IEEE 693 (2005) and FEMA 450 (2004) provide requirements for determining these response spectra. The design engineer is responsible for selecting the appropriate design response spectrum.

6.7.6 Ultimate Strength Design

The stresses in members and connections should be in accordance with Section 6.3.1.

6.7.7 Allowable Stress Design

The stresses in members and connections should be in accordance with Section 6.3.2.

6.8 BASE PLATE DESIGN

This section provides a method to determine the plate thickness for a base plate on leveling nuts. It is conservative to use this procedure for base plates mounted on concrete. Although the design of anchor bolts is discussed in Chapter 7, it is important to know that the number of anchor bolts will affect the determination of the base plate thickness. In general, a greater number of small bolts will allow the use of thinner base plates than a fewer number of larger bolts. However, when the total installed cost of the foundation and anchor bolts is considered, a slightly thicker base plate with fewer bolts may prove to be the most economical choice because of reduced construction costs. ASCE/SEI 48 (2005) also contains methods for base plate design.

Figure 6-1 shows some base plate connections that may be used in substation structures.

6.8.1 Determination of Bolt Loads

The anchor bolt setting plan is determined by the geometry of the column, the loads imposed on the column, and the proper clearance between the nuts and the column. Assuming that the base plate behaves as an infinitely rigid body, the load in bolt i, BL_i can be calculated by the following formula:

$$\mathrm{BL}_i = \left(\frac{P}{A_{\mathrm{BC}}} + \frac{M_x y_i}{I_{\mathrm{BC}x}} + \frac{M_y x_i}{I_{\mathrm{BC}y}} \right) A_i \qquad \text{(Eq. 6-3)}$$

where

P = total vertical load at the base of the column;

M_x = the base moment about the x axis;

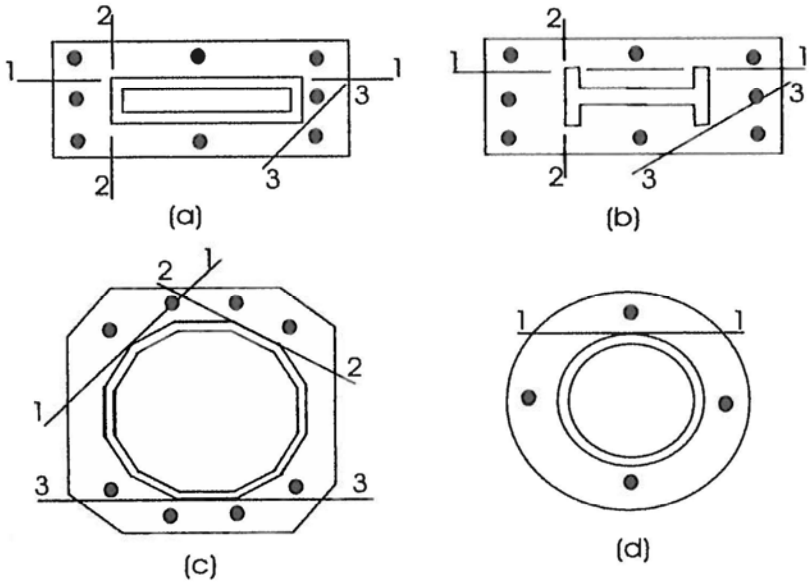

FIGURE 6-1. Examples of Base Plates.

M_y = the base moment about the y axis;
x_i, y_i = x and y distances of bolt i from reference axes;
A_i = the net area of bolt i;
A_{BC} = $\sum_{i=1}^{n} A_i$ = the total bolt cage area;
I_{BCx} = $\sum_{i=1}^{n} (A_i y_i^2 + I_i)$ = the bolt cage inertia about the x axis;
I_{BCy} = $\sum_{i=1}^{n} (A_i x_i^2 + I_i)$ = the bolt cage inertia about the y axis;
n = the total number of bolts; and
I_i = the moment of inertia of bolt i.

Because I_i is often small, it may be omitted when calculating I_{BCx} and I_{BCy}. Figure 6-2 illustrates the application of Eq. 6-3 to determine bolt loads.

6.8.2 Determination of Base Plate Thickness

A common design procedure for base plates assumes that bolt loads produce a uniform bending stress, F_b, along the effective portion of bend lines located at the face of the column. Each bend line is characterized by the following:

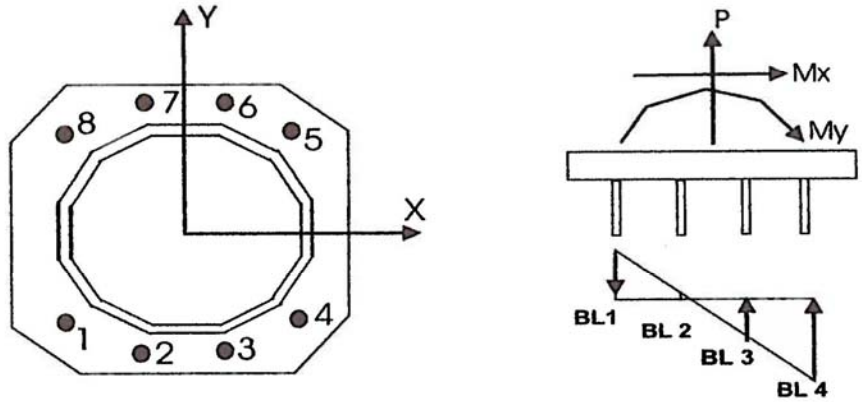

FIGURE 6-2. Bolt Load Calculation.

- k = the number of bolt load BL_i's contributing moment along the bend line;
- c_i = the shortest distance from bolt i to the bend line; and
- b_{eff} = the length of the bend line (depending on the shape of the column, the shape of the base plate, and k).

Figure 6-1 suggests some possible bend lines in various types of base plates. The most difficult task in the analysis of the base plate is the determination of the proper effective lengths of bend lines (b_{eff}) used to calculate the bending stress. Many times, b_{eff} should be limited to ensure that the bend line will be effectively loaded. One method to calculate b_{eff} assumes that the anchor bolt reactions are resisted at a bend line that is tangential to the column. The effective length of this bend line (b_{eff}) is assumed to be limited by the distance between the projected length of the first and last bolt acting on the bend line plus the sum of the perpendicular distances from these extreme bolts to the bend line. Manufacturers have used similar methods for many years and have had successful verification of this approach through full-scale testing. ASCE/SEI 48 (2005) can also be used to design base plates.

The bending stress F_{PL} for an assumed bend line can be calculated by the formula

$$F_{PL} = \left(\frac{6}{b_{eff}t^2}\right)(BL_1c_1 + BL_2c_2 + \ldots + BL_kc_k) \qquad \text{(Eq. 6-4)}$$

where t is the base plate thickness. The minimum base plate thickness is determined by keeping F_{PL} below the yield stress F_y (if the USD method is used) or the allowable stress F_b (if the ASD method is used). Equation 6-4 can be rewritten as

$$t_{min} = \sqrt{\left(\frac{6}{b_{eff}(F_y \text{ or } F_b)}\right)(BL_1c_1 + BL_2c_2 + \ldots + BL_kc_k)} \qquad \text{(Eq. 6-5)}$$

6.9 RIGID BUS DESIGN

Rigid bus design should be approached as a system requiring both an electrical engineer and a design engineer. The electrical engineer should be responsible for selecting the electrical parameters, including the minimum size bus required for ampacity (current-carrying capacity), insulators, hardware, electrical clearances, and determining the short-circuit fault current. The design engineer should be responsible for selecting support locations and structural analysis and design of the rigid bus conductors, insulators, and support structures. Ultimate strength design is the preferred method for rigid bus design. Additional design considerations for rigid bus conductors can be found in IEEE 605 (2006).

6.9.1 Structural Analysis

A-frames often connect a high bus conductor to a low bus conductor. The connection should be made using flexible cables. This connection enables a more simplified analysis of each bus conductor (high and low) individually. If flexible cables are not used, the entire system of rigid bus conductors, insulators, and structural supports should be modeled. The short-circuit force, when applicable, should be applied simultaneously in two directions.

For multiple structures supporting continuous spans of rigid bus conductors, the design of the insulator and structure may be modeled and designed as an entire system of structures, rather than designed as a typical single structure. For a continuous-beam model, the horizontal and vertical deflection of the bus conductors results in smaller deflections, whereas the bus wind loads on the insulators are higher.

The design engineer should determine boundary conditions for bus fittings and determine whether a simple or complex analysis is required.

6.9.2 Structure Design

Use the structural loads from Chapter 3 and design the structure in accordance with Section 6.3.1.