1. Introduction

In this chapter we focus on the role of the integration of inelastic constitutive relations in general nonlinear finite element analysis and present the basic objectives of the book. In order to motivate the subject of the book we also briefly refer to some example solutions of complex inelastic analyses.

1.1 The Objectives of this Book

Finite element inelastic analysis is now abundantly performed in various branches of engineering design and scientific research. A number of commercial computer programs are in widespread use and many smaller research computer programs are employed for the inelastic analysis of solids and structures.

The reason that inelastic analysis has gained such importance is that it is nowadays possible to analyze realistically very complex structures for their nonlinear response and the benefits of performing a nonlinear analysis can be large. In particular, a nonlinear analysis very frequently makes it possible to achieve a safer and more economical design. Also, a nonlinear analysis is frequently needed to understand the behavior of a structure that has been in use and service but unfortunately failed due to unusual loading conditions. In general, a nonlinear analysis may be of great value and indeed necessary to more accurately model nature (Bathe 1996; Bathe 2001a)

A general nonlinear structural analysis can include the effects of large displacements, large strains and nonlinear material conditions. When the material is responding nonlinearly, an inelastic response involving plasticity, creep, thermal effects, and so on, is usually most difficult to analyze. In this case, the inelastic conditions have to be calculated in an incremental solution and state-of-the-art computing resources and computational procedures may be required.

An effective inelastic analysis procedure provides general applicability and efficiency in modeling inelastic phenomena. General applicability is reached by using material models that can represent the inelastic behavior in general loading conditions and that are based on well-established principles of mechanics. Efficiency is reached by using stable and highly accurate algorithms to solve the nonlinear equations associated with the material models.

While the basic mechanics relations of inelastic analysis were largely formulated many years ago, the widespread use of inelastic analysis has spurred much further research in the field. This research has resulted in the development of new material models, to increase the general applicability of inelastic analysis, and in the development of increasingly more efficient finite element solution schemes. In today's practice of inelastic finite element analysis using commercial computer programs, extensive libraries of material models are available. These libraries can be used to model the inelastic response of many materials, such as metals, concrete, soil and rock structures, and synthetic materials. Also, a program user is able to code an own material model and use this model in a general finite element analysis.

With this background, *the objectives of this book* can be summarized as follows:

- To present, to a certain extent, *the fundamentals of inelasticity*, from basic experimental data and mechanical principles to the formulation of material models. These models are used to describe the inelastic material behavior.
- To derive in a consistent manner *robust implicit numerical algorithms* for the effective integration of inelastic constitutive relations within a time (load) step for *strain-driven problems*. These algorithms are applied to a number of commonly used material models.
- To illustrate the computed inelastic material response through *examples which elucidate the material behavior* in typical engineering conditions.

Hence, the objective of this book is to present basic inelastic material models and efficient computational methods for these models. The presentation helps the reader to model engineering problems for inelastic analysis, to understand typical inelastic solution schemes, and to possibly program an own material model.

1.2 Some Remarks on Explicit and Implicit Solutions of Nonlinear Response

There are in essence two approaches to solve nonlinear problems and also the inelastic material response - *the explicit and the implicit approaches*. Explicit solution algorithms can be very effective to solve high velocity phenomena, such as wave propagation problems. Implicit solution algorithms are effective for the analysis of static problems and structural dynamics problems.

Consider a *general nonlinear problem* in solids and structures. Since an incremental solution is required, we use time "t" to denote the generic time of load application. In static analysis, when a time-independent inelastic analysis is performed, "t" denotes only the load level, but when a time-dependent material response is considered (such as in creep analysis) "t" denotes the actual physical time of solution (see Bathe 1996).