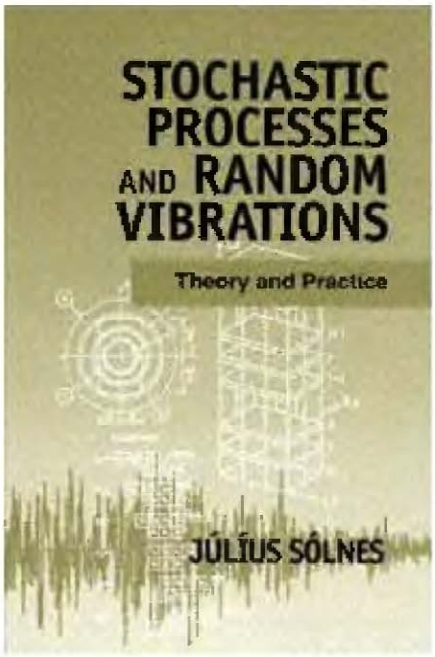

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Stochastic Processes and Random Vibrations

Theory and Practice

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Contents

Preface

The material which is contained in this book is the result of studies and research work that has been going on since early 1960s when I first became acquainted with engineering seismology and the behaviour of structures subjected to earthquake motion while studying at the International Institute of Earthquake Engineering and Seismology in Tokyo. There I was introduced to the work of K. Kanai and H. Tajimi and other renowned Japanese scientists in this field. Inspired by the many outstanding scientists, who had started to apply probabilistic methods in interpreting earthquake motions and the earthquake hazard, I tried to incorporate some of their ideas into my PhD thesis, which had to do with structural vibrations induced by earthquake motions. This work was encouraged by the late Professor K.W. Johansen and the Technical University of Denmark in Copenhagen (DTU), who supervised my doctoral studies there. Later, as a research engineer and associate professor at DTU I came to study another aspect of random phenomena in civil engineering, namely the random nature of atmospheric turbulence and wind forces acting on bluff structures. Following the pioneer work of Alan G. Davenport in the early 1960s this could only be handled properly by applying the theory of random processes. This led to studies of the fundamental theory of stochastic processes and related topics. Therefore, in the early 1970s, I published a set of lecture notes on random vibration theory and stochastic processes that was used in the courses given to civil engineering students at DTU at the time. Analysis of structural reliability and application of probability theory to the fundamental design of engineered structures, treating the loads and the material strength as random variables, also became a new field of investigation. This avenue followed a marked trend in advanced structural design philosophy in those years, where classical deterministic methods gave way to probabilistic methods, which soon became the basis of modern structural design codes.

In the early 1970s, I was asked to give a course on random vibrations and stochastic processes at the Institute of Engineering Seismology and Earthquake Engineering at the Kiril ii Methodii University in Skopje, Yugoslavia, for which I augmented and altered the material in my lecture notes. At this time, I had moved from Copenhagen to Iceland, where I had been appointed a professor of civil engineering at the newly established engineering school of the University of Iceland in Reykjavik. Busy with work that had to do with designing the curriculum in a new engineering school and organizing courses in most fields of structural design, there was little time to continue the very specialized studies in the field of random vibrations and stochastic processes. However, in 1979, I had the opportunity to work with Professor Stephen H. Crandall at MIT in Cambridge, Massachusetts, one of the leading authorities in the field of random vibration theory and who has done so much to advance engineering insight into this important subject. Needless to say, my stay as a visiting professor at MIT and collaborating with Professor Crandall was

a source of great inspiration, and I was able to increase and add new and a valuable material to my already growing notes. I would like to take this opportunity to thank Professor Crandall for kindly allowing me to use some of his old examples from his courses on random vibration. Almost immediately after my visit to MIT, I became a DAAD scholar at the Technical University of Karlsruhe in West Germany, where I stayed at the Institute of concrete and applied mechanics, collaborating with the late Professor P. Mueller, who was one of the leading German authorities on earthquake resistant design of structures. I was again asked to give a lecture course on random vibration and stochastic processes and had ample time to greatly improve my work and incorporate a lot of new material and examples.

During the 1980s, I was primarily occupied with administrative work in the university. I also had a brief brush with politics that put a severe strain on my research effort and academic work throughout the last half of the 1980s. It can be said that I was given a new opportunity when I was awarded a full sabbatical year during 1991/92 after leaving the world of politics, having been a member of parliament and the first Icelandic Minister of the Environment. I had the good fortune to be invited to stay as a visiting professor at the Institute of Geophysics of the National Autonomous University of Mexico in Mexico City (UNAM). This visit was instigated by Dr Ingvar Emilsson of Departmento de limnologia y ciencias del mar, a former UNESCO expert, who was instrumental in bringing me to Mexico and saw to that my stay evolved without problems. I also offer my thanks to Dr Gerardo Suarez Reynoso, the Director at the time of the Institute of Geophysics, who invited me to stay for almost a year in his institute. He also organized the necessary support from the National Science Foundation of Mexico, CONACYT, which made the stay possible.

Dr Cinna Lomnitz and Dr Krishna Singh of the Instituto de geofisica willingly explained to me the more sophisticated aspects of seismological research, which I was able to incorporate into my lecture notes for a new course on the theory of stochastic processes. I also collaborated with many other fine scientists in UNAM, which gave me a lot of new ideas and possibilities for application of stochastic processes in geophysics and related subjects. The 'students' in my course, some of whom were mature scientists themselves, were also a great source of inspiration. For instance, Dr Miquel de Icaza Herrera from the Instituto de fisica, who attended my course and sometimes made me feel like the egg that wanted to teach the hen, helped me unravel the mysteries of Kolmogorov's paper on fragmentation. Sr Ricardo Ruiz of Centro de Instrumentos, departmanto de acústica, was another stout ally in the field of stochastics, and persuaded me to give another course in his institute, which helped me put the final touches to the material. Dr Vladimir Kostoglov, formerly of the Institute of Physics of the Interior of the Earth in Moscow, my roommate in the office for visiting professors at Geofisica, with whom I had many interesting conversions about all kinds of scientific and wordly topics, introduced me to the latest computer techniques and word processing possibilities, that greatly simplified my work. The Russian club chaired by the late Dr Lautaro Ponce, which met every afternoon in our room for tea, was a continuous source of merriment and scientific discussions. However, it was Dr Lommitz who claimed that my loose and disorderly lecture notes were worthy of publication. He encouraged me to have the notes published and offered his help and advice. It was thus decided to prepare first an unrefined limited edition of the manuscript as an internal institute report. Dr Rosa Maria Proel undertook to have my notes published as a report under the auspices of the postgraduate section of the Institute.

Without the kind assistance of Dr Proel, Sr Gerardo Zentento and many others of the Institute, this book might never have been published. Finally, I would like to mention my partners and collaborators in Iceland, Mr Ásmundur Ásmundsson, civil engineer, and Mr Sæmundur Jónsson, mechanical engineer. Mr Jónsson flew all the way from Reykjavik * to Mexico City to assist with the computer graphics and taught me how to fit complicated mathematical curves into a pretty graphics background. When the computer methods failed, my old friend and schoolmate from Tokyo, Sr Carlos Correa, put his consulting engineering company at my disposal, where some of the more difficult figures were expertly drawn by hand. In this manner, the first printed draft of a manuscript that was later to become a fully fledged textbook came to light.

During the years to follow, the manuscript was being refined from time to time as much as heavy administrative duties allowed. A short stay at the Departmento de geofisica in the University of Chile in Santiago with Dr Lautaro Ponce, produced a lot of new material and modifications of the text. Professor Ottó Björnsson of the department of mathematics at the University of Iceland undertook to read through the first chapter on probability theory and offer critical remarks. This chapter was therefore completely rewritten with the kind assistance of Professor Björnsson. I would like to thank him and the many other colleagues from the Faculties of Engineering and Natural Sciences of the University of Iceland, who gave valuable advice and help with the various chapters. The final touches were then applied during a sabbatical leave at the University of Central Florida in Orlando last year. Finally, the University of Iceland, which has been my alma mater for so many years, has given me the facilities and offered me the opportunity to carry out this work.

The material of this book has been arranged in the following manner. In the first chapter, a short overview of the theory of probability is presented, covering only the essentials that are necessary for understanding the remaining material of the book. In the second chapter, the general theory of stochastic processes is presented, with emphasis on time series analysis, which has become so important for the treatment of the environmental and engineering processes, and also for interpretation of the response of engineered structures. In particular, wind loading processes are studied with examples of application to the analysis of bluff buildings. In the third chapter, a general outline of random vibration and systems analysis is offered, where the emphasis is on analysing the system response to random excitations in stochastic terms. The fourth chapter deals with extreme conditions such as distribution of the largest response peaks, probabilities of exceedance of certain limits and failure problems in connection with overloading and fatigue. A short overview of structural reliability and probability based design of structures is also included. In the fifth chapter, random vibrations of more complicated structural vibratory systems are treated, where examples of the earthquake response of tall multi-storey structures and wind loading of tall towers are offered. Then, in the sixth chapter, certain well-known stochastic processes are treated in more detail. The Gaussian and Poisson processes are covered extensively with application examples concerning the generation of artificial earthquake motion processes. Markov processes, Martingales and non-Markovian processes are also briefly discussed. The seventh chapter offers a presentation or an overview of Fourier transform analysis and data processing with emphasis of digital signal processing techniques. The eight and last chapter contains certain applications of probability theory in earthquake engineering with an emphasis on earthquake hazard and seismic risk analysis.

The subject material which is contained in these eight chapters is of course not original, not purports to show the latest advances in the field of stochastics. It is intended to offer the student an introduction to the world of uncertainties, and give any reader who wants to become familiar with problems of random nature and their interpretative solutions a quick and easy way to do so. This book is therefore a compilation of results and thoughts put forward by the many fine and outstanding scientists that have been involved in this field. They have made their contributions freely to advance both the mathematical part and the practical applications of the theory of stochastic processes and other random phenomena; they have thus advanced human knowledge and made modern communications technology possible, which is the basis of our everyday convenience. They have done so without expectation of being rewarded or remembered, perhaps driven only by the thirst for knowledge and the academic longing to solve puzzles. They have done so without the self-serving motivation that is often the driving force in the world of commerce, where their thoughts, ideas and knowledge have come to be utilized. However, their job is not entirely forgotten, since as long as there are students and seekers of knowledge, they will rely upon and travel the road paved by those scientists that came before. Their renown and reputation will at least be part of a heritage, cherished by those who want to follow in their footsteps, or as it is said so aptly in the ancient Hávamál from the Edda of Snorri Sturluson, the Icelandic medieval author and politician,

Deyr fé,
deyja frændr
deyr sjalfr et sama
en ordstirr
deyr aldrigi
hueim sér gódan getr

or in a poor English translation

Kine dies, kinsmen die
oneself dies the same
But word of fame for deeds well done
never dies

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1 Fundamentals of Probability Calculus with Applications

In this chapter, the fundamental concepts and definitions in probability calculus will be covered. The treatment can be neither thorough nor exhaustive because of the enormous material available on the theory of probability and statistical analysis. Here, it is primarily presented to provide a necessary basic tool for the treatment of stochastic processes, random vibration and related random phenomena, which will be the main topics of this book. This fundamental material and topics will be covered only superficially and designed more for a refresher course in probability theory and statistics. As such the material can therefore not supplant a fundamental course in this field. The treatment also presupposes that the reader has a sufficient background in applied mathematics. The presentation of the material is application oriented and many practical examples are shown. Of the numerous applications that are presented, general examples, which have to do with the random behaviour of civil and electromechanical structures, are shown. Also material that is believed to be useful for engineers and other scientists involved in earthquake risk analysis, seismic zoning and evaluation of earthquake loads on buildings, wind climate and wind loads on buildings and structures will be covered. However, the presentation is quite general and can be made use of in many kinds of problems that involve probabilistic measures or require application of the theory of stochastic processes. Therefore, the fundamental concepts necessary for understanding probability calculus are presented to give the necessary background, but without the stringency and rigour appropriate for this important subject. It is hoped that the treatment is sufficiently clear and thorough to give the reader a good overview of the necessary tools that can be applied in whichever field the concepts of probability and statistical analysis are found useful.

Besides describing the main topics of probability calculus such as distributions, conditional probability, marginal distributions, transformation of variables, moment generating functions, etc., a section on application of statistical methods, mostly for analysis of earthquake risk, is presented. However, the main emphasis is to present the necessary basis for the topics that are covered in the subsequent chapters. Application-oriented topics will be treated, however, whenever the occasion arises, within the text. Of course, there are many excellent texts on the theory of probability calculus and statistics, which can be of greater advantage in this context. Texts that treat the material in greater depth, albeit with different kind of emphasis, are for instance found in* [13],

* Numbers within brackets refer to various textbooks and scientific papers that are listed in a References and Further Reading list at the end of this book. These works have either been utilized, directly or indirectly, for the preparation of the text, or have been included as suitable for additional reading.