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Probabilistic Analysis of Immediate Settlement of a Rectangular Foundation using Various Reliability Software

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1. Introduction

By and large, the ground is one of the most highly variable, hence uncertain, engineering materials. Unlike quality controlled materials such as wood, concrete, or steel, whose probability distributions are well-known and relatively constant world-wide, geotechnical designers face large resistance uncertainties from site to site, and even within a site. Because of this site-specific uncertainty, there is a real desire in the geotechnical community to account for site understanding in order to achieve economical, yet safe designs. The foundation settlement is one of the geotechnical issues whose parameters are facing uncertainty.

In this study, a reliability analysis was performed using the distribution functions of random variables in the problem of immediate settlement of a rectangular foundation as well as defined relationships. For this purpose, various reliability methods such as first order reliability method, second order reliability method and Monte Carlo simulation were used to estimate the probability of failure and sensitivity analysis of random variables. These analyzes were performed in RT and @Risk software, which are powerful tools for performing probabilistic analyzes.

2. Reliability assessment methods and sensitivity analysis

The limit state function at its value of zero ($G(\mathrm{X}) = 0$), which is called the limit state surface, may be in the form of a straight line to a high degree curve. In the first order reliability method, this assumption is based on the linearity of the limit state surface, and it is linearized using Taylor's first-degree expansion to simplify the calculations ahead. In the second order method of reliability, a quadratic approximation is applied from the limit state surface around its most probable point. In other words, instead of approximating the limit state surface with a line, a parabola is replaced. The Monte Carlo simulation method is also one of the numerical methods which, by repeating a test in large numbers, leads to the determination of the probabilistic distribution of the limit state function. In this way, the probability of failure is calculated as follows:

$$P_f \approx \frac{n(G \le 0)}{N}$$

Sensitivity vectors α, β, δ, η and κ are among the sensitivity vectors that compare variables relative to each other by presenting the importance of variables in the form of a vector.

3. Analysis and results

The rectangular foundation settlement problem includes the impact variables according to the following equation. In this problem, the contact stress (q_o), Poisson’s ratio (ν) and elastic modulus (Es) are assumed to be random variables independent of the normal distribution.

$$\Delta H = 0.5Bq_0 \frac{1-\nu^2}{E_s} m \left(I_1 + \frac{1-2\nu}{1-\nu} I_2 \right) I_F$$

The amount of foundation settlement as an independent variable by combining the settlement threshold (50 mm), form the following limit state function:

$$G(X) = (\Delta H)_{\text{limit}} - \Delta H$$

The estimated probabilities of failure state in the second order reliability and Monte Carlo simulation methods are very close, while the first order reliability method estimates higher probability of failure than other methods. Since the result of the second order method is closer to the Monte Carlo simulation as a method with very high accuracy, it can be concluded that the limit state surface in this study is out of linear mode and is closer to the parabola. Therefore, in this case, the first order method for estimating the probability of failure with a linear approximation is erroneous.

Table 1. Failure probability calculated by reliability methods

MCS (Risk)	MCS (RT)	SORM	FORM	Method
9.6	9.54	9.59	10.81	Pf
_	1.308	1.305	1.237	β

The results of sensitivity analysis based on reliability showed that according to the figure below, the reliability index has a high sensitivity to the contact stress variable. It is clear that the contact stress has a huge effect on the amount of settlement, but in some cases it is impossible to reduce this stress. It is important to improve the environmental parameters. In this case, the Poisson's ratio is more important than the elastic modulus.

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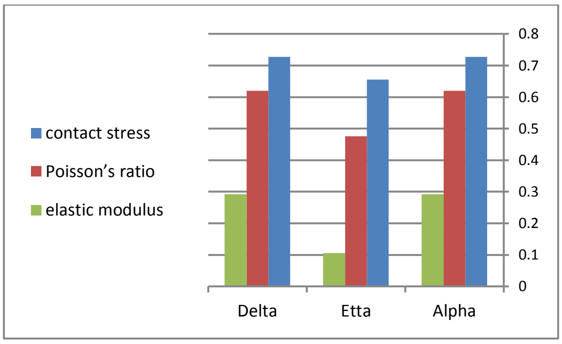

Figure 1. Graphs of sensitivity vectors of random variables

4. Conclusion

Studies have shown that the analyses performed with very little different results, confirm the high probability of failure (9.5%) for the immediate settlement of the rectangular foundation relative to the acceptable probability of failure in engineering. Moreover, the comparison of the calculated probability of failure of the methods showed that, considering the same result of the second order reliability method and the Monte Carlo simulation, which has a very high accuracy in estimating the probabilities, the limit state surface is closer to the parabola. For this reason, the first order reliability method, with a linear approximation of the limit state surface, does not make accurate predictions. As the Monte Carlo simulation requires a large amount of random data (n=280000) and replication of the simulation to reduce the changes in the probability of failure and to achieve a high-precision answer, for the present problem the second order method at a much lower computational cost is an alternative.