

Preface

Sizing circular cylindrical bodies of annular cross-section subjected to surface forces and thermal loads is one of the classic topics of Machine Design Theory and Methodology. And it is far from being straightforward, as a knowledge of elasticity theory is not sufficient for thorough analysis. It is often necessary to broaden the design horizons, to investigate what happens at pressures that stress the material beyond its yield point and at thermal loads that give rise to creep.

Many mechanical design textbooks and treatises devote ample space to calculating the strength of these structural components. However, the focus is often limited to stresses in the linear elastic field, and is seldom extended to load conditions that cause plastic flow as a result of stressing the material beyond the yield point, and/or viscous flow associated with creep. In current undergraduate and post-graduate programs, moreover, the subject is split up, covering the basic, specialized, and most advanced aspects in the first-cycle, second-cycle and third-cycle, and doctoral programs respectively.

This book has the two-fold aim of meeting the needs of university education and those of the engineering profession. In the first area, the goal is to provide a link between the material covered in the textbooks on the strength of materials intended for students in three-year first-cycle degree programs, and that addressed in the more advanced monographs on elasticity theory, plasticity theory, and creep theory used in second-cycle and third-cycle or doctoral programs. In the second area, the objective is provide practitioners and professional engineers working in research, industry, and services with an advanced knowledge of the subject that can serve as a basis for designing products that are safe and technologically sophisticated, or for developing innovative applications for these structural components.

Anyone who has ever worked with analysis and design of these components is well aware that in many actual engineering applications, cylindrical bodies are part of complex structures which must not only be analyzed as a whole, but must also be considered in terms of the interactions between their component parts and the resulting stress and strain states, including those that arise in dynamic conditions such as impact loading, vibration, high- and low-cycle fatigue, and so forth. Very often, the theoretical cylindrical geometry with annular cross-section is disregarded, both at the level of the overall structure, where it is obtained from roll formed tubular segments welded together (with longitudinal weld beads along the

length of each segment, and circumferential beads joining the segments) and at the local level (e.g., where holes are provided for inserting pipe segments, here again with welded joints). In such cases, the use of numerical methods such as FEA is inescapable.

All of the problems presented in this text are approached and solved using theoretical methods, focusing chiefly on the analytical-methodological aspects. Dealing with problems characterized by generalized axis-symmetry, it was possible to obtain accurate closed-form solutions, and general analytical expressions for stresses, strains, and deformations (displacements and rotations). In fact, the analytical solutions allow any desired parametric study, and quick calculations, and provide the basis to evaluate the error of the numerical solutions obtained with approximate numerical methods.

The analytical solutions proposed here are formulated so as to be of interest not only to academics, as was once almost exclusively the case, but also to the designer who deals with real engineering problems. This is because such solutions, though sophisticated and complex, have become immediately useable by practitioners in the field thanks to today's computers, which can readily solve demanding equations. For the reader, moreover, these solutions provide the grounding needed to achieve a full understanding of the requirements laid out in the standards applying in this area. In the majority of cases, the analytic relations developed for use in the design analysis and/or in the response analysis (or verification analysis) are also represented in graphical form. This gives the reader an immediate grasp of the underlying physical phenomena that these formulas explain, and clarifies exactly which major magnitudes must be borne in mind by the designer.

In dealing with certain topics, including, for example, the interaction between the substructures making up a complex structure, we have included fully developed exercises to draw the reader's attention to the aspects that are of greatest interest to the designer, as well as to clarify the calculation procedure. We have not considered it necessary to provide such exercises in cases where they could be solved immediately with the relations presented in each chapter, as it was felt that they would add nothing to an understanding of the text.

Each topic is addressed from a theoretical standpoint, but in such a way as not to lose sight of the physical phenomena at the basis of the strain mechanics of circular cylinders bodies under various types of loads. Analysis proceeds in steps, with particular attention to each stress and strain state. The material is thus organized so that the knowledge gained in the beginning chapters provides the grounding needed to understand the topics covered in the chapters that follow. Consequently, the problems that are normally encountered in studying the elastoplastic problem and the viscous problem associated with creep are significantly reduced, once a complete mastery of the elastic problem is achieved.

This text, which is also intended for the students in my course on Machine Design Theory and Methodology (*Progettazione Meccanica e Costruzione di Macchine*) at the Università di Roma Tor Vergata, consists of an introduction

which describes and discusses the general hypotheses and assumptions underlying the proposed theoretical approaches and solution methods, plus 11 chapters.

The first three chapters deal with thin-walled circular cylinders under internal and/or external pressure and stressed in the linear elastic field, and their design analysis and response analysis on the basis of different strength theories. The instability affecting these components as a result of external pressure alone and external pressure with initial geometric imperfections is also addressed, as are other types of instability such as global and local instability resulting from axial load, instability due to torsional load and flexural ovalization instability during bending.

The Chap. 4 covers thick-walled circular cylinders under internal and/or external pressure, again stressed in the linear elastic field, giving relations for design analysis and response analysis on the basis of several strength theories; the results obtained are then compared to provide information that can be used in component design. The Chap. 5, which also deals with the linear elastic field, addresses the problem of circular cylinders assembled with a radial interference fit and of multilayer structures, as well these components' optimization on the basis of their constituent materials and strength properties. The influence of centrifugal load on the force-fit assembly is also analyzed.

The Chap. 6 covers thick-walled circular cylinders subjected in the elastic field to a temperature gradient as a result of radial heat flow according to Fourier's law of heat conduction. The relations for thin-walled bodies are determined as a limiting case of those for thick-walled bodies. The chapter also discusses the edge effects occurring at the free ends of a thin-walled circular cylindrical body of finite length, and of transient thermal load in a solid cylindrical structure.

The Chaps. 7–9 are devoted to the nonlinear problems of pressure loading beyond initial yielding. Specifically, Chaps. 7 and 8 address the problem of thick-walled cylindrical bodies made of a material showing elastic-perfectly plastic behavior, determining the stress and strain states starting from the pressure leading to the onset of the plastic state at the inner radius, up to the pressure at which the entire wall thickness is in the fully plastic state, as well as the residual stress states after the autofrettage pressure is released. These chapters also cover prestressing in terms of overstressing and overstrain, both with and without reverse yielding, as well as with cyclic repressurizing during a more complex autofrettage process, extending these concepts to composite multilayer structures.

In the Chap. 9, the restrictive assumption of an elastic-perfectly plastic material is relaxed and the problem is generalized in order to deal with real materials that undergo strain hardening when stressed beyond yield, or that exhibit viscous behavior associated with creep during service at high temperatures in steady state conditions. Here again, discussion is extended to multilayer structures. All three of these chapters provide relations whereby the designer will be able to develop structures capable of achieving high performance after an optimized preliminary prestressing process.

The Chaps. 10 and 11 address the bending problems arising from edge effects, or in other words resulting from the discontinuities in geometry and form that

cause the substructures of a complex structure to have different responses in terms of stiffness. The [Chap. 10](#) discusses the bending theory for cylindrical shells of annular cross-section under axisymmetric loads, presenting the fundamental relations. The chapter deals with both long and short cylindrical shells, i.e., those having axial lengths that are greater or lesser than the so-called extinction length or decay distance, under the concentrated and distributed axisymmetric loads that are of interest for design purposes.

The [Chap. 11](#) covers cylindrical pressure vessels with flat ends and with dished ends whose generating meridians are hemispherical and semi-elliptical. To clarify its scope, both the membrane theory and the bending theory for double-curvature shells of revolution under axisymmetric loads are used. The stresses arising from discontinuities, which are superposed on the membrane stresses, are analyzed using an approximate bending theory which introduces well-known simplifying assumptions and hypotheses. This makes it possible to arrive at closed-form relations which are known to provide results of unquestioned utility for design.

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