan^2(45+Ø'/2)\,e^{\pi\tan Ø'}+1\}\tan Ø']+225598.17(1-\sin Ø')\gamma\tan 0.8Ø'$

The Normal distribution is generally applicable fundamental distribution, in math and engineering. It is the simplest distribution to understand, but is not directly relevant to soils and rocks **(Look and Griffiths, 2004)** . In geotechnical parameter whose values doesn't exist in negative value are distribute in log-normal distribution. Thus, in this study log-normal distribution is presented for the soil strength parameter and a normal distribution for applied load. The equation of bearing capacity obtained from Meyerhof equation in terms of cohesion, unit weight and friction angle are not a linear, Thus Non-linear analysis is carried out to determine the Reliability index using the First Order Reliability Method (FORM).

$X=\mu \exp(-ZV)$

$C'=\mu_c \exp(-Z_cV)$, $\gamma=\mu_\gamma \exp(-Z_\gamma V)$, $\phi'=\mu_\phi \exp(-Z_\Phi V)$

Choose an arbitrary first design point $Z=\beta\alpha$

i.e, $Z_c=\beta\alpha_c$, $Z\gamma=\beta\alpha_\gamma$, $Z_\Phi=\beta\alpha_\Phi$

$=1553.32*\mu_c \exp(-\alpha_c\beta V_c)*\{\tan^2(45+\mu_\phi \exp(-\alpha_\phi \beta V_\phi)/2)*e^{\pi\tan(\mu_\phi \exp(-\alpha_\phi \beta V_\phi))}-1\}*$
$\mathrm{Cot}(\mu_\phi \exp(-\alpha_\phi \beta V_\phi))+19997.43*\mu_\gamma \exp(-\alpha_\gamma \beta V_\gamma)*\{\tan^2(45+\mu_\phi \exp(-\alpha_\phi \beta V_\phi)/2)*e^{\pi\tan(\mu_\phi \exp(-\alpha_\phi \beta V_\phi))}\}-1655.11*\mu_\gamma \exp(-\alpha_\gamma \beta V_\gamma)+7221.63*\mu_\gamma \exp(-\alpha_\gamma \beta V_\gamma)$
$[2\{\tan^2(45+\mu_\phi \exp(-\alpha_\phi \beta V_\phi)/2)*e^{\pi\tan(\mu_\phi \exp(-\alpha_\phi \beta V_\phi))}+1\}^*\tan(\mu_\phi \exp(-\alpha_\phi \beta V_\phi))]+$
$225598.17*\{1-\sin(\mu_\phi \exp(-\alpha_\phi \beta V_\phi))\}*\mu_\gamma \exp(-\alpha_\gamma \beta V_\gamma)*$
$\tan\{0.8*(\mu_\phi \exp(-\alpha_\phi \beta V_\phi))\}$

In order to address the variable uncertainty and randomness of bearing capacity, Mean, Standard deviation and coefficient of variation are applied for each random variable with the geotechnical report and it could be verified by some reference of literature.

$\sigma_c=1.67$, $\mu_c=6.42$,$V_c=0.26$, $\sigma_\gamma=1.54$, $\mu_\gamma=16.75$, $V_\gamma=0.09$, $\sigma_\phi=4.99$, $\mu_\phi=26.47$, $V_\phi=0.18$

Performance function i.e Safety Marginal value is calculated as,

$g=Q-S=0$

Where,

g=Marginal value, Q=Ultimate load carrying capacity, i.e Demand

S= Applied Load i.e Supply=362298.9KN

At limit equilibrium,

$[9972.31*\exp(-0.26\alpha_c\beta)*\{\tan^2(45+13.23\exp(-0.18\alpha_\phi \beta))*e^{\pi\tan(26.47\exp(-0.18\alpha_\phi \beta))}-1\}*$
$\mathrm{Cot}(26.47\exp(-0.18\alpha_\phi \beta))+334956.95\exp(-0.09\alpha_\gamma \beta)*\{\tan^2(45+13.23\exp(-0.18\alpha_\phi \beta))*e^{\pi\tan(26.47\exp(-0.18\alpha_\phi \beta))}\}-27723.09\exp(-0.09\alpha_\gamma \beta)+120962.3\exp(-0.09\alpha_\gamma \beta)$
$[2\{\tan^2(45+13.23\exp(-0.18\alpha_\phi \beta))*e^{\pi\tan(26.47\exp(-0.18\alpha_\phi \beta))}+1\}^*\tan(26.47\exp(-0.18\alpha_\phi \beta))]$
$+3778769.34*\{1-\sin(26.47\exp(-0.18\alpha_\phi \beta))\}*\exp(-0.09\alpha_\gamma \beta)*$
$\tan\{0.8*(26.47\exp(-0.18\alpha_\phi \beta))\}]-362298.9=0$

$$\beta=1/(\alpha_\gamma{}^*-0.09)*[\ln[1/27723.09*[9972.31*\exp(-0.26\alpha_c\beta)*\{\tan^2(45+13.23\exp(-0.18\alpha_\phi\beta))*$$
$$e^{\pi\tan(26.47\exp(-0.18\alpha_\phi\beta))}-1\}*\mathrm{Cot}(26.47\exp(-0.18\alpha_\phi\beta))+334956.95\exp(-0.09\alpha_\gamma\beta)*$$
$$\{\tan^2(45+13.23\exp(-0.18\alpha_\phi\beta))*e^{\pi\tan(26.47\exp(-0.18\alpha_\phi\beta))}\}+120962.3\exp(-0.09\alpha_\gamma\beta)$$
$$[2\{\tan^2(45+13.23\exp(-0.18\alpha_\phi\beta))*e^{\pi\tan(26.47\exp(-0.18\alpha_\phi\beta))}+1\}^*\tan(26.47\exp(-0.18\alpha_\phi$$
$$\beta))]+3778769.34*\{1-\sin(26.47\exp(-0.18\alpha_\phi\beta))\}*\exp(-0.09\alpha_\gamma\beta)*$$
$$\tan\{0.8*(26.47\exp(-0.18\alpha_\phi\beta))\}]-362298.9]]$$

The partial derivative of performance function with respect to Z_c, Z_γ and $Z_\varnothing$

$$\alpha_c=\frac{\partial g}{\partial Z_c}=-2592.8*\exp(-0.26\alpha_c\beta)*\{\tan^2(45+13.23\exp(-0.18\alpha_\phi\beta))*$$
$$e^{\pi\tan(26.47\exp(-0.18\alpha_\phi\beta))}-1\}*\mathrm{Cot}(26.47\exp(-0.18\alpha_\phi\beta))$$

$$\alpha_\gamma=\frac{\partial g}{\partial Z_\gamma}=-30146.1\exp(-0.09\alpha_\gamma\beta)*\{\tan^2(45+13.23\exp(-0.18\alpha_\phi\beta))*e^{\pi\tan(26.47\exp(-0.18\alpha_\phi\beta))}\}+$$
$$2495.08\exp(-0.09\alpha_\gamma\beta)-10883.4\exp(-0.09\alpha_\gamma\beta)[2\{\tan^2(45+13.23$$
$$\exp(-0.18\alpha_\phi\beta))*e^{\pi\tan(26.47\exp(-0.18\alpha_\phi\beta))}+1\}^*\tan(26.47\exp(-0.18\alpha_\phi\beta))]$$
$$-340089.2*\{1-\sin(26.47\exp(-0.18\alpha_\phi\beta))\}*\exp(-0.09\alpha_\gamma\beta)*$$
$$\tan\{0.8*(26.47\exp(-0.18\alpha_\phi\beta))\}$$

$$\alpha_\phi=\frac{\partial g}{\partial Z_\varnothing}=9972.31*\exp(-0.26\alpha_c\beta)*\{-4.76*\tan(45+13.23\exp(-0.18\alpha_\phi\beta))*\sec^2(45+$$
$$13.23\exp(-0.18\alpha_\phi\beta))*e^{\pi\tan(26.47\exp(-0.18\alpha_\phi\beta))}*\mathrm{Cot}(26.47\exp(-0.18\alpha_\phi\beta))-14.96$$
$$\tan^2(45+13.23\exp(-0.18\alpha_\phi\beta))*e^{\pi\tan(26.47\exp(-0.18\alpha_\phi\beta))}*\sec^2(26.47\exp(-0.18\alpha_\phi\beta))*$$
$$\mathrm{Cot}(26.47\exp(-0.18\alpha_\phi\beta))+4.76\tan^2(45+13.23\exp(-0.18\alpha_\phi\beta))*e^{\pi\tan(26.47\exp(-0.18\alpha_\phi\beta))}$$
$$*\mathrm{Cosec}^2(26.47\exp(-0.18\alpha_\phi\beta))-4.76\mathrm{Cosec}^2(26.47\exp(-0.18\alpha_\phi\beta))\}+334956.95$$
$$\exp(-0.09\alpha_\gamma\beta)*\{4.76\tan(45+13.23\exp(-0.18\alpha_\phi\beta))*\sec^2(45+13.23\exp(-0.18\alpha_\phi\beta)$$
$$)*e^{\pi\tan(26.47\exp(-0.18\alpha_\phi\beta))}-14.96\tan^2(45+13.23\exp(-0.18\alpha_\phi\beta))*e^{\pi\tan(26.47\exp(-0.18\alpha_\phi\beta))}*$$
$$\sec^2(26.47\exp(-0.18\alpha_\phi\beta))\}+120962.3\exp(-0.09\alpha_\gamma\beta)[-9.52*\tan(45+13.23$$
$$\exp(-0.18\alpha_\phi\beta))*\sec^2(45+13.23\exp(-0.18\alpha_\phi\beta))*e^{\pi\tan(26.47\exp(-0.18\alpha_\phi\beta))}*$$
$$\tan(26.47\exp(-0.18\alpha_\phi\beta))-14.96\tan^2(45+13.23\exp(-0.18\alpha_\phi\beta))*$$
$$e^{\pi\tan(26.47\exp(-0.18\alpha_\phi\beta))}*\sec^2(26.47\exp(-0.18\alpha_\phi\beta))*\tan(26.47\exp(-0.18\alpha_\phi\beta))-$$
$$9.52*\tan^2(45+13.23\exp(-0.18\alpha_\phi\beta))*e^{\pi\tan(26.47\exp(-0.18\alpha_\phi\beta))}*\sec^2(26.47\exp(-0.18\alpha_\phi$$
$$\beta))-9.52*\sec^2(26.47\exp(-0.18\alpha_\phi\beta))]+3778769.34*\exp(-0.09\alpha_\gamma\beta)*[-$$
$$3.81*\sec^2\{0.8*(26.47\exp(-0.18\alpha_\phi\beta))\}-3.81*\sec^2\{0.8*(26.47\exp(-0.18\alpha_\phi\beta))\}$$
$$*\sin(26.47\exp(-0.18\alpha_\phi\beta))-4.76*\cos(26.47\exp(-0.18\alpha_\phi\beta))*$$
$$\tan\{0.8*(26.47\exp(-0.18\alpha_\phi\beta))\}]$$

$$\alpha_i=\frac{-\frac{\partial g}{\partial Z_i}}{[\sum_1^n(\frac{\partial g}{\partial Z_i})^2]^{\wedge 1/2}}$$

This obtained value of α_i is placed in the equation of β and repeat these processes until the value of β converse. The value of reliability index is obtained from coding in C Programming language. The value of load, cohesion, unit weight and friction angle changing up to $\pm 30\%$ and the variation of reliability index, Probability of failure and Reliability respectively presented in table and graph shown below.

Table 2: Reliability index in changing the uncertainty parameters

	Reliability index at varying uncertainty						
Variation of uncertainty	-30%	-20%	-10%	0%	10%	20%	30%
Cohesion	4.679	4.698	4.717	4.735	4.754	4.773	4.792
Unit Weight	4.291	4.455	4.602	4.735	4.857	4.97	5.075
Friction Angle	4.206	4.404	4.578	4.735	4.882	5.019	5.151
Loading	4.828	4.798	4.767	4.735	4.704	4.672	4.64

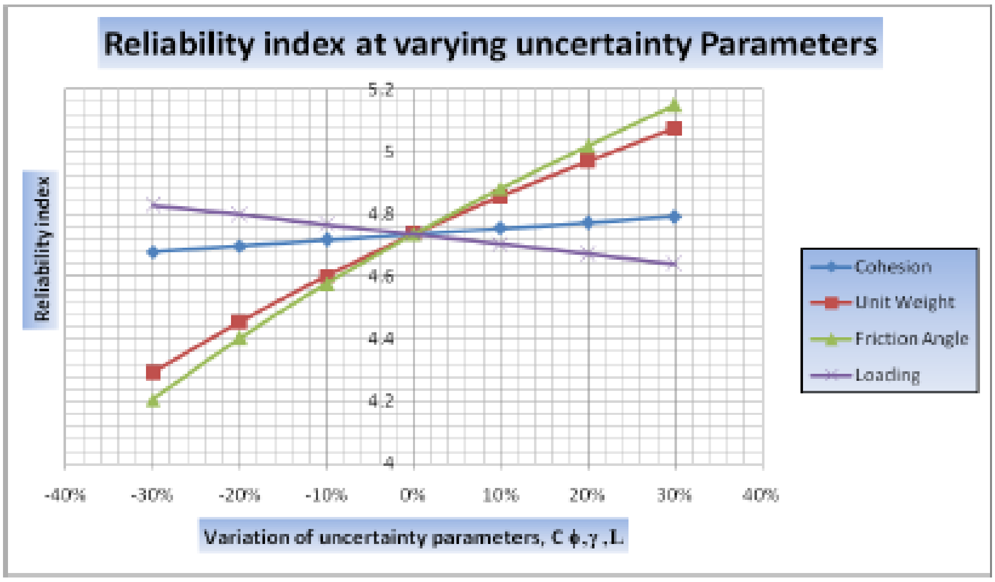

Fig2. Reliability index vs changing the uncertainty parameters Cohesion, Unit weight, Friction angle and load.

The probability of failure determined from a relation with the reliability index is given in table 1.

Table 3: Probability of failure in changing the uncertainty parameters

	Reliability index at varying uncertainty						
Variation of uncertainty	-30%	-20%	-10%	0%	10%	20%	30%
Cohesion	0.00000233	0.00000197	0.00000162	0.00000128	0.00000099	0.00000095	0.00000092
Unit Weight	0.00000961	0.00000653	0.00000377	0.00000128	0.00000079	0.00000056	0.00000035
Friction Angle	0.00002047	0.00000749	0.00000422	0.00000128	0.00000074	0.00000046	0.00000020
Loading	0.00000084	0.00000090	0.00000097	0.00000128	0.00000186	0.00000246	0.00000306

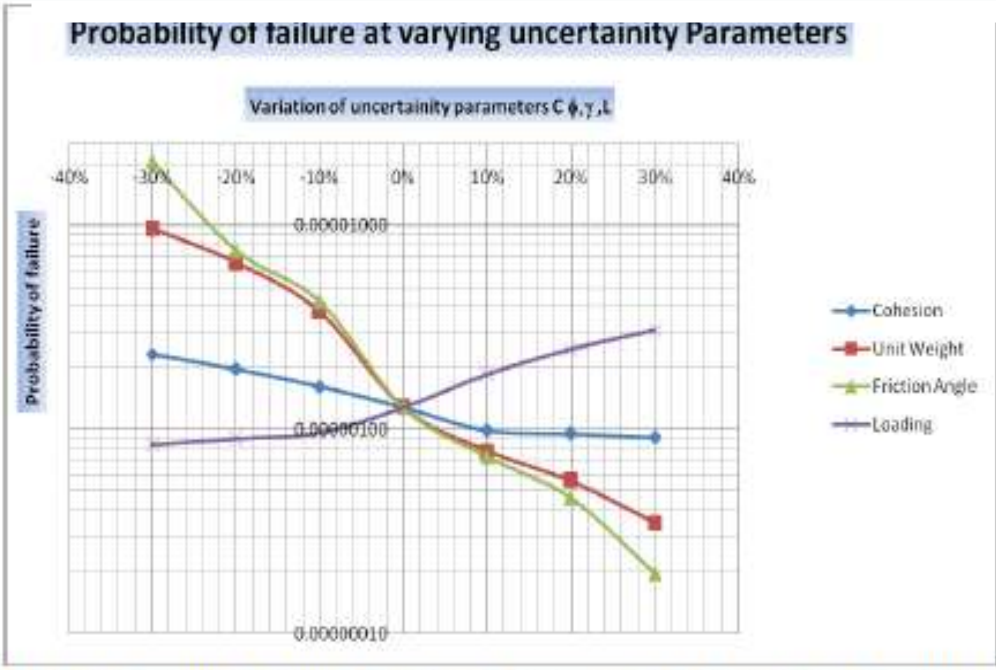

Fig3. Probability of failure vs changes in uncertainty parameters Cohesion, Unit weight, Friction angle and load.

Reliability is the simply complement of the probability of failure. Thus, the sum of reliability and probability of failure is 1.

Table 4: Reliability of failure in changing the uncertainty parameters

	Reliability at varying uncertainty						
Variation of uncertainty	-30%	-20%	-10%	0%	10%	20%	30%
Cohesion	0.99999767	0.99999803	0.99999838	0.99999872	0.99999901	0.99999905	0.99999908
Unit Weight	0.99999039	0.99999347	0.99999623	0.99999872	0.99999921	0.99999944	0.99999965
Friction Angle	0.99997953	0.99999251	0.99999578	0.99999872	0.99999926	0.99999954	0.99999980
Loading	0.99999916	0.99999910	0.99999903	0.99999872	0.99999814	0.99999754	0.99999694

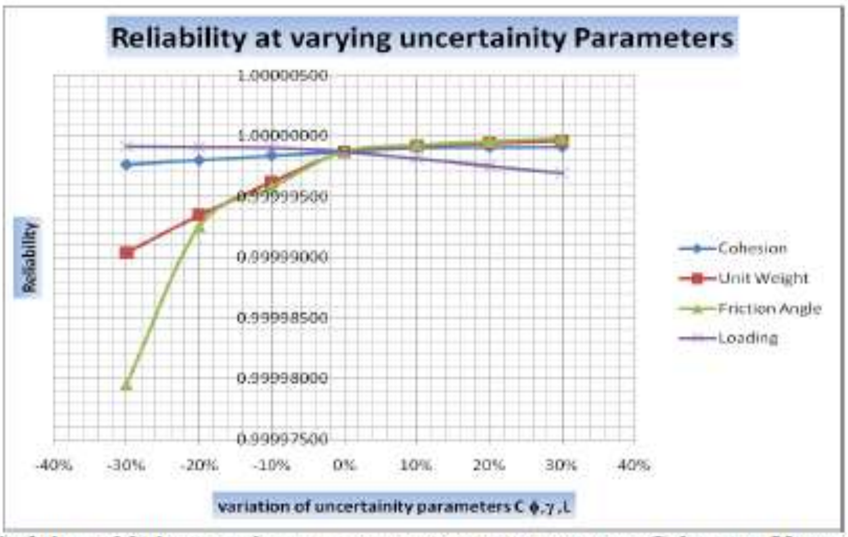

Fig 4. Reliability of failure vs changes in uncertainty parameters Cohesion, Unit weight, Friction angle and load.

From C programming language, the reliability index of CPRF of Dharaharais is 4.735. Also, here by adopting a different range of coefficient of variance (CV %) up to; ±30% and other factor remaining same, the reliability has been analyzed.
Higher the slope of the curve means the small change in uncertain parameters have a large variation on bearing capacity and have a more sensitive parameter. Among these four variables cohesion, unit weight, friction angle and load, the friction angle has been found most sensitive and then unit weight has been found as a moderately sensitivite, cohesion and load have a significant effect on bearing capacity.

Validation of work

The result obtained from the C programming language coding is validated to the Euro Code-Basis of Structural Design (EN 1990:2002). In order to validate the research work by code, reference period (Ta), consequences classes (CC) and Reliability class (RC) are associated with decision.

1. Consequences classes

For the purpose of reliability differentiation, consequences classes (CC) may be established by considering the consequences of failure as given in Table (BS EN 1990:2002).

Table 5: Definition of consequences classes (EN 1990:2002)

Consequences Class	**Description**	**Examples of buildings and civil engineering works**
CC3	High consequence for loss of human life, or economic, social or environmental consequences are very great.	Grandstands, public buildings where consequences of failure are high (e.g. a concert hall)
CC2	Medium consequence for loss of human life, economic, social or environmental consequences are considerable.	Residential and office buildings, public buildings where consequences of failure are medium (e.g. an office building)
CC1	Low consequence for loss of human life, and economic, social or environmental consequences are small or negligible.	Agricultural buildings where people do not normally enter (e.g. storage buildings, greenhouses)

2. Reference-period

It is chosen a period of time that is used as a basis for assessing statistically variable actions, and possibly for accidental actions (BS EN 1990:2002)

3. The reliability classes (RC)

Three reliability classes RC1, RC2 and RC3 defined by reliability index may be associated with the three consequences classes CC1, CC2 and CC3.

Table 6: Recommended minimum values for reliability (BS EN 1990:2002)

Reliability Class	**Minimum values for β**	
	1 year reference period	**50 years reference period**
RC3	5.2	4.3
RC2	4.7	3.8
RC3	4.2	3.3

From a result of coding, Reliability index of CPRF of Dharahara is 4.735 (>4.3), taking a 50 years reference period, Reliability class is RC3 and Consequence class is CC3 (i.e, High consequence for loss of human life, or economic, social or environmental consequences very great) and the scenario of Dharahara is same, thus the work is validated with Euro code-Basis of Structural Design.

Conclusion

The main task of the Reliability analysis of CPRF of Dharahara is found as 0.99999872% and the probability of failure of a foundation is 0.00000128% at a reliability index of 4.735 has been obtained. Also, the reliability has been analyzed by adopting a different range of coefficient of variance (CV %) of any uncertainty parameter up to $\pm 30\%$ and other uncertainty remaining the same. Among these four uncertainty variables c, ϕ, γ and load, it may be concluded from the slope of the graph, the friction angle has been found most sensitive and then unit weight has been found as a moderately sensitivite, cohesion and load have a significant effect on bearing capacity.

The proposed method of analysis becomes more realistic with directly knowing the probability of failure, Reliability and consequences class. This may be helpful for structural/foundation engineers to design and calculate the bearing capacity with more accurate, realistic and the structural properties of piled raft more effectively.

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