FOUNDATION AND STRUCTURAL PROBLEMS

Solved by Microcomputer

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Preface

Introduction

This book attempts to bridge the gap between the traditional methods of analysis and the modern computer-based approach. It describes what might be called a 'partially computerised' design system intermediate between 'hand calculation' and 'fully computerised' methods. The first essential in all cases is to acquire a proper grasp of fundamental theory and its relation to structural behaviour. Once this is achieved, one can look to ways in which the computer can assist in obtaining results more efficiently and speedily using simple programs or routines; this is the stage described in the book. The next 'fully computerised' stage requires a specialised knowledge of machine code programming, assembly language, binary and hexadecimal notation, Boolean algebra, masking techniques, interrupts, logical file handling, graphics creation, data generation, editing functions and post processing, among other subjects, to take full advantage of the computer's remarkable powers. This is likely to remain the domain of the computer specialist rather than that of the practising engineer in the author's view. The book, therefore, is aimed primarily at the student or practising engineer equipped with a microcomputer who wishes to use it for solving common structural problems using software with which he is thoroughly familiar and which he can develop to his or her own requirements.

Scope

The book describes in Parts 1 and 2 how to deal with analytical problems commonly encountered in the design of foundations, soil retaining structures and temporary works including sheet piling, laterally loaded piles, continuous footings, falsework, coffer dams, trench shores, strutted beams, raft foundations and concrete formwork. Examples have been selected to represent the type of practical problems met with in consultants' or design offices.

General structural problems are dealt with in Parts 3 and 4 which cover analysis of lattice girders, roof trusses, beam frameworks and grillages with and without torsion, rigid portal frames, multi-storey and multi-bay frames and box culverts.

More emphasis than usual has been placed on design of foundations and temporary works, since recent failures in civil engineering construction have highlighted the necessity for checking these as thoroughly as other features. Correct analysis of foundations and earthworks is as important as that of the superstructure, of course, if the building or bridge is to perform satisfactorily, although textbooks commonly segregate the two for some reason. Basic procedures are outlined in the book to facilitate analysis and encourage computer checks on works that are often treated as of minor importance, therefore. A modified flexibility method of analysis is used for this purpose, as described in Chapter 1.

Computer programs

Computer programs listed in the book make use of standard numerical subroutines for the solution of simultaneous equations. They are written in elementary BASIC and fully explained, so both programs and the concepts on which they are based are comprehended by the reader. This contrasts with the situation with commercial software which is usually efficient but seldom simple or understandable to the user and, indeed, may be deliberately shrouded in secrecy. The dangers in a blind acceptance of imperfectly understood output (the 'black box' syndrome) are a matter of concern to many teachers and practising engineers, especially in view of some unfortunate mishaps in recent years.

It has always been held that an engineer should be familiar with any method of analysis he employs. Part of his training is not merely to know the various formulae used in analysis, but also to understand their derivation so that they can be used with confidence. Use of computers should not nullify this principle. In the book this has been borne in mind and, since all problems are tackled from first principles, the computer output should be completely understood.

Simple software of this nature, although limited in scope and incapable of utilising the modern computer's potentialities to the full, has its advantages. Programs are comparatively short and can be keyed in easily for storage. The number of variables to input can be kept to a minimum, unlike comprehensive programs covering a variety of structures, so they may be run with few interruptions. So-called 'user friendly' messages are omitted to enable the program to run continuously as far as possible; explanatory comments and headings are confined mainly to the program specification for the same reason.

Data preparation time is minimised also, which is considered a most important factor. Thus, the designer has more time to concentrate on the implications of the results or to indulge in comparative design studies. Programs are not 'interactive' but it is left to the user to decide, from a study of the output, what alterations to make for satisfactory results. The emphasis, in fact, is on the user retaining full control of the program. Once a feeling of confidence is achieved, the programs should form a useful means of checking more sophisticated output.

The importance of checking output from imperfectly understood 'bought-in' software cannot be overstressed and is referred to again in Chapter 1. Failure to satisfy himself on this score means that the engineer must rely primarily on the software supplier for the safety of the structure. This will not only pose contractual and legal difficulties but will in time lead to a downgrading of the engineer's professional standing should this become common practice.

Program usage

It will be observed that the computer is given a subsidiary, although highly important, role in the solving of problems. The author's aim has been to reduce engineering analysis to a simple, understandable process using the microcomputer to cope with the tedious or intricate mathematical steps. Some knowledge of elementary BASIC programming and familiarity with matrix notation is assumed as well as a grasp of simple structural mechanics. As no special mathematical skills are required, it is hoped that the book will be of some value to non-structural students and technicians as well as to practising engineers. For this reason, every effort has been made to avoid the use of jargon or highly technical language in the text.

Some knowledge of matrix algebra is required to follow the derivation of the matrix inversion program (MATIN), but preference has been given to the use of a tabular or 'spreadsheet' format in expressing equations in condensed form. This is in line with computer data practice in other disciplines. Avoidance of matrix algebra is seen as a help in focusing attention on the relationship between the equations and what they represent in the structure. Thus, solutions are obtained not by manipulation of matrices, transformations or other mathematical devices, but from consideration of actual displacements, sways or rotations as they occur in the structure. Line diagrams, in which significant angular rotations and linear displacements are clearly identified, are used extensively for the same reason.

Because programs are written in elementary BASIC without recourse to assembly language or machine code routines, they may be run on most microcomputers with only minor changes to accommodate non-standard BASIC statements, such as instructions to clear the screen. REM statements are included where these occur in the printed listings. One reason for this portability is the absence of screen graphics. Where a frame is described by a co-ordinate system, it is almost essential to have a line diagram displayed on the screen to check that the frame geometry has been input correctly, as errors in co-ordinates can occur very easily. Where, as in the book, the frame members are described by their relationship to a fixed 'reference element', the data can be verified simply by visual inspection. Graphics are not of great value for checking the input, therefore.

Similarly, when the output consists of bending moment values, for instance, it is assumed in all cases that the reader has the ability to construct the 'free' bending moment diagram in each span for the given load system. By imposing the output values on this, one can immediately draw the final bending moment diagram in permanent record form, as illustrated by several examples in the book. Furthermore, once the moments are known, it is not a difficult task to determine manually the shear forces and reactions, as described in Chapter 6, and to present them in diagrammatic form, if required. Extension of the programs to display such diagrams on the screen has not been considered as of much real benefit, therefore, despite their undoubted attraction to computer users.

The main computer listings will be found in Appendix B. Subsidary listings and sub-routines are shown at the end of the chapter describing their use. Although six program listings are included in the book, all problems in fact, can be resolved with no more than three of these – the others illustrate alternative means of obtaining the same results. Thus, the amount of keyboard work involved in implementing the method of analysis described is not severe. (Indeed, one program (XBEAM) would suffice for all problems, but this would be contrary to the principle adopted in the book of making the computer program appropriate to the task in hand.) The ability to obtain results with comparative ease using the simple listings in the book will, it is hoped, generate a greater feeling of confidence and understanding when the reader moves on to more advanced computer-aided design systems.

Teaching of structural theory

A concern that graduate engineers are giving 'calculations' more emphasis than 'seeing and feeling' structural behaviour initiated a recent study into the teaching of the Theory of Structures (23). One of the main inferences drawn from the study was that the concepts of structural theory appeared difficult for students to grasp for some reason. Despite the stress in modern curricula on flexibility and stiffness matrix methods, the survey revealed the outstanding popularity in practice of the Hardy Cross moment distribution method – often regarded by academics as 'archaic'. Many of the features of this attractive method of analysis will be found included in the list in Chapter 5 pertaining to the release-deformation method, used throughout the book. Indeed, the latter evolved from an original attempt to produce a 'computerised moment distribution method' which was found to be too restricted in scope.

The importance of acquiring a sound appreciation of structural behaviour is endorsed by the following quotation from the study group's report.

> 'Lack of appreciation of structural behaviour e.g. the inability to appraise how a structure will deform under load, is leading to an increase in design mistakes. Sophisticated and detailed analysis which ignores the most basic principles of structural behaviour has led to structural inadequacy and even collapse.'

One remedy for this sad state of affairs lies in greater attention to actual deformations and displacements in structures, which is a primary concern of this book.

Software

Readers who wish to avoid the trouble of keying in the listings or the time inevitably involved in putting error-free programs on disk can obtain software from the following supplier:

Prom Management Ltd
4, Ranelagh
Dublin 6
Republic of Ireland

Disks supplied are suitable for IBM or compatible PCs using DOS-plus or MS DOS and incorporate both listed and merged programs as well as examples of their use.

It should be noted that, while every care has been taken in the preparation of programs listed in the book, no guarantee can be given that they provide the correct solution to a particular problem; this remains the user's responsibility.

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Redmond Holloway

Notation index

A	Angular displacement equation
	Cross-section area
a	Length, grid spacing
b	Width, grid spacing
c	Soil cohesion
	Elastic foundation factor, a^2b
d	Depth
E	Young's modulus of elasticity
	Equilibrium equation
e	Eccentricity
	Change in length
F	Force, action
f	Stress
G	Shear modulus of elasticity
g	Subgrade reaction factor, $\frac{6EI}{qa^2}$
H	Height of column
	Horizontal reaction
h	Height above ground level
I	Second moment of inertia
J	Second polar moment of inertia
K	Relative flexibility ratio
	e.g. $K_1 = \frac{L_1}{I_1} \frac{I_n}{L_n} = \frac{k_n}{k_1}$
k	Stiffness ratio, $\frac{I}{L}$
L	Linear displacement equation
	Span
M	Bending moment
N	Number of equations, matrix columns, etc.
n	Reference element suffix
O	Origin, nodal point
P	Stiffness ratio factor, $\frac{6E_nI_n}{L_n}$
p	Pressure intensity, subgrade reaction

q	Coefficient of subgrade reaction
R	Reaction, resultant
r	Stiffness parameter, $\frac{E_nA_n}{L_n}$
	Ratio, e.g. $\frac{a}{b}$, $\frac{b}{b_0}$, etc.
S	Relative flexibility parameter
	e.g. $S_1 = \frac{L_1}{E_1A_1}\frac{E_nA_n}{L_n}$
	Strut spacing
T	Torsion, thrust
	Torsional displacement equation
V	Vertical reaction
	Number of vectors
W	Total distributed load
	Concentrated load
w	Loading intensity
X, Y	Co-ordinate axes
$\bar{x}$	Distance to centre of gravity
α	Angle
β	Angle
	Torsional factor for rectangular sections
γ	Factor for angular displacement in bending
	Rankine distribution factor $= \frac{1 - \sin\phi}{1 + \sin\phi}$
Δ	Vertical deflection, displacement
λ	Sway, lateral displacement
	Poisson's ratio
ϕ	Angle of internal friction
	Unit torsional rotation
θ	Angular rotation
Ω	Torsional constant $= 6E_nI_n\phi_n$

Contents

PART 1
GENERAL

1 Design basis

Method of analysis

The book concentrates on one particular method of analysis and shows how this can be applied to the design of engineering works. This has been called the 'release-deformation' method, since it is based on the introduction of 'hinges' or releases at specific points and an examination of the resulting deformed shape of the structure. The discontinuities are noted on a diagram, as well as the forces or moments applied to eliminate them and restore the structure to its pre-release state. Their relationship enables a series of equations to be written down which are then put into a compact tabular matrix or 'spreadsheet' format. The coefficient matrix and column vectors are fed as DATA into an appropriate computer program which, when run, provides the required results. Statements are included for printing the data and critical stages of the analysis for checking purposes.

The analytical method adopted in the book is a variation of the conventional flexibility method, but has the advantage of stressing the affinity between the behaviour of the structure and the derived equations rather than relying on somewhat abstruse mathematical concepts. It is easier for the non-mathematician to grasp; furthermore the sign convention, often a crucial factor, is based on actual physical conditions displayed in graphical form in the deformation diagram. The coefficient matrices and vectors are expressed in general terms for each basic structural form. The data for a particular problem can be obtained directly from these expressions, so that the analysis is virtually automatic in most cases.

A useful feature is in the use of one member as a 'reference element'. This device simplifies data preparation since only relative E or I values are required and trusses or frames can be described succintly without recourse to a cumbersome and error-prone co-ordinate system, as required in most other methods. Not being a recognised method of analysis, the release-deformation method must offer some benefits to justify the trouble needed to master it. These are listed in full in Chapter 5, in addition to the points touched on here.

The book reflects the growing popularity of flexibility methods in the computer analysis of structures, in contrast to earlier interest in stiffness methods. In the study of continuum structures, such as raft foundations on an elastic medium, a finite difference approach is adopted which