

Chapter 1

Nonlinear Mechanics

1.1 Introduction

Numerous different nonlinearities can occur in solid mechanics which are either of geometrical or of physical nature. The treatment of associated problems demands a large bandwidth of methods and algorithms which will be discussed in the following chapters. Based on introductory examples, different phenomena of nonlinear behaviour will be described to introduce the reader the nature of the problems. Deliberately simplified mechanical models are used, which are just complicated enough to represent the desired nonlinear feature. All solutions can still be solved analytically which helps to understand the problem. However, engineering problems cannot be formulated with such simplified models. Due to that numerical methods have to be applied for real world applications.

1.2 Geometrical Nonlinearity

In structural analysis, it is usually sufficient to consider only small deformations and strains since many parts of the structure can only undergo small strains to maintain their usability. With this restriction, a linear constitutive equation can be introduced when elastic deformations are present. However, even under this assumption, there are many problems which depict large displacements or rotations, such as cables, beams or shells. Such problems require a nonlinear theory which includes the geometry in an exact way. Some examples which represent different geometrically nonlinear behaviour are discussed in the following.

1.2.1 Large Displacements of a Rigid Beam

The first example for geometrically nonlinear behaviour is a rigid beam of length l , (Fig. 1.1) which is supported by an elastic rotational spring with stiffness c at its left end.

Equilibrium at the deformed system yields directly, (see Fig. 1.1),

$$Fl \cos \phi = c\phi. \quad (1.1)$$

Equation (1.1) relates the force F in a nonlinear way to the beam rotation ϕ . The nonlinearity stems from the change of geometry in the equilibrium equation. Hence this type of behaviour is known as geometrical nonlinearity.

For small rotations ϕ the approximation $\cos \phi \rightarrow 1$ is obtained. With this the linear solution $F = c\phi/l$ can be derived from (1.1). Figure 1.2 shows the increase of the force as a function of the rotation ϕ for both cases. One observes clearly that the linear solution deviates from the exact geometrically nonlinear one for large rotations.

Often the so-called second order theories are applied to include nonlinear effects in the mechanical model. The idea is to describe the nonlinear terms using a Taylor series which is terminated after the second term.

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