Chapter 3
Analysis of Nanoindentation Test Data

3.1 Analysis of Indentation Test Data

As described in Chapter 2, estimations of both elastic modulus and hardness of the specimen material in a nanoindentation test are obtained from load versus penetration measurements. Rather than a direct measurement of the size of residual impressions, contact areas are instead calculated from depth measurements together with a knowledge of the actual shape of the indenter. For this reason, nanoindentation testing is sometimes referred to as depth-sensing indentation testing. In this chapter, methods of the analysis of load-displacement data that are used to compute hardness and modulus of test specimens are presented in detail. It is an appropriate introduction to first consider the case of a cylindrical punch indenter — even though this type of indenter is rarely used for this type of testing, its response illustrates and introduces the theory for the more complicated cases of spherical and pyramidal indenters.

3.2 Analysis Methods

3.2.1 Cylindrical Punch Indenter

Consider the case of a cylindrical flat punch indenter that has an elastic–plastic load displacement response as shown in Fig. 3.1. Figure 3.1 (a) shows the displacements for the elastic–plastic contact at full load P_t and the displacements at full unload. The unloading response is assumed to be fully elastic. Elastic displacements can be calculated using Eq. 3.2.1a:

$$P = 2aE^*h \tag{3.2.1a}$$

Putting h equal to the displacement u_z at $r = 0$ and by taking the derivative dP/dh, we can arrive at an expression for the slope of the unloading curve:

$$\frac{dP}{dh} = 2E^*a \tag{3.2.1b}$$

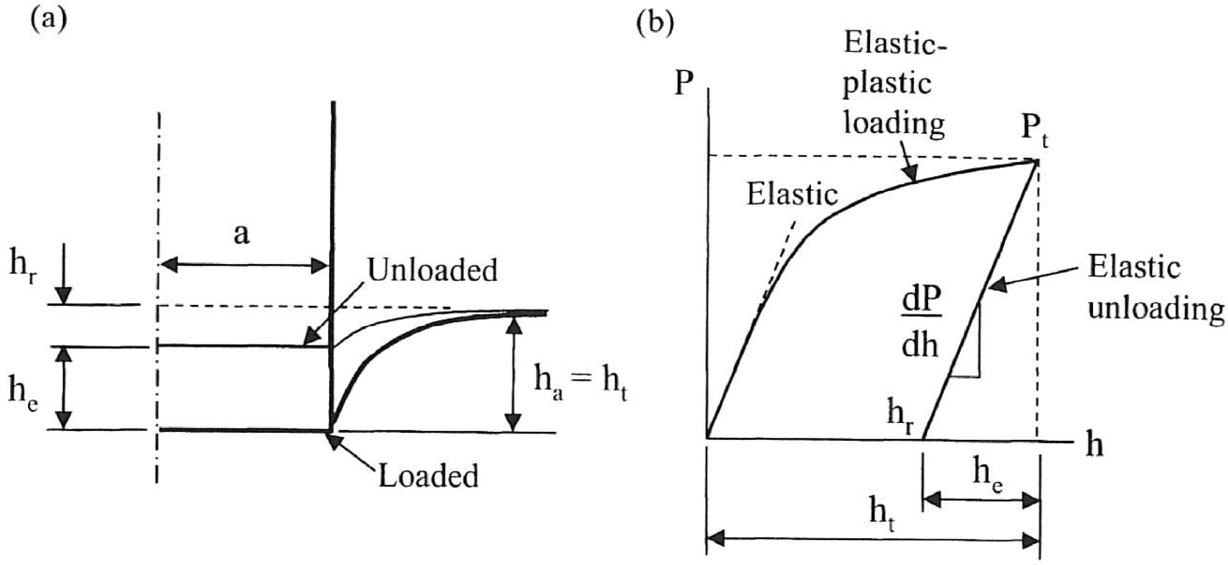

Fig. 3.1 (a) Schematic of indenter and specimen surface geometry at full load and full unload for cylindrical punch indenter. (b) Load versus displacement for elastic–plastic loading followed by elastic unloading. h_r is the depth of the residual impression, h_t is the depth from the original specimen surface at maximum load P_t, h_e is the elastic displacement during unloading, and h_a is the distance from the edge of the contact to the specimen surface, here equal to h_t for cylindrical indenter (after reference 1).

In Eqs. 3.2.1a and 3.2.1b, a is the contact radius, which, for the case of a cylindrical punch, is equal to the radius of the indenter. Expressing this in terms of the contact area:

$$\frac{dP}{dh} = 2E^* \frac{\sqrt{A}}{\sqrt{\pi}} \quad (3.2.1c)$$

Pharr, Oliver, and Brotzen[2] show that Eq. 3.2.1c applies to all axial-symmetric indenters. Equation 3.2.1c shows that the slope of the unloading curve is proportional to the elastic modulus and may be calculated from the known radius of the punch. As shown in Fig. 3.1, h_e is the displacement for the elastic unloading. Thus, the slope of the unloading curve is also given by:

$$\frac{dP}{dh} = \frac{P_t}{h_e} \quad (3.2.1d)$$

Now, for a cylindrical indenter, there is no need for an estimation of the size of the contact area from depth measurements because it is equal to the radius of the indenter. However, the situation becomes quite complicated when this is not the case, such as for the Berkovich indenter.