

Contents

Preface	xii
Acknowledgements	xv
About the author	xvii
01. Introduction	1
1.1. Overview of shell applications	1
1.2. Shell action in relation to beam, arch and plate actions	8
1.3. Thin-shell theories in relation to more general theories	12
1.4. Historical developments in linear shell theory and analytical solutions	12
1.5. General aspects of the membrane theory of shells	23
References	31
02. Membrane theory of shells of revolution	35
2.1. General shells of revolution under axisymmetric loading	35
2.2. Special cases of axisymmetric shells of revolution of zero Gaussian curvature	41
2.3. General shells of revolution under non-axisymmetric loading	44
2.4. Deformations in axisymmetrically loaded shells of revolution	52
03. Membrane solutions for various shells of revolution under axisymmetric loading	57
3.1. Pressure vessels	57
3.2. Elevated liquid-filled vessels	68
3.3. Roofs and domes	102
3.4. Cooling towers	117
References	121
04. Membrane solutions for shells of revolution under non-axisymmetric loading	123
4.1. Spherical shell	123
4.2. Conical shell	131
05. Axisymmetric bending of cylindrical shells	135
5.1. Introduction	135
5.2. Derivation of the governing equation	136
5.3. General solution	143
5.4. The case of a long cylinder	143
5.5. The case of a short cylinder	147
5.6. Practical applications	150
References	153
06. Axisymmetric bending of general shells of revolution	155
6.1. Introduction	155
6.2. Derivation of the governing differential equations	155
6.3. Practical solutions for the spherical shell	165
6.4. Practical solutions for the conical shell	193
6.5. Approximate solutions for general shells of revolution	201
References	202

07.....	Flexibility analysis of shell-ring systems and multi-shell assemblies	205
7.1.	Pressure vessels	205
7.2.	Intze tanks	214
7.3.	Domes with edge ring beams	224
7.4.	Multi-segmented spherical vessels	226
	References	246
08.....	Parametric studies of liquid-containment shells of revolution and roof domes	247
8.1.	Elevated liquid-filled spherical vessels	247
8.2.	Egg-shaped sludge digesters	280
8.3.	Spherical domes and caps	302
	References	325
09.....	Membrane theory and solutions for general cylinders	327
9.1.	Definition	327
9.2.	Governing equations and general solution	327
9.3.	Boundary conditions	330
9.4.	Solutions for horizontal circumferentially closed cylindrical vessels filled with liquid	333
9.5.	Solutions for horizontal troughs filled with liquid	339
9.6.	Solutions for barrel roofs	344
9.7.	Bending considerations for barrel roofs	347
	References	347
10.....	Membrane theory and solutions for shells of arbitrary shape	349
10.1.	Governing equations	349
10.2.	Solution approach based on a stress function	353
10.3.	Application to shell-roof problems	354
	References	364
11.....	Buckling of shells	365
11.1.	Introduction	365
11.2.	Cylindrical shells	366
11.3.	Results for other shells	383
	References	389
12.....	Finite element analysis of shells	391
12.1.	Introduction	391
12.2.	A simple formulation for shells of revolution	393
12.3.	General procedure for stress analysis	399
12.4.	General formulation for dynamic analysis	402
12.5.	General formulation for stability problems	403
12.6.	Flat shell elements	406
12.7.	Isoparametric finite elements	407
12.8.	Concluding remarks	420
	References	420

13	Design considerations for shell structures	421
13.1.	Introduction	421
13.2.	Steel shells	421
13.3.	Concrete shells	428
References		434
Author index		435
Subject index		437

The finite element method is a general numerical procedure that can be applied back to many engineering problems and it is used to analyse shell structures to any desired degree of accuracy. It is necessary to model the behaviour of the basic individual elements more accurately than the behaviour of the whole structure, and this is done by adding the relevant material properties by finite element analysis. Between adjacent elements, conditions of compatibility of forces and moments, as well as boundary conditions, are imposed to improve the quality of the structure. In this way, the overall behaviour of the complete structure is approximated. The finite element method is easier to apply than a traditional approach, where the main difficulties consist of the problem being approximated such as using finite difference equations, which can then be solved by conventional numerical methods. Numerical modelling is particularly useful to take account of the mathematical formulation resulting in sets of discontinuous, non-smooth, discontinuous or variable material properties, such as in composite materials and graded material designs.

However, the method, where the behaviour of the structure can be in sets of discontinuous and variable material properties, is not always appropriate. The numerical solution depends on the element size and the updating actual values of stresses and strains, which is a problem, as we know, is the main element for the process of optimising the choice of varying a single parameter (such as the thickness of a shell) for the behaviour of design. If we make such a change in material thickness, and the programme has to be carried out, either by a computer programme or by the computer program may be necessary to obtain a comprehensive understanding of the effect (on the stresses and deformations) of the variation of a parameter of interest through the full range of possibilities. Thus the process of optimising design can easily become very complex if several structural parameters need to be studied.

It is also necessary to note that numerical simulation can be extremely useful. In fact, we may justify the search of exact mathematical solutions to the differential equations of the shell, again where numerical solution approaches have become very reliable owing to their computational efficiency, on the grounds that analytical solutions provide valuable insights on the key parameters that control the behaviour of the shell. The main advantage is systematic parametric study using numerical formulation, which can produce a mesh (sometimes the only option) for checking the performance of numerical solution procedures.