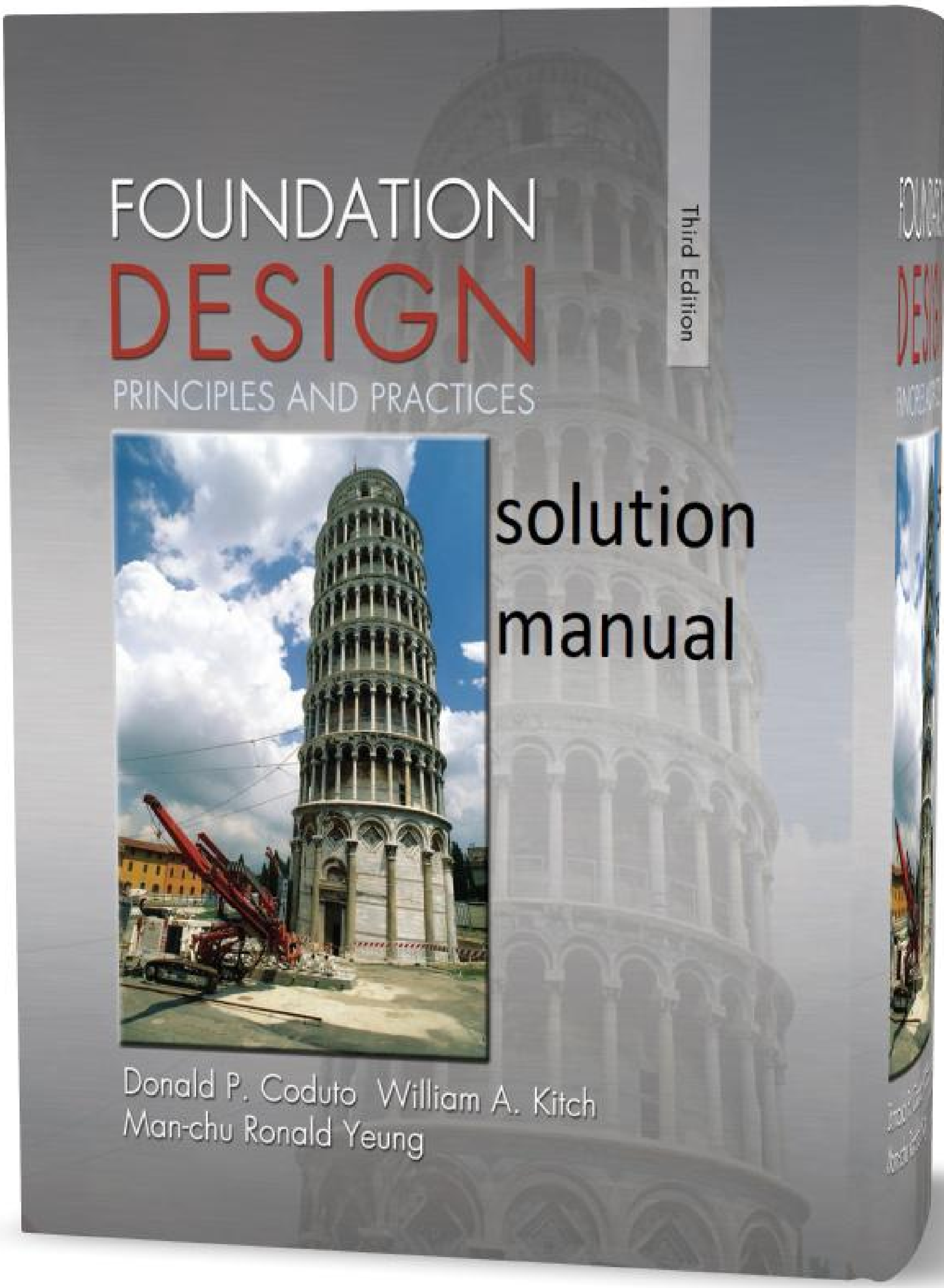

FOUNDATION
DESIGN
PRINCIPLES AND PRACTICES
Third Edition
solution
manual
Donald P. Coduto William A. Kitch
Man-chu Ronald Yeung

Classify the uncertainty associated with the following items as either aleatory or epistemic and explain your reason for your classification: average wind speed over a 30-day period, location of a certain applied load, change in strength of a soil caused by sampling method, capacity determined by a certain analysis method, magnitude of live load caused by vehicles traveling on a bridge, soil shear strength as measured by a certain method.

Step-by-step solution

Step 1 of 1

The classification of the items is done below

1) Average wind speed over 30 day period: the uncertainty associated with the average wind speed over 30 day period is Aleatory, because the wind speed is random, it can change, and this classifies average wind speed as Aleatory, Aleatory uncertainty is a type of uncertainty is related to inherent randomness of nature. This randomness or uncertainty cannot be eliminated but only reduced.

2) Location of a certain applied load: the uncertainty associated with location of a certain applied load is epistemic, because here the uncertainty is related to imperfect knowledge of a system or process. And so the location of certain applied load is classified as epistemic. The epistemic uncertainty can be eliminated by having better knowledge of the process, conducting the process accurately.

3) Change in strength of soil caused by sampling method: the uncertainty associated with change in strength of soil caused by sampling method is Aleatory, because the strength of soil keeps changing and is not certain and this uncertainty is related to inherent randomness of nature. The Aleatory uncertainty cannot be eliminated but only reduced.

---

4) Capacity determined by certain analysis method: the uncertainty associated with capacity determined by certain analysis method is epistemic, the capacity determined is classified as epistemic, because here the uncertainty is related to imperfect knowledge of a system or process, the capacity can be determined accurately by performing the analysis method in a correct way. And the epistemic uncertainty can be eliminated by having better knowledge of the process, conducting the process accurately. Conduct the analysis method without any manual errors.

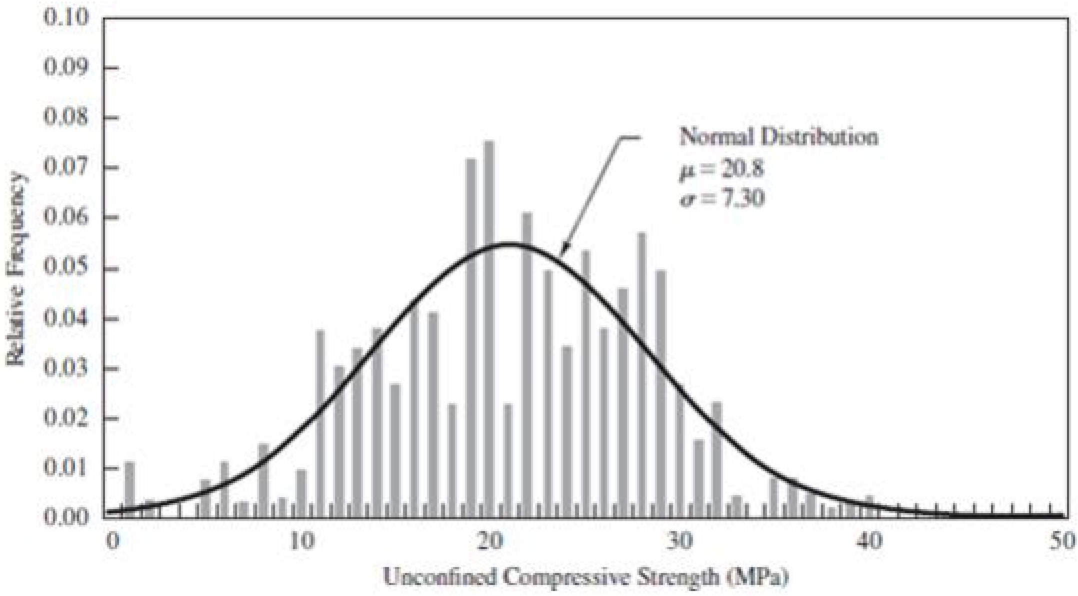
5) Magnitude of live load caused by vehicle travelling on a bridge: the uncertainty associated with magnitude of live load caused by vehicle travelling on a bridge is epistemic, because here the uncertainty is related to imperfect knowledge of a system or process, the magnitude of live load can be determined accurately without any uncertainty by performing the process correctly. And the epistemic uncertainty can be eliminated by having better knowledge of the process, conducting the process accurately. Calculate the magnitude of live load accurately by having perfect knowledge of the method, and by taking accurate measurements.

6) Soil shear strength as measured by certain method: the uncertainty associated with soil shear strength measured by certain method is Aleatory, because the uncertainty of soil shear strength is purely dependent on nature, and so the uncertanity is related to inherent randomness of nature. This randomness or uncertainty cannot be eliminated but only reduced, even if many samples are taken and also if the method is performed perfectly without any errors.

Comment

Figure shows the PDF for a normal distribution determined from the unconfined compression tests shown in the histogram. Does the mean and standard deviation of this PDF represent aleatory or epistemic uncertainty? Explain.

Figure Histogram and the corresponding normal distribution of unconfined compressive strength of sandstone sampled at the Confederation Bridge site, Canada (data from Becker et al., 1998).



Step-by-step solution

Step 1 of 2

Aleatory uncertainty and epistemic uncertainty are two different types of uncertainties. Aleatory uncertainty is an uncertainty of soil which is associated with inherent randomness of nature. The undrained shear strength in a certain soil varies at different points and at different times. This type of soil comes under category aleatory uncertain soil. The difference in strength and actual strength of a soil at this point is the aleatory uncertainty, and the uncertainty can be reduced, but it can never be eliminated. When there are uncertainties due to imperfect knowledge of a process to determine the shear strength of the samples, this sample is categorized as epistemic uncertainty.

Comment

Step 2 of 2

The estimated mean and standard deviation of the unconfined compressive strength of this sandstone are 20.8 and 7.30. The epistemic uncertainty is associated with the number of samples used to estimate the parameters. If the samples considered were more the estimate would be better. However, the particular sample also contains a large number of measurements. Therefore the estimated standard deviation is probably very close to the aleatory uncertainty and testing more specimens is unlike to reduce the uncertainty significantly.

Comment

List three sources of epistemic uncertainty associated with determining the soil strength at a given site and describe how you might reduce these uncertainties.

Step-by-step solution

Step 1 of 2

The three sources of epistemic uncertainty associated with determining the soil strength at a given sited are listed below

1) Imperfect knowledge of the process

2) Manual errors

3) Carrying out the method wrongly

Comment

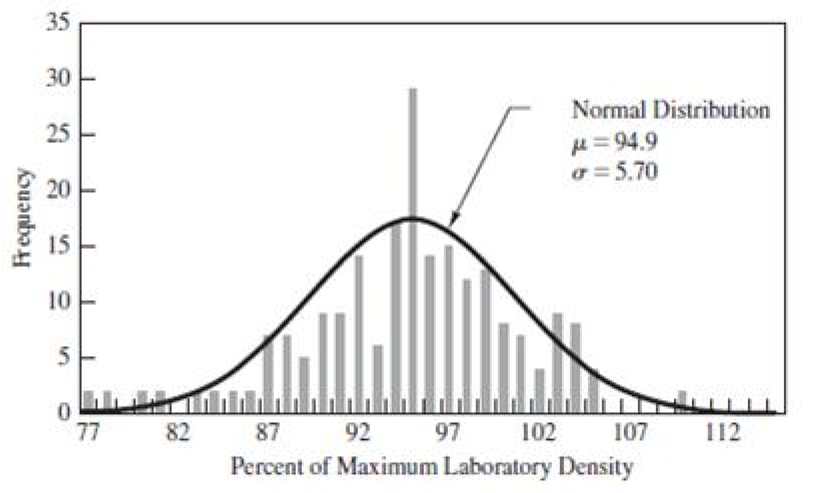
Step 2 of 2

The above three sources which lead to epistemic uncertainty can be eliminated by having full knowledge of the system or process or by using improvised and correct formulas, making accurate measurements without making any mistakes in carrying out the method and by carrying out the method or process perfectly step by step without any minute errors in calculations.

Comment

Using a random number generator create a sample of four relative densities using the PDF presented in Figure. Repeat the exercise to create three different sample sets. Compute the mean and standard deviation of your sample. Compute the mean and standard deviation of each sample set. Compare the means and standard deviations of your samples with each other and with the mean and standard deviation of the original distribution. Discuss the differences among the sample sets and the original distribution, including the type of uncertainties you are dealing with. How many samples do you think are needed to reliably determine the mean and standard deviation of the relative density of this particular soil?

Figure Histogram and the corresponding normal distribution of dry unit weight of a compacted soil at a road site in Los Alamos, New Mexico (data from Petit, 1967).



Step-by-step solution

Step 1 of 6

Use spreadsheet to generate random number and to create a sample of four relative densities using the probability density function presented in Figure 2.2, "Histogram and the corresponding normal distribution of dry unit weight of a compacted soil at a road site in Los Alamos, New Mexico".

Form the table in spreadsheet to calculate the random sample set as in Figure (1).

	A	B	C	D	E
1	Sample No	Mean, μ	Standard deviation, σ	Normal distribution, N	Z
2	1	94.9	5.7	=NORM.S.INV(RAND())	=B2+(C2*D2)
3	2	94.9	5.7	=NORM.S.INV(RAND())	=B3+(C3*D3)
4	3	94.9	5.7	=NORM.S.INV(RAND())	=B4+(C4*D4)
5	4	94.9	5.7	=NORM.S.INV(RAND())	=B5+(C5*D5)
6				Mean, μ	=AVERAGE(E2:E5)
7				Standard deviation, σ	=STDEV.S(E2:E5)

Comment

Step 2 of 6

Show the calculation of first sample set as in Figure (2).

Sample No	Mean, μ	Standard deviation, σ	Normal distribution, N	Z
1	94.9	5.7	-0.1643	93.96
2	94.9	5.7	0.0321	95.08
3	94.9	5.7	-0.5113	91.99
4	94.9	5.7	0.3931	97.14
			Mean, μ	94.54
			Standard deviation, σ	2.15

Comment

Step 3 of 6

Show the calculation of second sample set as in Figure (3).

Sample No	Mean, μ	Standard deviation, σ	Normal distribution, N	Z
1	94.9	5.7	0.0669	95.28
2	94.9	5.7	-0.5991	91.49
3	94.9	5.7	1.3245	102.45
4	94.9	5.7	1.2576	102.07
			Mean, μ	97.82
			Standard deviation, σ	5.36

Comment

Step 4 of 6

Show the calculation of second sample set as in Figure (4).

Sample No	Mean, μ	Standard deviation, σ	Normal distribution, N	Z
1	94.9	5.7	-0.8250	90.20
2	94.9	5.7	0.3896	97.12
3	94.9	5.7	1.1396	101.40
4	94.9	5.7	0.2424	96.28
			Mean, μ	96.25
			Standard deviation, σ	4.61

Comment

Step 5 of 6

Compare the computed three sample sets as in Figure (5).

Sample No	Trial I	Trial II	Trial III
1	93.96	95.28	90.20
2	95.08	91.49	97.12
3	91.99	102.45	101.40
4	97.14	102.07	96.28
Sample Mean, μ	94.54	97.82	96.25
Sample Standard deviation, σ	2.15	5.36	4.61

Comment

Step 6 of 6

The average of the samples range from 0.36 below the distributed mean to 2.92 above it.

The standard deviation of the sample set is nearly half that of the original distribution in one set and the standard deviation of the remaining sample sets are in the range of the original distribution.

The number of samples required to achieve a certain value of accuracy (Confidence level) with the involved parameters can be determined using the sampling theory.

In general, increasing the number of samples reduces the variability in the values of mean and standard deviation.

Comment

A certain column will carry a dead load estimated to be 400 k with a COV of 0.1 and a live load of 200 k with a COV of 0.25. What is the mean and standard deviation of the total column load? Assuming the load is normally distributed, what is the probability that this load will exceed 750 k?

Step-by-step solution

Step 1 of 4

Calculate the mean by using the following formula:

$$\mu = 5.7\mu_s + D\mu_\gamma$$

Here, the depth is *D*, and means of the footing are μ_s, μ_γ.

Assume depth of the footing to be 5ft

Substitute 400k for μ_s, 5ft for D and 200k for μ_γ.

$$\begin{aligned}\mu &= 5.7\times400+5\times200\\ &= 2280+1000\\ &= 3280\text{k}\end{aligned}$$

Comment

Step 2 of 4

Calculate the value of σ_s as follows:

$$\sigma_s = \text{COV}\mu_s$$

Here, the coefficient of variation is COV.

Substitute 0.1 for COV and 400k for μ_s.

$$\begin{aligned}\sigma_s &= 0.1\times400\\ &= 40\text{k}\end{aligned}$$

Calculate the value of σ_γ as follows:

$$\sigma_\gamma = \text{COV}\mu_\gamma$$

Substitute 0.25 for COV and 200k for μ_γ.

$$\begin{aligned}\sigma_\gamma &= 0.25\times200\\ &= 50\text{k}\end{aligned}$$

Comment

Step 3 of 4

Calculate standard deviation of normal bearing capacity as follows:

$$\sigma_{qn} = \sqrt{5.7^2\sigma_s^2 + D^2\sigma_\gamma^2}$$

Substitute 40k for σ_s, 50k for σ_γ and 5ft for D

$$\begin{aligned}\sigma_{qn} &= \sqrt{5.7^2\times40^2+5^2\times50^2}\\ &= \sqrt{32.49\times1600+25\times2500}\\ &= \sqrt{114484}\\ &= 338.35\text{k}\end{aligned}$$

Comment

Step 4 of 4

Calculate the probability by using the following relation:

$$P = \Phi\left(\frac{a-\mu}{\sigma_{qn}}\right)$$

Here, the constant is Φ and the variable is a.

Substitute 750k for a, 3280k for μ and 338.35k for σ_{qn}.

$$\begin{aligned}P &= \Phi\left(\frac{750-3280}{338.35}\right)\\ &= \Phi(-7.47)\end{aligned}$$

Here, the normal distribution is symmetric; hence, $P(x \le 90\%) = 1-\phi(7.47)$.

Refer table B1 "Cumulative standard normal distribution probability table" for $\phi(7.47)$ value.

$$\phi(7.47) = 6.81\times10^{-14}$$

Substitute 6.81×10^{-14} for $\varphi(7.47)$.

$$\begin{aligned}P(x\le90\%) &= 1-6.81\times10^{-14}\\ &= 0.99\end{aligned}$$

Therefore, the value of mean deviation is and $\boxed{3280\text{ k}}$, the value of standard deviation is $\boxed{338.35\text{ k}}$, and the probability that the load will exceed 750k is $\boxed{99.9\%}$.

Comment

Problem

A simply supported beam has a length of 3 m and carries a distributed load with a mean of 5 kN/m and a COV of 0.2. Assuming the load is normally distributed, what are the mean and standard deviation of the maximum moment in the beam? What is the probability the maximum moment will exceed 7 kN-m?

Step-by-step solution

Step 1 of 4

Calculate the value of mean by using following equation:

$$\mu = D\mu_\gamma$$

Here, μ_γ is the mean, and D is depth of the footing.

Substitute 5kN/m for μ_x and 3m for D.

$$\begin{aligned}\mu &= D\mu_\gamma \\ &= 3\times 5 \\ &= 15\text{kN/m}\end{aligned}$$

Comment

Step 2 of 4

Calculate the value of Standard deviation using the following equation:

$$\sigma_\gamma = \text{COV}\mu_\gamma$$

Here, COV is coefficient of variation

Substitute 0.2 for COV and 5kN/m for μ_γ.

$$\begin{aligned}\sigma_\gamma &= 0.2\times 5 \\ &= 1\text{ kN/m}\end{aligned}$$

Comment

Step 3 of 4

Calculate standard deviation σ_{qn} of normal bearing capacity by using the following equation:

$$\sigma_{qn} = \sqrt{D^2\sigma_\gamma^2}$$

Substitute 1 kN/m for σ_γ and 3m for D.

$$\begin{aligned}\sigma_{qn} &= \sqrt{3^2\times 1^2} \\ &= \sqrt{9} \\ &= 3\text{ kN/m}\end{aligned}$$

Comment

Step 4 of 4

Calculate the probability P using equation

$$P = \Phi\left(\frac{a-\mu}{\sigma_{qn}}\right)$$

Here, Φ is a constant and a is a variable.

Substitute 7 kN/m for a, 15 kN/m for μ, and 3 kN/m for σ_{qn}.

$$\begin{aligned}P &= \Phi\left(\frac{7-15}{3}\right) \\ &= \Phi(-2.67)\end{aligned}$$

Since the normal distribution is symmetric, $\phi(-x) = 1-\phi(x)$

Therefore, $\varphi(-2.67) = 1-\varphi(2.67)$.

Refer table B1 "Cumulative standard normal distribution probability table" for $\phi(2.67)$ value.

From table B1, $\phi(2.67) = 0.9962$

Therefore,

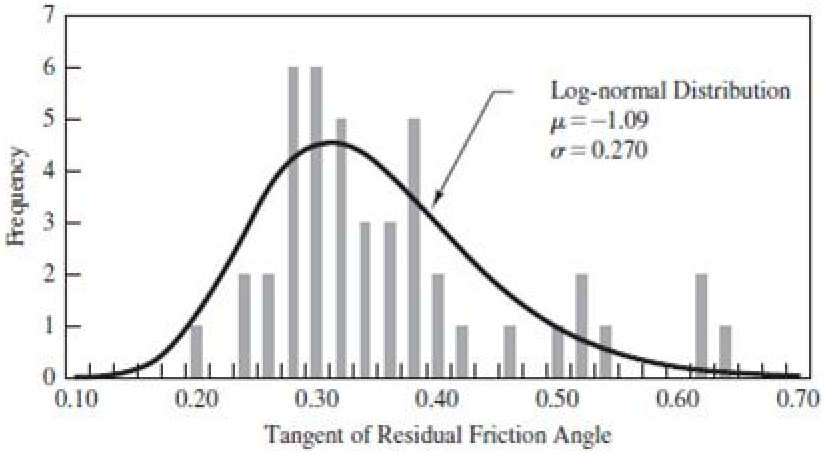
$$\begin{aligned}P(x\le 90\%) &= 1-0.9962 \\ &= 0.0038\end{aligned}$$

Hence, the mean and standard deviation are 3280k and 338.35k and the probability that the load will exceed 750k is $\boxed{0.38\%}$.

Comment

Using the data shown in Figure, determine the probability that the tangent of the friction angle for the mudstone at the Confederation Bridge site is less than 0.25.

Figure Histogram of tangent of residual friction angle of mudstone at the Confederation Bridge site, Canada (data from Becker et al., 1998).



Step-by-step solution

Step 1 of 2

Write the formula for the probability as follows:

$$P(\tan\phi < 0.25) = \Phi\left(\frac{\ln a - \mu}{\sigma}\right)$$

Here, the constant is Φ and the variable is a.

Obtain the values of μ and σ from the figure.

Substitute 0.25 for *a*, -1.09 for μ, and 0.270 for σ.

$$\begin{aligned} P(\tan\phi < 0.25) &= \Phi\left(\frac{\ln 0.25 - (-1.09)}{0.270}\right) \\ &= \Phi\left(\frac{-0.29629}{0.270}\right) \\ &= \Phi(-1.09738) \end{aligned}$$

Comment

Step 2 of 2

Here, the normal distribution is symmetric; hence, $\Phi(-1.09738) = 1 - \Phi(1.09738)$.

Obtain the value of $\Phi(1.09738)$ from the table B-1.

$$\Phi(1.09738) = 0.862143428$$

Calculate the probability as follows:

$$\begin{aligned} P(\tan\phi < 0.25) &= 1 - \Phi(1.09738) \\ &= 1 - 0.862143428 \\ &= 0.1378 \\ &= 13.7\% \end{aligned}$$

Therefore, $\boxed{13.7\%}$ chance that $\tan\phi$ will be less than 0.25.

Comment

The capacity for a certain foundation system is estimated to be 620 kN with a COV of 0.3. The demand on the foundation is estimated to be 150 kN with a COV of 0.15. Compute the mean factor of safety of this foundation and its probability of failure assuming both capacity and demand are normally distributed.

Step-by-step solution

Step 1 of 2

Calculate the mean factory of safety F using equation (1)

$$F = \frac{\mu_C}{\mu_D} \quad \ldots\ldots (1)$$

Here, μ_C, μ_D are mean capacity and mean demand

Substitute 620KN for μ_C and 150KN for μ_D

$$F = \frac{620}{150} = 4.14$$

In order to calculate probability, first calculate mean and standard deviation

Also first calculate the mean of safety margin μ_m using equation (2)

$$\mu_m = \mu_C - \mu_D \quad \ldots\ldots (2)$$

Substitute 620KN for μ_C and 150KN for μ_D

$$\mu_m = 620 - 150 = 470\text{KN}$$

Calculate standard deviation σ of capacity and demand using equations (3) and (4)

$$\sigma = \text{COV}\mu_C \ldots\ldots (3)$$

$$\sigma = \text{COV}\mu_D \ldots\ldots (4)$$

Here, COV is coefficient of variation

Substitute 0.3 for COV and 620KN for μ_C in equation (3)

$$\sigma_C = \text{COV}\mu_C = 0.3 \times 620 = 186\text{KN}$$

Comment

Step 2 of 2

Substitute 0.15 for COV and 150KN for μ_D in equation (4)

$$\sigma_D = \text{COV}\mu_D = 0.15 \times 150 = 22.5\text{KN}$$

Calculate mean of standard deviation σ_m using equation (5)

$$\sigma_m = \sqrt{\sigma_C^2 + \sigma_D^2} \quad \ldots\ldots (5)$$

Substitute 186KN for σ_C and 22.5KN for σ_D

$$\sigma_m = \sqrt{186^2 + 22.5^2} = \sqrt{34596 + 506.25} = \sqrt{35102.25} = 187.35$$

The probability P, m is less than or equal to 0 is

$$P(m \le 0) = 1 - \Phi\left(\frac{\mu_m}{\sigma_m}\right) \quad \ldots\ldots (6)$$

Here, Φ is constant

Substitute 470KN for μ_m and 187.35KN for σ_m

$$P(m \le 0) = 1 - \Phi\left(\frac{470}{187.35}\right) = 1 - \Phi(2.5)$$

Refer table B1 "Cumulative standard normal distribution probability table" for $\phi(2.5)$ value

From table B1,

$$\phi(2.5) = 0.9937$$

Therefore,

$$P(m \le 0) = 1 - 0.9937 = 0.0063$$

Hence, the mean factor of safety is 4.14 and the probability of the failure assuming both capacity and demand are normally distributed is $\boxed{0.63\%}$.

Comment

We wish to design a shallow foundation with a probability of failure of 10–3. The footing supports a column carrying a dead load with a mean of 30 k and COV of 0.05 and a live load with a mean of 10 k and COV of 0.15. Based on the uncertainty of soil properties and our analysis method, we estimate the COV of the foundation capacity to be 0.2. For what mean capacity does the foundation need to be designed? Assume both loads and capacity are normally distributed.

Step-by-step solution

Step 1 of 4

In order to calculate probability, first calculate mean and standard deviation of load and capacity

Calculate the mean of safety margin μ_m using equation (1)

$\mu_m = \mu_C - \mu_D - \mu_L$ …… (1)

Here, μ_C, μ_L are mean of capacity, dead load and live load

Substitute 30k for mean of deal load and 10k for mean live load

$$\mu_m = \mu_C - 30 - 10$$

Comment

Step 2 of 4

Write the standard deviation σ of capacity and dead load and live load equations:

$\sigma = \text{COV}\mu_C$ …… (3)

$\sigma = \text{COV}\mu_D$ …… (4)

$\sigma = \text{COV}\mu_L$ …… (5)

Here, COV is coefficient of variation

Substitute 0.3 for COV in equation (3).

$$\sigma_C = \text{COV}\mu_C = 0.2 \times \mu_C$$

Substitute 0.05 for COV and 30K for μ_D in equation (4).

$$\sigma_D = \text{COV}\mu_D = 0.05 \times 30 = 1.5\text{K}$$

Substitute 0.15 for COV and 10K for μ_L in equation (5).

$$\sigma_L = \text{COV}\mu_L = 0.15 \times 10 = 1.5\text{K}$$

Comment

Step 3 of 4

Calculate mean of standard deviation σ_m using equation (6).

$\sigma_m = \sqrt{\sigma_C^2 + \sigma_D^2 + \sigma_L^2}$ …… (6)

Substitute 0.2 μ_C for σ_C, 1.5K for σ_D and 1.5K for σ_L

$$\sigma_m = \sqrt{(0.2\mu_C)^2 + 1.5^2 + 1.5^2} = \sqrt{0.4\mu_C^2 + 2.25 + 2.25}$$

The probability P, m is less than or equal to 0 is calculated using equation (7).

$P(m \le 0) = 1 - \Phi\left(\frac{\mu_m}{\sigma_m}\right)$ …… (7)

Here, Φ is constant

Comment

Step 4 of 4

Substitute $\mu_C - 30 - 10$ for μ_m, 10^{-3} for P and $\sqrt{0.4\mu_C^2 + 2.25 + 2.25}$ for σ_m

$$10^{-3} = 1 - \Phi\left(\frac{\mu_C - 30 - 10}{\sqrt{0.4\mu_C^2 + 2.25 + 2.25}}\right)$$

$$10^{-3} = 1 - \Phi\left(\frac{\mu_C - 40}{\sqrt{0.4\mu_C^2 + 4.5}}\right)$$

Square both the sides

$$(10^{-3})^2 = 1^2 - \Phi\left(\frac{(\mu_C - 40)^2}{0.4\mu_C^2 + 4.5}\right)$$

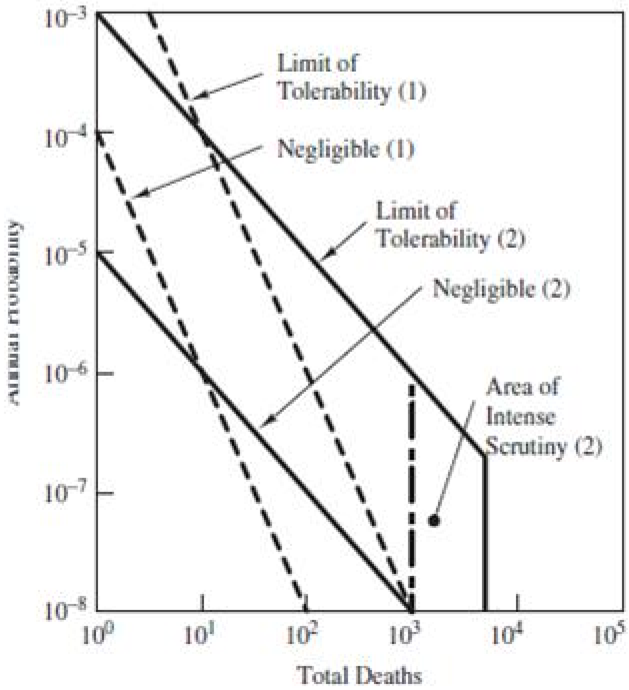
$$\mu_C = 20\text{k}$$

Hence, the mean factor of safety is $\boxed{4.14}$ and the mean capacity that the foundation need to be designed is $\boxed{20\text{k}}$.

Comment

Assume the foundation in Problem was to support a high-voltage transmission line near the Danish city of Arhus. If the transmission line fails, it will potentially kill 50 people. If the computed probability of failure is for a design life of 100 years, is risk associated with the failure of design acceptable based on the Danish guidance in Figure? Explain.

Figure F-N diagrams used by (1) Denmark and (2) Hong Kong to evaluate the acceptability of project risk (data from Jan Duijm, 2009 and Govt. of Hong Kong, 1998).



Problem

We wish to design a shallow foundation with a probability of failure of 10–3. The footing supports a column carrying a dead load with a mean of 30 k and COV of 0.05 and a live load with a mean of 10 k and COV of 0.15. Based on the uncertainty of soil properties and our analysis method, we estimate the COV of the foundation capacity to be 0.2. For what mean capacity does the foundation need to be designed? Assume both loads and capacity are normally distributed.

Step-by-step solution

Step 1 of 2

Yes the risk associated with the failure of design is acceptable based on the Danish guidance. The requirements of building regulations can be achieved by following Danish guidance. According to Danish guidance for foundation of typical structures, there is consensus that the appropriate probability of failure for design should be 10^{-3} to 10^{-3}.

Comment

Step 2 of 2

The foundation in problem 2.9 has the probability of failure of 10^{-3}. As the risk is within the limits, risk associated with failure of design is acceptable. Hence, the risk associated with failure of design is acceptable based on the Danish guidance.

Comment

If the ASD design method has worked satisfactorily for over 50 years, what's the value in changing to the LRFD method?

Step-by-step solution

Step 1 of 2

There are two most common design methods used to design foundations, one is ASD (Allowable stress design) method and LRFD (Load and resistance factor design) method. The ASD and LRFD methods use factor of safety to ensure the appropriate reliability of foundation designs.

Comment

Step 2 of 2

The ASD method is the most reasonable method to design reliable foundation systems for over 50 years. The value that's used to change into LRFD method is 10^{-3} to 10^{-4}.

Hence, the value required in changing to the LRFD method is $\boxed{10^{-3}\text{ to}10^{-4}}$.

Comments (2)