The Author and The Book

Professor Wilson has over sixty years of professional experience in Civil, Mechanical and Aerospace Engineering. He was a Professor of Structural Engineering at the University of California at Berkeley during the period 1965 to 1991 and has published over 180 papers and books. His research and development contributions have earned him many awards including the election to the National Academy of Engineering in 1985.

Professor Wilson wrote the first automated finite element analysis computer program in 1961 and was the original developer of the **CAL**, **SAP** and **ETABS** series of computer programs. These programs are noted for their accuracy, speed, use of very efficient numerical algorithms and accurate finite elements. During the past 40 years, Ed Wilson has worked as a Senior Consultant to **CSI** on the programming and documentation of these new methods of computational structural analysis.

The major purpose of this book is to summarize the theoretical development of the finite elements and numerical methods used in the latest versions of the **SAP** and **ETABS** programs. Most of the elements and numerical methods used in these programs are new and are not presented in current textbooks on structural analysis. In addition, the book summarizes the fundamental equations of mechanics.

A minimum mathematical background is required in order to completely understand the material presented in the book. However, an understanding of the physical behavior of real structures is essential. A computer programming background is not required.

A new three-dimensional quadrilateral **SHELL** element, with normal rotational degrees-of-freedom, is presented that is accurate for both thin and thick plates and shells. Therefore, shell elements can be easily connected to classical **FRAME** elements. The three-dimensional **SOLID** element can be used to model both fluids and solids.

Dynamic analysis is presented as a logical extension of static analysis in which inertia and damping forces are added to satisfy equilibrium at every point in time. The use of **L**oad **D**ependent **R**itz, **LDR**, vectors in a dynamic analysis produce far more accurate results than if the exact dynamic eigenvectors are used.

The use of **LDR** vectors allows the classical mode superposition method to be extended to nonlinear dynamic analysis by the use of the **F**ast **N**onlinear **A**nalysis, **FNA**, method. This new method of nonlinear, dynamic analysis allows structures, with a limited number of nonlinear elements, to be analyzed with almost the same computational time as required for a linear dynamic analysis of the same structure.

This is a **must read** book for all researchers and professionals working in the field of modern structural engineering.

Three Dimensional

Static and Dynamic

Analysis of Structures

A Physical Approach

With Emphasis on Earthquake Engineering

Edward L. Wilson

Professor Emeritus of Structural Engineering

University of California at Berkeley

Copies of this publication may be obtained from:

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Preface

This edition of the book contains corrections and additions to the July 1998 edition. Most of the new material that has been added is in response to questions and comments from the users of SAP2000, ETABS and SAFE.

Chapter 22 has been written on the direct use of absolute earthquake displacement loading acting at the base of the structure. Several new types of numerical errors, for absolute displacement loading, are identified. First, the fundamental nature of displacement loading is significantly different from the base acceleration loading traditionally used in earthquake engineering. Second, a smaller integration time step is required to define the earthquake displacement and to solve the dynamic equilibrium equations. Third, a large number of modes are required for absolute displacement loading in order to obtain the same accuracy as produced when base acceleration is used as the loading. Fourth, the 90 percent mass participation rule, intended to assure accuracy of the analysis, does not apply for absolute displacement loading. Finally, the effective modal damping for displacement loading is larger than when acceleration loading is used.

In order to reduce theses errors associated with displacement loading a higher order integration method, based on a cubic variation of loads within a time step, is introduced in Chapter 13. In addition, static and dynamic participation factors have been defined which allow the structural engineer to minimize the errors associated with displacement type of loading. In addition, Chapter 19 on viscous damping has been expanded in order to illustrate the physical effects of modal damping on the results of a dynamic analysis.

Appendix H, on the speed of modern personal computers, has been updated. It is now possible to purchase a personal computer for approximately $1,500 that is 25 times faster than a $10,000,000 CRAY computer produced in 1974.

Several other additions and modifications have been made in this printing. Please send your comments and questions *to ed-wilson1@juno.com*.

Edward L. Wilson

April 2000

Personal Remarks

My freshman Physics instructor dogmatically warned the class "do not use an equation you cannot derive". The same instructor once stated that "if a person had five minutes to solve a problem, that their life depended upon, the individual should spend three minutes reading and clearly understanding the problem". For the past forty years these simple, practical remarks have guided my work and I hope that the same philosophy has been passed along to my students. With respect to modern structural engineering, one can restate these remarks as "do not use a structural analysis program unless you fully understand the theory and approximations used within the program" and "do not create a computer model until the loading, material properties and boundary conditions are clearly defined".

Therefore, the major purpose of this book is to present the essential theoretical background in order that the users of computer programs for structural analysis can understand the basic approximations used within the program, verify the results of all analyses and assume professional responsibility for the results. It is assumed that the reader has an understanding of statics, mechanics of solids, and elementary structural analysis. The level of knowledge expected is equal to that of an individual with an undergraduate degree in Civil or Mechanical Engineering. Elementary matrix and vector notations are defined in the Appendices and are used extensively. A background in tensor notation and complex variables is not required.

All equations are developed using a physical approach, since this book is written for the student and professional engineer and not for my academic colleagues. Three dimensional structural analysis is relatively simple due to the high speed of the modern computer. Therefore, all equations are presented in three dimensional form and anisotropic material properties are automatically included. A computer programming background is not necessary in order to use a computer program intelligently. However, detailed numerical algorithms are given in order that the readers completely understand the computational methods that are summarized in this book. The Appendices contain an elementary summary of the numerical methods used; therefore, it should not be necessary to spend additional time reading theoretical research papers in order to understand the theory presented in this book.

The author has developed and published many computational techniques for the static and dynamic analysis of structures. It has been personally satisfying that many members of the engineering profession have found these computational methods useful. Therefore, one reason for compiling this theoretical and application book is to consolidate in one publication this research and development. In addition, the recently developed Fast Nonlinear Analysis (FNA) method and other numerical methods are presented in detail for the first time.

The fundamental physical laws that are the basis of the static and dynamic analysis of structures are over 100 years old. Therefore, anyone who believes they have discovered a new fundamental principle of mechanics is a victim of their own ignorance. This book contains computational tricks that the author has found to be effective for the development of structural analysis programs.

The static and dynamic analysis of structures has been automated to a large degree due to the existence of inexpensive personal computers. However, the field of structural engineering, in my opinion, will never be automated. The idea that an expert-system computer program, with artificial intelligence, will replace a creative human is an insult to all structural engineers.

The material presented in the first edition, *Three Dimensional Dynamic Analysis of Structures*, is included and updated in this book. I am looking forward to additional comments and questions from the readers in order to expand the material in future editions of the book.

Edward L. Wilson
July 1998

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