Chapter 1

Introduction

The rupture of a mechanical specimen can be interpreted primarily as an interruption in the continuity of the specimen (this is in fact a particular definition of "failure"). In this case, the application of continuum mechanics faces a singularity due to the presence of cracks in the specimen.

Fracture mechanics is simply the application of continuum mechanics and the behavior laws of a material to a body whose boundary conditions are introduced in the presence of crack geometry.

Rupture can occur after a large deformation, usually after a plastic instability resulting from the presence of two opposite effects: one reducing the section; and the other consolidation of the material by hardening. It can, however, occur without significant prior deformation under generalized stresses that is often the case in the elastic domain. We are then in the presence of a brittle fracture.

The analysis of stresses and strains near the crack tip is a basis for understanding the behavior of cracks. Although a plastic or damaged zone is present at the tip of the crack, the linear elastic analysis provides us with an accurate enough mapping of reality for materials such as steel. In the case of ductile materials or extreme loads, however, we need to take into account the elastic-plastic behavior laws.

Fracture mechanics assumes the existence of an initial crack in the structure being studied. This introduces geometric discontinuity singularity to the stress and strain fields and deformations at the crack tip.

The phase that explains the behavior of the structure of intact state where the structure contains a macroscopic crack is called the *initiation phase* of the crack. Priming of a crack is usually in the vicinity of defects in the design of the structure (e.g. geometric discontinuities) due to poor execution or welding, etc. These defects create local high stresses that promote the initiation of cracks without generalized stresses that exceed the yield strength of the material.

When the cracks are initiated, their propagation can be sudden or gradual. This may result in brittle fracture or crack growth by fatigue. When the propagation of these cracks is accompanied by plastic deformations it is the plastic fracture mechanics, if not a mechanical linear elastic fracture, that will be responsible.

Table 1.1 shows the different types of failure mentioned. Indeed, each type of rupture is a set of assumptions, definitions and analysis.

Various types of crack growth			
Behavior law	Brutal (sudden)	Progressive (gradual)	Other types of fracture evolution
Elastic	Brittle Fracture (I)	High cycle fatigue (III)	-
Elastoplastic	Ductile fracture (II)	Low cycle fatigue (IV)	-
Other behavior laws	-	-	-

Table 1.1. *Types of failure according to the behavior laws*

We will mainly study the two types of failure – I and III – in the context of this book.

The basic problem in linear fracture mechanics can be seen as the analysis of a stress field in plane linear elastic cracked media. This is for theoretical reasons (since the elastic plane is the means by which we find analytical solutions), and for technical and practical reasons (there are structures that are cracked, in which generalized constraints are below the elastic limit).

The definition of a failure criterion (or security) is a specific preoccupation, and is of major importance. This definition comes from a collection of reflections the engineer has on the basis of disparate elements, such as the behavior of the structure, industry, socioeconomics, etc. The safety criterion is given in Figure 1.1 and determines how it can be structured.

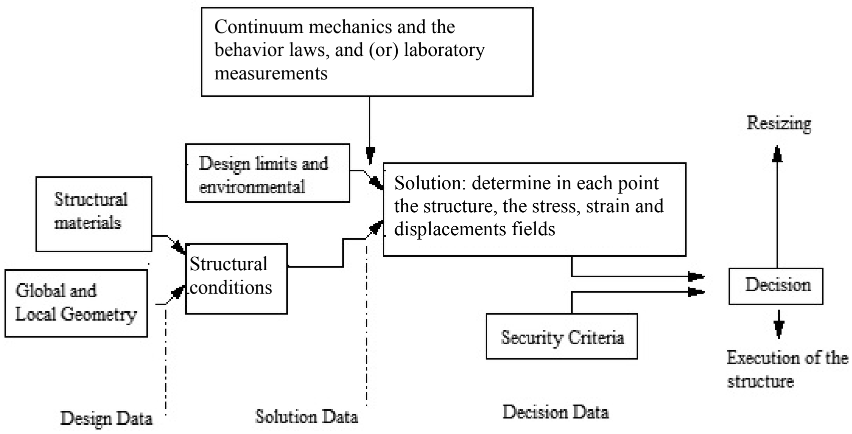

Figure 1.1. *The safety criterion*

Three essential elements exist for any judgments on the safety behavior of a structure:

– global and local geometry;

– the boundary conditions (by forces and displacements); and

– the safety criterion (or failure).

It is the comparison between the solution obtained from the first two elements and the safety criterion that is essential. In the triangle created by the geometry, the failure criterion and boundary conditions (see Figure 1.2), the intervention of one or more peaks can resize the structure.

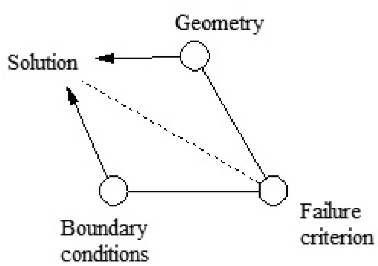

Figure 1.2. *The interaction of geometry, boundary conditions and the failure criterion*

To study failure, it is essential to analyze the stress, strain and displacement fields in the cracked structure, especially near the tips of existing cracks. This is encompassed in the study of fracture mechanics. This theoretical study should interpret the phenomenological aspects of the rupture, yet these aspects cannot be addressed without experimentally observing the fracture surface, the rate of crack growth, etc. A presentation of the results of continuum mechanics and the behavior laws, however, appears to be necessary to determine the mechanical fields (displacements, strains and stresses) near the tip of a crack (or a singularity). A review of experimental observations, in light of the calculated mechanical fields gives us a better understanding of failure criteria under quasi-static loading and fatigue. Practical applications for the propagation of cracks in welded joints are detailed in Chapter 7 to illustrate the analytical process.