M1L1

Probability and its role in Civil Engineering

1. Introduction

Idealized assumptions and simplification of natural processes are considered to ignore uncertainty and adopt deterministic/quantitative approaches. However, such assumptions and simplifications are not sufficient in many cases and uncertainties are unavoidable in almost all engineering analysis and design problems.Thus, quantitative methods, being based on idealized assumption(s), may not be valid due to the existence of uncertainty, irrespective of degree of sophistication adopted. Uncertainty mostly arises due to – a) incompleteness of the available information/data, and b) consideration of natural processes and phenomena, which are inherently random. Definite decision in such cases cannot be taken. However, the decisions are required even with the incomplete information/data and for the natural processes.

Decisions in such situations are taken under the condition of uncertainty. Towards this a proper assessment of associated uncertainty is essential, and the effects of uncertainty in engineering problems are very crucial. Probability theory provides a *formal basis* for quantifying risk or uncertainty in engineering problems which are otherwise being dealt with qualitative approach using engineering judgments. Role of probability methods in engineering can be broadly summarize as (Ang and Tang, 1975) - a) The modeling of engineering problems and evaluation of systems performance under conditions of uncertainty; b) Systemic development of design criteria, explicitly taking into account the significance of uncertainty, and c) The logical framework for risk assessment and risk benefit tread off analysis relative to decision making.

2. Uncertainty and Probability Methods

There could be different types of uncertainties to be considered – a) Parameter uncertainties; b) Data uncertainties; c) Operational uncertainties, etc.

Inability to quantify the accurate model parameters and inherent variability in model inputs lead to the parameter uncertainty. Moreover, different descriptive statistics, such as, mean, standard deviation, skewness etc. also vary from one sample data to another. Thus, uncertainties are also associated with these descriptive statistics.

Error in measurements, problems in consistency and homogeneity of data are known as data uncertainty. Limitations in adequate representation of sample data are addressed by quantifying data uncertainty. Generally, histograms are basic graphical representation of such uncertainty and probability density functions (pdf) are fitted with the histograms to assessed the uncertainty associated with the data. This will be discussed in detail in the subsequent classes.

Operational uncertainties arise from change in operational conditions of structures and errors associated with construction, manufacture, deterioration, maintenance, human activities etc. All the uncertainties are assessed with help of the concept embodied in the theory of probability.

3. Applications in Civil Engineering

3.1. Environmental Engineering

Issues related to environmental risk assessment include health effects, impact on natural resources or man-made structures due to pollution, change in climatic conditions, water quality of streams etc. There are different parametric, non-parametric and empirical models are used to address these issues. Probability methods play a role in (i) estimation of model parameters, (ii) identification of probability distribution, (iii) determination of dependencies among variables, (iv) estimation of model uncertainties etc.

3.2. Geotechnical Engineering

In geotechnical engineering, there are different sources of uncertainty. For instance, variable nature of characteristics of rock affects the load bearing capacity. Heterogeneous soil properties and other in-situ conditions are also uncertain. Due to the inherent heterogeneity of the characteristics of soil and rock, probabilistic methods are essential to compute the bearing. Uncertainties are assessed through basic probabilistic analyses and statistics, such as, histogram analysis, sample mean, variance, standard deviation, Coefficient of Variance (CV) and Probability Density Function (pdf) etc. These methods are very useful for estimation of in-situ properties from limited soil samples and for comparison of field test to field performance data. Reliability of design and construction methods is also assessed in probabilistic way. Moreover, use of probability methods is inevitable to carry out the trade off analysis between cost and benefits of proposed design strategies adopted in geotechnical engineering.

3.3. Hydrology and Water Resources Engineering

Uncertainties in hydrology and water resources engineering arises from incompleteness of historical data, limitations in adequate representation of sample data, variability of hydrologic data, uncertain predictions etc. Assessment of uncertainty is carried out through different probability methods, i.e., distribution fitting to data, probability and quantile estimation, interval estimation of parameters etc.

Hydrologic extreme events, such as, Probable Maximum Precipitation (PMP) and Probable Maximum Flood (PMF) are estimated from historical data. However, the estimation procedure requires different probability methods. Different hydrologic variables, such as, rainfall, streamflow are inherently uncertain. Prediction of such hydrologic variables are often requires probabilistic method to quantify the uncertainty associated with the predictions. In design of hydraulic structures, estimation of design life and risk analysis also requires probability methods.

3.4. Structural Engineering

In structural engineering, failure can cause excessive monetary loss and injury or death. Thus, an extremely low rate of failure is assured in design. Safety factors are determined by considering risk or probability of failure. The concept of ‘low-probability high-consequence’ risks events is the key issue in the design of complex structures, such as, offshore structures, nuclear plants and highexposure public structures. Sources of uncertainty in structural engineering lies in magnitude of load, strength of structural material, number of load cycles until fatigue failure etc. For instance, determination of maximum wind effect, consideration of earthquake force etc. are uncertain and their assessment requires probability methods. Similar reasoning applies for assessment of strength of structural material and number of load cycles until fatigue failure as well. In structural design, Probabilistic Structural Design Optimization (PSDO) is able to handle uncertainties in material properties, geometry, loadings, boundary conditions, and mathematical simulation.

Different standards of acceptance are developed based on the probability concepts. This is helpful to ensure that the standards should not be too stringent or too lax. For example, characteristic strength of concrete is defined as the compressive strength that is exceeded by 95% of the concrete cubes of size 150 mm tested after 28 days of curing. This 95% mark is a probability concept and so decided to make the criterion ‘not too stringent or too lax’.

3.5. Construction Planning and Management

In construction planning and management, several factors are uncertain. For examples, duration of various activities in a construction project, time of supply of material, availability of required manpower, weather condition etc. Thus, estimation of total duration of the project is uncertain. As a consequence, estimation of cost involved is also uncertain. To assess these parameters decisions are inferred at different probabilistic confidence level, for which probability methods are established to be very useful.

3.6. Transportation Engineering

In transportation engineering, uncertainties arise from vagueness, ambiguity and risk against safety of traffic. Accidents in air traffic movement, accidents on highways are considered as ‘Low Probability-High Risk’ events and to deal with such events probability methods are utilized. Probability methods are also useful in different design related issues. For examples, in pavement design, different design factors may include width of pavement, thickness of subgrade layers and top finished layer, slope etc. Considering thickness only, it is easily understood that the cost will increase with the thickness keeping others factors same. High thickness will incur high initial cost and less maintenance cost whereas low thickness will incur low initial cost and high maintenance cost. Thus, a trade off analysis is required to determine the thickness. For this trade off analysis, relationship between life of pavement and its thickness is required. Pavement life depends on drainage and moisture content, temperature range, density and degree of compaction of the subgrade. These factors are random, and thus, the pavement life should be estimated probabilistically. Total cost and trade-off analysis also require probability methods.

4. Concluding Remarks

Though the probabilistic methods are not adequate to solve all engineering problems, the role of probability methods in engineering is to provide the formal basis for analyzing uncertainties and risks. Particularly in civil engineering, risk assessment, reliability analysis, data QA/QC, cost-benefit trade-off analysis are common application fields where probability methods are advantageous. The common probabilistic theories and tools like histogram, estimation of mean, variance, standard deviation, probability distribution functions are useful for all different disciplines in civil engineering.

References

Ang, A. H-S. and W. H. Tang, (1975), Probability Concepts in Engineering Planning and Design, Volume I, Basic Principles, John Wiley & Sons, Inc., USA