IUTAM SYMPOSIUM ON
ADVANCES IN NONLINEAR STOCHASTIC MECHANICS

SOLID MECHANICS AND ITS APPLICATIONS
Volume 47

Series Editor: G.M.L. GLADWELL
Solid Mechanics Division, Faculty of Engineering
University of Waterloo
Waterloo, Ontario, Canada N2L 3G1

Aims and Scope of the Series

The fundamental questions arising in mechanics are: *Why?*, *How?*, and *How much?* The aim of this series is to provide lucid accounts written by authoritative researchers giving vision and insight in answering these questions on the subject of mechanics as it relates to solids.

The scope of the series covers the entire spectrum of solid mechanics. Thus it includes the foundation of mechanics; variational formulations; computational mechanics; statics, kinematics and dynamics of rigid and elastic bodies; vibrations of solids and structures; dynamical systems and chaos; the theories of elasticity, plasticity and viscoelasticity; composite materials; rods, beams, shells and membranes; structural control and stability; soils, rocks and geomechanics; fracture; tribology; experimental mechanics; biomechanics and machine design.

The median level of presentation is the first year graduate student. Some texts are monographs defining the current state of the field; others are accessible to final year undergraduates; but essentially the emphasis is on readability and clarity.

For a list of related mechanics titles, see final pages.

IUTAM Symposium on

Advances in Nonlinear Stochastic Mechanics

Proceedings of the IUTAM Symposium
held in Trondheim, Norway,
3–7 July 1995

Edited by

A. NAESS

Department of Structural Engineering,
Norwegian University of Science and Technology,
Trondheim, Norway

and

S. KRENK

Division of Mechanics,
Lund Institute of Technology,
Lund University,
Sweden

KLUWER ACADEMIC PUBLISHERS
DORDRECHT / BOSTON / LONDON

A C.I.P. Catalogue record for this book is available from the Library of Congress.

ISBN-13: 978-94-010-6630-3 e-ISBN-13: 978-94-009-0321-0
DOI : 10.1007/978-94-009-0321-0

Published by Kluwer Academic Publishers,
P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

Kluwer Academic Publishers incorporates
the publishing programmes of
D. Reidel, Martinus Nijhoff, Dr W. Junk and MTP Press.

Sold and distributed in the U.S.A. and Canada
by Kluwer Academic Publishers,
101 Philip Drive, Norwell, MA 02061, U.S.A.

In all other countries, sold and distributed
by Kluwer Academic Publishers Group,
P.O. Box 322, 3300 AH Dordrecht, The Netherlands.

All Rights Reserved
© 1996 Kluwer Academic Publishers
Softcover reprint of the hardcover 1st edition 1996
No part of the material protected by this copyright notice may be reproduced or
utilized in any form or by any means, electronic or mechanical,
including photocopying, recording or by any information storage and
retrieval system, without written permission from the copyright owner.

PREFACE

The IUTAM Symposium on Advances in Nonlinear Stochastic Mechanics, held in Trondheim July 3-7, 1995, was the eighth of a series of IUTAM sponsored symposia which focus on the application of stochastic methods in mechanics. The previous meetings took place in Coventry, UK (1972), Southampton, UK (1976), Frankfurt/Oder, Germany (1982), Stockholm, Sweden (1984), Innsbruck/Igls, Austria (1987), Turin, Italy (1991) and San Antonio, Texas (1993).

The symposium provided an extraordinary opportunity for scholars to meet and discuss recent advances in stochastic mechanics. The participants represented a wide range of expertise, from pure theoreticians to people primarily oriented toward applications. A significant achievement of the symposium was the very extensive discussions taking place over the whole range from highly theoretical questions to practical engineering applications. Several presentations also clearly demonstrated the substantial progress that has been achieved in recent years in terms of developing and implementing stochastic analysis techniques for mechanical engineering systems. This aspect was further underpinned by specially invited extended lectures on computational stochastic mechanics, engineering applications of stochastic mechanics, and nonlinear active control. The symposium also reflected the very active and high-quality research taking place in the field of stochastic stability. Ten presentations were given on this topic of a total of 47 papers. A main conclusion that can be drawn from the proceedings of this symposium is that stochastic mechanics as a subject has reached great depth and width in both methodology and applicability.

The Opening Address of the symposium was given by The Secretary General of the IUTAM, Dr. F. Ziegler. On the first day of the symposium, a reception in the Archbishop's Palace was hosted by the City of Trondheim. This was preceded by an organ concert hosted by Golar Nor Offshore AS in the Nidaros Cathedral. The symposium banquet was hosted by Dr. Steen Krenk and Dr. Arvid Naess in the Banquet Hall of the Ringve Museum of Musical History, with Dr. Y.K. Lin serving as the banquet speaker. The Closing Address was delivered by Dr. K. Sobzcyk, Member of the IUTAM Symposium Committee.

On behalf of the Scientific and Organizing Committees, we would like to thank the IUTAM Bureau for promoting and sponsoring this symposium. We are also greatly in debt to the other sponsors, whose contributions made this symposium possible. The contributions of the authors and participants in the symposium are, of course, instrumental in producing a successful meeting and its proceedings, and we deeply appreciate their efforts. The assistance in processing the manuscripts provided by Mrs. A.M. Soeberg of the Norwegian Institute of Technology and Ms. M. Jönsson of Lund University is gratefully acknowledged.

A. Naess S. Krenk

Opening Address of the Secretary General of IUTAM

Chairmen, Ladies and Gentlemen,

On behalf of the International Union of Theoretical and Applied Mechanics it is my duty and my pleasure to welcome you at the IUTAM Symposium on Advances in Nonlinear Stochastic Mechanics. The proposal to arrange this Symposium was accepted in August 1992 by the General Assembly of IUTAM. Since that time both chairmen, Professor S Krenk and Professor A Naess have done an excellent job in preparing the scientific program. The chairmen have been advised by the Scientific Committee in selecting and inviting participants from all over the world.

There are sometimes some misunderstandings about the appointment of the Scientific Committee by IUTAM: If you look back to the related IUTAM Symposia held in Turin 1991 and San Antonio 1993, to mention just the two recent ones, you see different members of the Scientific Committees with only a small overlap to the current one: Professor S T Ariaratnam, Professor P Bernard, Professor V Bolotin, Professor R N Iyengar, Professor Y K Lin, Professor J B Roberts, Professor W Schiehlen (ex officio), Professor K Sobczyk and Professor P Spanos. Since the value and quality of IUTAM is reflected by its Symposia, we are very happy to have the series of proceedings and meetings in the field of Stochastic Mechanics. There are many more meetings referring to that important subject, some people even speak of an inflation, however, the quality of the IUTAM Symposia is hardly reached elsewhere.

Norway is a member of IUTAM since 1949. Its National Committee is represented in the Union by the Chairman, Professor B Gjevik, University of Oslo. There have been many important conferences organized in Norway, I just refer to the recent 15th International Congress of Acoustics (Norwegian Institute of Technology, Trondheim, Norway, 26-30 June 1995) which is related to our Union. However, we are opening the first IUTAM Symposium to be held in this beautiful country.

We look forward to a dense, but exciting program, divided into 16 Sessions. I am especially happy to see sessions devoted to evolving fields like Stochastic Finite Elements and System Identification and Control. Stochastic Mechanics will be present at the 19th ICTAM, Kyoto, 25-31 August 1996, to celebrate 20 years of IUTAM engagement in that field that have passed since the first IUTAM Symposium held in 1976 in Southampton, England. The General Assembly held during the Congress will decide on future Symposia for the years 1998/99, depending on the quality of the proposals received. It would be a good idea to consider the future of Stochastic Mechanics in the tenure of our Symposium. We shall start with an exciting session with the specially invited lecture given by Professor Masanobu Shinozuka on Computational Stochastic Mechanics.

Thank you for your kind attention.

Franz Ziegler

Final Address at the Closing Ceremony on behalf of IUTAM

Ladies and Gentlemen,

The Secretary General of IUTAM - Professor F Ziegler- and the former Secretary General - Professor W Schiehlen - who were here with us during the first part of the Symposium had to leave earlier because of other important commitments. So, being recently associated with IUTAM as a member of the IUTAM Symposium Panel, I have the honor and pleasure to say a few words on behalf of IUTAM, and in the name of Professor F Ziegler, particularly. Above all, I wish to express thanks and gratitude to the chairmen of this Symposium - Professor Arvid Naess and Professor Steen Krenk - for all the arrangements which they have made in connection with our Symposium. I also wish to express the appreciation of IUTAM to the Local Organizing Committee for all the technical and administrative help in bringing this Symposium to its successful end.

We have spent five exciting days together, presenting papers, participating in discussions and deliberations on stochastic mechanics - our favourite field of science. But we also had the occasion - which is extremely important as well - to familarize ourselves a little with this unique and beautiful country. The visit to Ringve Museum of Musical History, followed by the Symposium Dinner, will remain in our memories as an impressive sign of the Norwegian culture and hospitality.

Let me now say a few words on the future IUTAM Symposium on Stochastic Mechanics. IUTAM encourages all of you to continue your engagement in this series of Symposia. What is especially needed now is preparation of good proposals for the next symposium of this type. According to the Secretary General, various competitive proposals are welcome. Proposals for the Symposium in 1998/1999 should be sent to the Secretary General by the end of April of next year. The decision will be made by the General Assembly of IUTAM, after careful evaluation of the proposals by the IUTAM Symposia Panel.

In closing, I wish to thank you - Arvid and Steen - once again for this very successful Symposium. I wish you all a good journey back home and pleasant summer vacations.

K Sobczyk

CONTENTS

A.A. Afaneh and R.A. Ibrahim: Experimental random excitation of nonlinear systems with multiple internal resonances 1

S.T. Ariaratnam: Stochastic stability of viscoelastic systems under bounded noise excitation 11

L. Arnold and B. Schmalfuss: Fixed points and attractors for random dynamical systems 19

A.K. Belyaev, H. Irschik and F. Ziegler: Nonlinear wave propagation in complex structures modelled by random media with self-stresses ... 29

P. Bernard: Stochastic linearization and large deviations 39

V.V. Bolotin: Meandering propagation of fatigue cracks through solids with randomly distributed properties 47

F. Bontempi and L. Faravelli: The study of bifurcations through the solution of the Fokker-Planck equation 59

R. Bouc and M. Defilippi: Spectral response of a beam-stop system under random exitation 69

K. Breitung: Higher order approximations for maxima of random fields 79

S. Caddemi and G. Muscolino: Extension of the stochastic differential calculus to complex processes 89

G.Q. Cai and Y.K. Lin: Response of a hysteretic system under non-stationary earthquake excitation 99

F. Casciati: Nonlinear active control and stochastic excitation 109

G. Dasgupta: Viscoplastic responses with stochastic Q-damping for soil 117

O. Ditlevsen and S. Randrup-Thomsen: Gaussian white noise excited elasto-plastic oscillator of several degrees of freedom 127

K. Dolinski and P. Colombi: Fatigue crack growth under stochastic loading 143

M.M. Doyle, N. Sri Namachchivaya and L. Arnold: Small noise expansion of moment Lyapunov exponents for two-dimensional systems 153

I. Elishakoff, Y.J. Ren and M. Shinozuka: Non-perturbative FEM for deterministic and stochastic beams through inverse of stiffness matrix 169

L. Gao, A. Haldar and N. Shome: Strength and serviceability requirements in seismic deign using nonlinear SFEM 179

M. Grigoriu: Parametric models and stochastic integrals 189

R.N. Iyengar and O.R. Jaiswal: Stochastic response of irregular tracks under moving vehicles 213

E.A. Johnson, L.A. Bergman, D.E. Goldberg and S.J. Dyke: Monte Carlo simulation of dynamical systems of engineering interest in a massively parallel computing environment: An application of genetic algorithms 225

A. Kareem and X. Song: Stochastic response of coupled platform-tether system under multi-directional seas 235

A.S. Kovaleva: Optimal control problems for nonlinear oscillatory systems with random perturbations 247

H.U. Köylüoglu, S.R.K. Nielsen and A.S. Cakmak: Stochastic dynamics of nonlinear structures with random properties subject to stationary random excitation 257

S. Krenk: Wind field coherence and dynamic wind forces 269

R.S. Langley: Wave propagation through randomly disordered near-periodic structures 279

C.S. Manohar and B.R. Shashirekha: Harmonic response analysis of stochastic rods using spatial stochastic averaging 289

N.K. Moshchuk, R.A. Ibrahim, R.Z. Khasminskii and P.L. Chow: Ship capsizing in random sea waves and the mathematical pendulum 299

A. Naess: Random vibration of ship hulls 311

J. Naprstek and L. Fryba: Stochastic response of a system with space imperfections under moving load 321

S.R.K. Nielsen, R. Iwankiewicz and P. Skjærbæk: Moment equations for non-linear systems under renewal-driven random impulses with gamma-distributed interarrival times 331

M. Ostoja-Starzewski: Micromechanically based constitutive laws and random fields in solid mechanics: Elasticity, plasticity and fracture ... 341

M. Di Paola and G. Falsone: Response correlations of linear systems with white noise linearly parametric inputs 351

J.B. Roberts, J.F. Dunne and A. Debonos: Parameter estimation for randomly excited non-linear systems 361

W. Schiehlen, B. Hu and S. Schaub: Amplitude bounds of stochastic nonlinear multibody systems 373

G.I. Schuëller: Engineering applications of stochastic mechanics 383

M. Shinozuka and R. Zhang: Wind induced vibrations of high-rise structures 403

E. Simiu and M. Franaszek: A new tool for the investigation of a class of nonlinear stochastic differential equations: The Melnikov process 427

K. Sobczyk and J. Trebicki: Non-stationary response of stochastic systems via maximum entropy principle 437

C.W.S. To and M.L. Liu: Lyapunov exponents and information dimensions of multi-degree-of-freedom systems under deterministic and stationary random excitations 449

J. Trebicki: Randomly excited vibratory systems with variable structure 459

W.V. Wedig: Stability and invariant measures of perturbed dynamical systems 469

S.F. Wojtkiewicz, B.F. Spencer and L.A. Bergman: New insights on the application of moment closure methods to nonlinear stochastic systems 479

S.C.S. Yim and H. Lin: Unified analysis of complex nonlinear motions via densities 489

W.Q. Zhu: Some recent advances in theory of stochastically excited and dissipative Hamiltonian systems 499