



## Article

## Stochastic Dynamic Buckling Analysis of Cylindrical Shell Structures Based on Isogeometric Analysis

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**Abstract:** In this paper, we extend our previous work on the dynamic buckling analysis of isogeometric shell structures to the stochastic situation where an isogeometric deterministic dynamic buckling analysis method is combined with spectral-based stochastic modeling of geometric imperfections. To be specific, a modified Generalized- $\alpha$  time integration scheme combined with a nonlinear isogeometric Kirchhoff–Love shell element is used to simulate the buckling and post-buckling problems of cylindrical shell structures. Additionally, geometric imperfections are constructed based on NURBS surface fitting, which can be naturally incorporated into the isogeometric analysis framework due to its seamless CAD/CAE integration feature. For stochastic analysis, the method of separation is adopted to model the stochastic geometric imperfections of cylindrical shells based on a set of measurements. We tested the accuracy and convergence properties of the proposed method with a cylindrical shell example, where measured geometric imperfections were incorporated. The ABAQUS reference solutions are also presented to demonstrate the superiority of the inherited smooth and high-order continuous properties of the isogeometric approach. For stochastic dynamic buckling analysis, we evaluated the buckling load variability and reliability functions of the cylindrical shell with 500 samples generated based on seven nominally identical shells reported in the geometric imperfection data bank. It is noted that the buckling load variability in the cylindrical shell obtained with static nonlinear analysis is also presented to show the differences between dynamic and static buckling analysis.

**Keywords:** shell dynamic buckling; isogeometric analysis; stochastic analysis; geometric imperfection

**MSC:** 74G60; 65P40



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## 1. Introduction

The stability of thin-shell structures is sensitive to all kinds of imperfections, among which the geometric imperfection is of paramount importance [1,2]. It is reported that the buckling loads obtained by experiments for cylindrical shells show large discrepancies and scatters and are much lower than the theoretical one [3–5]. To account for the randomness of imperfections, a well-known NASA SP-8007 design criterion is adopted in practice, which is proven to be over-conservative for engineering design. New design guidelines are under development to further improve the reliability of numerical prediction methods in stability problems [6]. It is noted that, for dynamic problems, the buckling loads of cylindrical shell structures can be higher or lower than the corresponding static buckling loads, which depend on the loading parameters applied. This phenomenon might be misleading for designers [7–9]. Therefore, further research on stochastic dynamic buckling problems in cylindrical shell structures is needed.

# Stochastic And Dynamic

**R Pring**



## **Stochastic And Dynamic:**

*Elements Of Stochastic Dynamics* Guo-qiang Cai, Weiqiu Zhu, 2016-08-11 Stochastic dynamics has been a subject of interest since the early 20th Century. Since then much progress has been made in this field of study and many modern applications for it have been found in fields such as physics, chemistry, biology, ecology, economy, finance, and many branches of engineering including Mechanical, Ocean, Civil, Bio, and Earthquake Engineering. *Elements of Stochastic Dynamics* aims to meet the growing need to understand and master the subject by introducing fundamentals to researchers who want to explore stochastic dynamics in their fields and serving as a textbook for graduate students in various areas involving stochastic uncertainties. All topics within are presented from an application approach and may thus be more appealing to users without a background in pure Mathematics. The book describes the basic concepts and theories of random variables and stochastic processes in detail, provides various solution procedures for systems subjected to stochastic excitations, introduces stochastic stability and bifurcation, and explores failures of stochastic systems. The book also incorporates some latest research results in modeling stochastic processes in reducing the system degrees of freedom and in solving nonlinear problems. The book also provides numerical simulation procedures of widely used random variables and stochastic processes. A large number of exercise problems are included in the book to aid the understanding of the concepts and theories and may be used for as course homework.

[Introduction to Stochastic Dynamic Programming](#) Sheldon M. Ross, 1995-08-24

[Introduction to Stochastic Dynamic Programming](#) [Markov Decision Processes](#) Martin L. Puterman, 2014-08-28 The Wiley Interscience Paperback Series consists of selected books that have been made more accessible to consumers in an effort to increase global appeal and general circulation. With these new unabridged softcover volumes, Wiley hopes to extend the lives of these works by making them available to future generations of statisticians, mathematicians, and scientists. This text is unique in bringing together so many results hitherto found only in part in other texts and papers. The text is fairly self-contained, inclusive of some basic mathematical results needed, and provides a rich diet of examples, applications, and exercises. The bibliographical material at the end of each chapter is excellent, not only from a historical perspective but because it is valuable for researchers in acquiring a good perspective of the MDP research potential. Zentralblatt für Mathematik: it is of great value to advanced level students, researchers, and professional practitioners of this field to have now a complete volume with more than 600 pages devoted to this topic. *Markov Decision Processes: Discrete Stochastic Dynamic Programming* represents an up-to-date, unified, and rigorous treatment of theoretical and computational aspects of discrete-time Markov decision processes. *Journal of the American Statistical Association* [Stochastic Dynamic Programming and the Control of Queueing Systems](#) Linn I. Sennott, 1998-09-30 A path-breaking account of Markov decision processes theory and computation. This book's clear presentation of theory, numerous chapter-end problems, and development of a unified method for the computation of optimal policies in both discrete and continuous time make it an excellent course text for graduate

students and advanced undergraduates Its comprehensive coverage of important recent advances in stochastic dynamic programming makes it a valuable working resource for operations research professionals management scientists engineers and others Stochastic Dynamic Programming and the Control of Queueing Systems presents the theory of optimization under the finite horizon infinite horizon discounted and average cost criteria It then shows how optimal rules of operation policies for each criterion may be numerically determined A great wealth of examples from the application area of the control of queueing systems is presented Nine numerical programs for the computation of optimal policies are fully explicated The Pascal source code for the programs is available for viewing and downloading on the Wiley Web site at [www.wiley.com](http://www.wiley.com) products subject mathematics The site contains a link to the author's own Web site and is also a place where readers may discuss developments on the programs or other aspects of the material The source files are also available via ftp at [ftp://ftp.wiley.com/public/sci\\_tech\\_med/stochastic](ftp://ftp.wiley.com/public/sci_tech_med/stochastic) Stochastic Dynamic Programming and the Control of Queueing Systems features Path breaking advances in Markov decision process techniques brought together for the first time in book form A theorem proof format proofs may be omitted without loss of continuity Development of a unified method for the computation of optimal rules of system operation Numerous examples drawn mainly from the control of queueing systems Detailed discussions of nine numerical programs Helpful chapter end problems Appendices with complete treatment of background material

**Stochastic Equations: Theory and Applications in Acoustics, Hydrodynamics, Magnetohydrodynamics, and Radiophysics, Volume 2** Valery I. Klyatskin, 2014-07-14 In some cases certain coherent structures can exist in stochastic dynamic systems almost in every particular realization of random parameters describing these systems Dynamic localization in one dimensional dynamic systems vortexgenesis vortex production in hydrodynamic flows and phenomenon of clustering of various fields in random media i e appearance of small regions with enhanced content of the field against the nearly vanishing background of this field in the remaining portion of space are examples of such structure formation The general methodology presented in Volume 1 is used in Volume 2 Coherent Phenomena in Stochastic Dynamic Systems to expound the theory of these phenomena in some specific fields of stochastic science among which are hydrodynamics magnetohydrodynamics acoustics optics and radiophysics The material of this volume includes particle and field clustering in the cases of scalar density field and vector magnetic field passive tracers in a random velocity field dynamic localization of plane waves in layered random media as well as monochromatic wave propagation and caustic structure formation in random media in terms of the scalar parabolic equation

**Stochastic Dynamics of Structures** Jie Li, Jianbing Chen, 2009-09-28 In Stochastic Dynamics of Structures Li and Chen present a unified view of the theory and techniques for stochastic dynamics analysis prediction of reliability and system control of structures within the innovative theoretical framework of physical stochastic systems The authors outline the fundamental concepts of random variables stochastic process and random field and orthogonal expansion of random functions Readers will gain insight into core concepts such as stochastic process models

for typical dynamic excitations of structures stochastic finite element and random vibration analysis Li and Chen also cover advanced topics including the theory of and elaborate numerical methods for probability density evolution analysis of stochastic dynamical systems reliability based design and performance control of structures Stochastic Dynamics of Structures presents techniques for researchers and graduate students in a wide variety of engineering fields civil engineering mechanical engineering aerospace and aeronautics marine and offshore engineering ship engineering and applied mechanics Practicing engineers will benefit from the concise review of random vibration theory and the new methods introduced in the later chapters The book is a valuable contribution to the continuing development of the field of stochastic structural dynamics including the recent discoveries and developments by the authors of the probability density evolution method PDEM and its applications to the assessment of the dynamic reliability and control of complex structures through the equivalent extreme value distribution A H S Ang NAE Hon Mem ASCE Research Professor University of California Irvine USA The authors have made a concerted effort to present a responsible and even holistic account of modern stochastic dynamics Beyond the traditional concepts they also discuss theoretical tools of recent currency such as the Karhunen Loeve expansion evolutionary power spectra etc The theoretical developments are properly supplemented by examples from earthquake wind and ocean engineering The book is integrated by also comprising several useful appendices and an exhaustive list of references it will be an indispensable tool for students researchers and practitioners endeavoring in its thematic field Pol Spanos NAE Ryon Chair in Engineering Rice University Houston USA

**Stochastic Dynamics** Hans Crauel, Matthias Gundlach, 2007-12-14 The conference on Random Dynamical Systems took place from April 28 to May 2 1997 in Bremen and was organized by Matthias Gundlach and Wolfgang Kliemann with the help of th itz Colonius and Hans Crauel It brought together mathematicians and scientists for whom mathematics in particular the field of random dynamical systems is of relevance The aim of the conference was to present the current state in the theory of random dynamical systems RDS its connections to other areas of mathematics major fields of applications and related numerical methods in a coherent way It was ho veer not by accident that the conference was centered around the 60th birthday of Ludwig Arnold The theory of RDS o ves much of its current state and status to Ludwig Arnold Many aspects of the theory a large number of results and several substantial contributions were accomplished by Ludwig Arnold An even larger number of contributions has been initiated by him The field be fited much from his enthusiasm his openness for problems not completely aligned with his o vn research interests his ability to explain mathematics to researchers from other sciences as well as his ability to get mathema clans interested in problems from applications not completely aligned with their research interests In particular a considerable part of the impact stochastics had on physical chemistry as well as on engineering goes back to Ludwig Arnold He built up an active research group kno vn as the Bremen group

Linearization Methods for Stochastic Dynamic Systems Leslaw Socha, 2007-12-20 For most cases of interest exact solutions to nonlinear equations describing stochastic dynamical systems

are not available This book details the relatively simple and popular linearization techniques available covering theory as well as application It examines models with continuous external and parametric excitations those that cover the majority of known approaches

**Dynamic State Variable Models in Ecology** Colin W. Clark, Marc Mangel, 2000-02-10 This book introduces readers to a set of powerful and extremely flexible modeling techniques starting at square one and continuing with carefully chosen applications Some of these applications of methodology include insect oviposition behavior overwinter survival of birds and fish avian migration resource management conservation biology agroecology and human behavior This book also explains how to construct test and use dynamic state variable models in a wide range of contexts in evolutionary ecology and its complete and up to date coverage allows readers to immediately begin using the described techniques Dynamic State Variable Models in Ecology is designed for self instruction or for use in upper division undergraduate or graduate courses It is ideal for students and scientists interested in behavior ecology anthropology conservation biology and related fields

**Applied Stochastic Models and Control for Finance and Insurance** Charles S. Tapiero, 2012-12-06 Applied Stochastic Models and Control for Finance and Insurance presents at an introductory level some essential stochastic models applied in economics finance and insurance Markov chains random walks stochastic differential equations and other stochastic processes are used throughout the book and systematically applied to economic and financial applications In addition a dynamic programming framework is used to deal with some basic optimization problems The book begins by introducing problems of economics finance and insurance which involve time uncertainty and risk A number of cases are treated in detail spanning risk management volatility memory the time structure of preferences interest rates and yields etc The second and third chapters provide an introduction to stochastic models and their application Stochastic differential equations and stochastic calculus are presented in an intuitive manner and numerous applications and exercises are used to facilitate their understanding and their use in Chapter 3 A number of other processes which are increasingly used in finance and insurance are introduced in Chapter 4 In the fifth chapter ARCH and GARCH models are presented and their application to modeling volatility is emphasized An outline of decision making procedures is presented in Chapter 6 Furthermore we also introduce the essentials of stochastic dynamic programming and control and provide first steps for the student who seeks to apply these techniques Finally in Chapter 7 numerical techniques and approximations to stochastic processes are examined This book can be used in business economics financial engineering and decision sciences schools for second year Master s students as well as in a number of courses widely given in departments of statistics systems and decision sciences

**Slope Stochastic Dynamics** Yu Huang, Min Xiong, Liuyuan Zhao, 2022-02-02 This book provides a new framework for analysis of slope nonlinear stochastic seismic dynamic response based on the new theoretical tool of stochastic dynamics The coupling effects of uncertainty of geological parameters strong dynamic nonlinearity and randomness of ground motion are considered in the process of the seismic dynamic stability assessment of slope In this book an intensity frequency non stationary

stochastic ground motion model based on time domain stochastic process description is preliminarily established to characterize the randomness of earthquakes The spatial distribution random field model of geotechnical parameters is established to describe the time space variability of geotechnical parameters Based on the basic theory of stochastic dynamics the seismic stability performance evaluation method of slope is established The slope seismic dynamic model test based on large complex shaking table is performed to verify and modify the proposed framework and method This book sheds new light on the development of nonlinear seismic stochastic dynamics and seismic design of slope engineering

**Stochastic Dynamics of Structures** Abdelkhalak El Hami, Bouchaib Radi, 2016-12-27 This book is dedicated to the general study of the dynamics of mechanical structures with consideration of uncertainties The goal is to get the appropriate forms of a part in minimizing a given criterion In all fields of structural mechanics the impact of good design of a room is very important to its strength its life and its use in service The development of the engineer's art requires considerable effort to constantly improve structural design techniques Lectures on Dynamics of Stochastic Systems Valery I.

Klyatskin, 2010-09-09 Fluctuating parameters appear in a variety of physical systems and phenomena They typically come either as random forces sources or advecting velocities or media material parameters like refraction index conductivity diffusivity etc Models naturally render to statistical description where random processes and fields express the input parameters and solutions The fundamental problem of stochastic dynamics is to identify the essential characteristics of the system its state and evolution and relate those to the input parameters of the system and initial data This book is a revised and more comprehensive version of Dynamics of Stochastic Systems Part I provides an introduction to the topic Part II is devoted to the general theory of statistical analysis of dynamic systems with fluctuating parameters described by differential and integral equations Part III deals with the analysis of specific physical problems associated with coherent phenomena A comprehensive update of Dynamics of Stochastic Systems Develops mathematical tools of stochastic analysis and applies them to a wide range of physical models of particles fluids and waves Includes problems for the reader to solve

**Stochastic Dynamics of Deterministic Systems** Marcelo Viana, 1997 **Stochastic Dynamic Equations** Suman Sanyal, 2008 We propose a new area of mathematics namely stochastic dynamic equations which unifies and extends the theories of stochastic differential equations and stochastic difference equations After giving a brief introduction to the theory of dynamic equations on time scales we construct Brownian motion on isolated time scales and prove some of its properties Then we define stochastic integrals on isolated time scales The main contribution of this dissertation is to give explicit solutions of linear stochastic dynamic equations on isolated time scales We illustrate the theoretical results for dynamic stock prices and Ornstein Uhlenbeck dynamic equations Finally we study almost sure asymptotic stability of stochastic dynamic equations and mean square stability for stochastic dynamic Volterra type equations Abstract leaf iii Stochastic Dynamics Of Complex Systems: From Glasses To Evolution Henrik Jeldtoft Jensen, Paolo Sibani, 2013-02-20 Dynamical evolution over

long time scales is a prominent feature of all the systems we intuitively think of as complex for example ecosystems the brain or the economy In physics the term ageing is used for this type of slow change occurring over time scales much longer than the patience or indeed the lifetime of the observer The main focus of this book is on the stochastic processes which cause ageing and the surprising fact that the ageing dynamics of systems which are very different at the microscopic level can be treated in similar ways The first part of this book provides the necessary mathematical and computational tools and the second part describes the intuition needed to deal with these systems Some of the first few chapters have been covered in several other books but the emphasis and selection of the topics reflect both the authors interests and the overall theme of the book The second part contains an introduction to the scientific literature and deals in some detail with the description of complex phenomena of a physical and biological nature for example disordered magnetic materials superconductors and glasses models of co evolution in ecosystems and even of ant behaviour These heterogeneous topics are all dealt with in detail using similar analytical techniques This book emphasizes the unity of complex dynamics and provides the tools needed to treat a large number of complex systems of current interest The ideas and the approach to complex dynamics it presents have not appeared in book form until now a      Stochastic Algorithms: Foundations and Applications Oleg B. Lupanov, Oktay M. Kasim-Zade, Alexander V. Chaskin, Kathleen Steinhöfel, 2005-11-03 This book constitutes the refereed proceedings of the Third International Symposium on Stochastic Algorithms Foundations and Applications SAGA 2005 held in Moscow Russia in October 2005 The 14 revised full papers presented together with 5 invited papers were carefully reviewed and selected for inclusion in the book The contributed papers included in this volume cover both theoretical as well as applied aspects of stochastic computations with a special focus on new algorithmic ideas involving stochastic decisions and the design and evaluation of stochastic algorithms within realistic scenarios      **Nonlinear Stochastic Dynamic Engineering Systems** Franz Ziegler, Gerhard I. Schueller, 2012-12-06 This symposium held at Innsbruck Igls on June 21-26 1987 is the fifth in a series of IUTAM Symposia on the application of stochastic methods in mechanics The first two meetings in Warwick 1972 and Southampton 1976 concentrated on the stability of stochastic dynamical systems and stochastic methods in dynamics respectively The third meeting in Frankfurt Oder 1982 added aspects of reliability while the fourth symposium in Stockholm 1984 dealt mainly with fatigue and fracture problems The general theme of the present symposium is devoted to nonlinear stochastic dynamics of engineering systems which is believed of great importance for providing the tools for basic development and progress in various fields of mechanical structural and aeronautical engineering particularly in the areas of vehicle dynamics multi storey structural dynamics systems identification offshore structural dynamics nuclear structures under various stochastic loading conditions i e wind earthquake parametric excitations etc The contributions collected in this volume cover a wide spectrum of topics ranging from more theoretical analytical and numerical treatment to practical application in various fields The truly international character of the meeting is accomplished by 42 contributions and 86



participants from as many as 19 countries and hence contributed to the original idea of IUTAM which is to foster international cooperation It should be recalled that for getting this cooperation started again after the First World War Theodore von Kanmm and Tullio Levi Civita called the world s flrst international IUTAM conference on hydro and aerornechanics in 1922 in Innsbruck Austria

**Linearization Methods for Stochastic Dynamic Systems** Leslaw Socha,2007-11-30 For most cases of interest exact solutions to nonlinear equations describing stochastic dynamical systems are not available This book details the relatively simple and popular linearization techniques available covering theory as well as application It examines models with continuous external and parametric excitations those that cover the majority of known approaches

**Stochastic Dynamics of Power Systems** Ping Ju,2019 This book discusses stochastic dynamics of power systems and the related analytical methodology It summarizes and categorizes the stochastic elements of power systems and develops a framework for research on stochastic dynamics of power systems It also establishes a research model for stochastic dynamics of power systems and theoretically proves stochastic stability in power systems Further in addition to demonstrating the stochastic oscillation mechanism in power systems it also proposes methods for quantitative analysis and stochastic optimum control in the field of stochastic dynamic security in power systems This book is a valuable resource for researchers scholars and engineers in the field of electrics

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