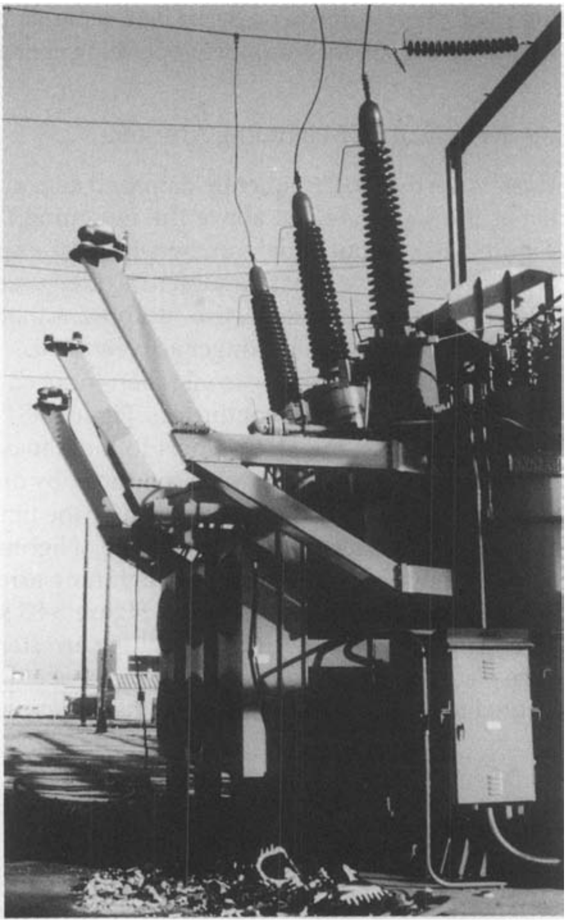

FIGURE 5-84. Three Failed Lightning Arresters.

Note: The drops from the overhead conductor were removed before the picture was taken.

a disconnect switch. The disconnect switch support structure was relatively flexible.

Most 500-kV and many lower-voltage lightning arresters are mounted on their own support posts near the transformer. Other substation equipment, such as potential transformers, current-voltage transformers, and wave traps have similar supports. There have been some failures of this type of detail. Figure 5-86 shows the failure of the weld between the post and the base plate. Close inspection suggests poor weld penetration. Figure 5-87 shows concrete breakout of an anchor bolt. There have been many cases where the anchor bolts have stretched or pulled out of the foundation slabs. This can be difficult to evaluate because the nuts are often spiked to prevent

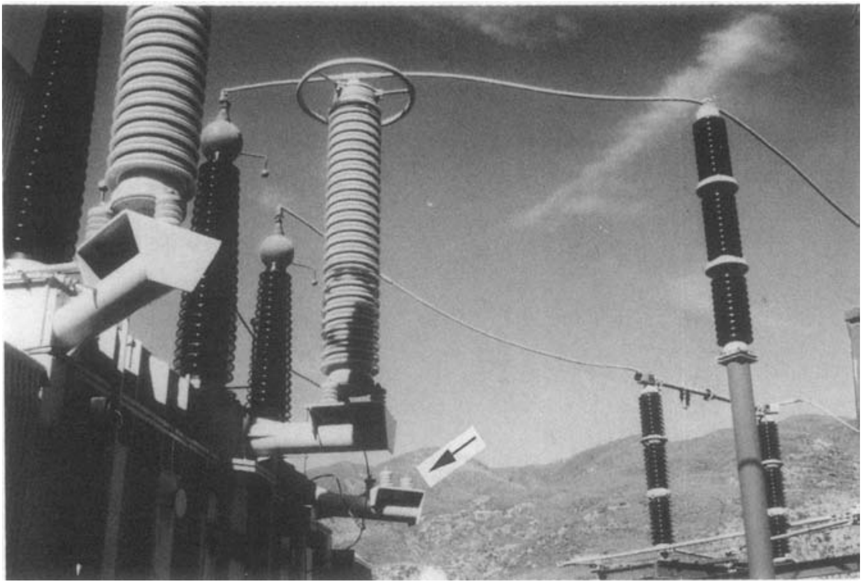

FIGURE 5-85. This Lightning Arrester Probably Failed Because of the Lack of Slack between It and the Disconnect Switch to Which It Was Connected.

them from turning or the loads have jammed the nut and bolt so that they do not turn freely. For this reason, it is very useful to place a washer under the nut. If the bolt has stretched, it is easy to check if the washer is loose. One factor that contributes to the dynamic response is flexibility of the anchor detail. It is important to distinguish between the strength of an anchorage and its flexibility. A thin base plate with anchor bolts relatively far from the support column and no gusset plates can constitute a flexible overall system. This tends to lower the natural frequency into the high-energy part of the earthquake spectra and to generate relatively large displacements at the top of the lightning arrester. Depending on the conductor configuration, the restraining loads may be transmitted to the transformer bushing.

5.9.2 Mitigation and Retrofit of Lightning Arresters

The result of most lightning arrester failures is that the transformer shuts down, since the dangling lightning arrester typically causes a short circuit with the transformer case or other grounded member. A potentially more disruptive effect is damage to a transformer bushing. This can occur when the failed lightning arrester swings into the bushing. Falling lightning arresters have also damaged conductor posts on bushings.

In some configurations, it may be possible to reconnect the conductors on the lightning arrester so that it is not connected directly to the bushing; it

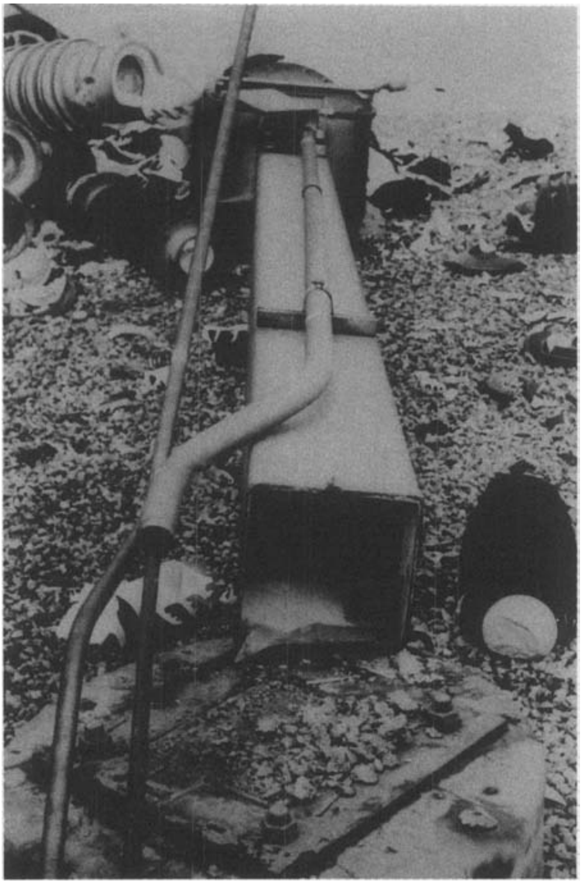

FIGURE 5-86. This Post Fell Over When the Weld between the Base Plate and Post Failed.

may also be possible to use a smaller conductor to the bushing. These methods are discussed in detail in the Section 5.9.4 on recommended installation practices.

About half of lightning arrester failures can be attributed to vulnerable standoffs. The earthquake performance can be improved by removing the standoff when strike counters are no longer actively used or by replacing standoffs with less vulnerable designs.

5.9.3 Emergency Response Procedures for Lightning Arresters

Within California, the most common practice is to remove a damaged lightning arrester from the circuit so that the transformer can be put back into service. It is not uncommon for months to elapse before units are

FIGURE 5-87. Loads on a Post Anchor Caused the Bolt To Break Out of the Foundation Because of Inadequate Edge Distance.

replaced. In most areas of California, lightning is very rare most of the year. This practice would be ill advised in areas more vulnerable to lightning.

5.9.4 Recommended Installation Practices for Lightning Arresters

Figure 5-88 shows several alternatives, including the preferred methods, for connecting a lightning arrester to a transformer. Some of the principles can be used for other conductor configurations, including the use of a rigid bus. Case A shows one of the common methods of configuring the conductor. The difference between it and Case E is that the upper connection of the drop to the lightning arrester is moved away from the bushing. The intent of this configuration is that, if the lightning arrester fails, it will swing away from the bushing and be less likely to strike and damage the bushing.

Cases B and C are similar to Case F. It is preferable to connect the lightning arrester conductor to the conductor that drops to the bushing, rather than connecting it directly to the bushing binding post. In the preferred method, Case F, if the lightning arrester fails, the weight of the falling lightning arrester is placed on the conductor drop. This connection will be more flexible, so the impact load will be less and the load will be shared by the upper end of the drop and the bushing. If it is connected to the bushing binding post, all of the load will be applied to the bushing; because this connection is relatively stiff, impact loads will be large. Finally, the size of the lightning arrester–bushing conductor can be lighter weight. This will not

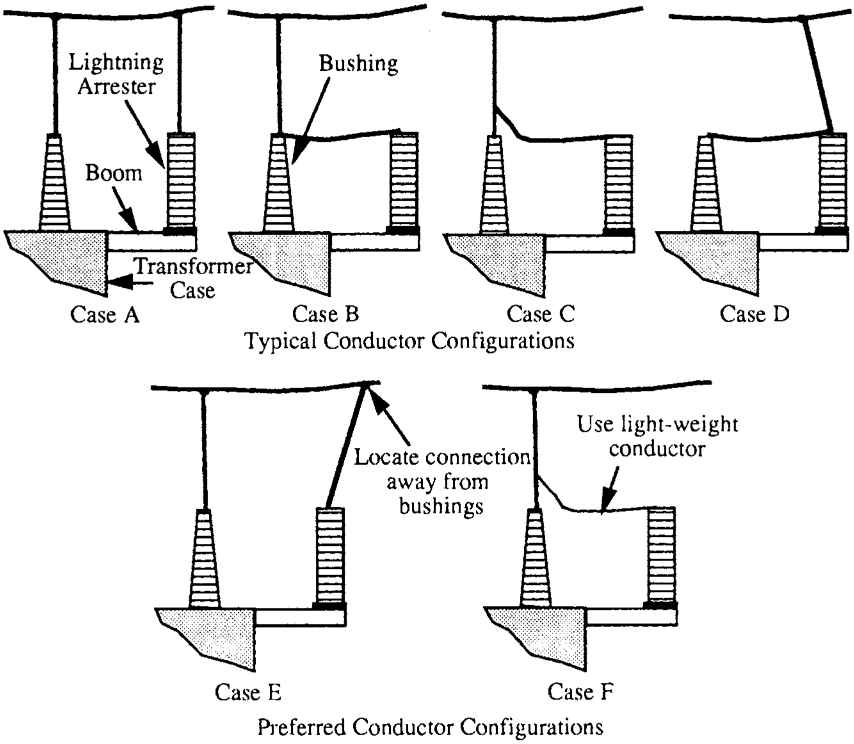

FIGURE 5-88. Variations in Bushing–Lightning Arrester Connections.

affect the operation of the lightning arrester, and the connection may break at a lower force level, reducing the load on the bushing and its conductor.

The least desirable configuration is Case D; the transformer current is carried on bushing–lightning arrester conductor, so its size cannot be reduced and, if the lightning arrester fails, it will tend to swing into the bushing. In some configurations, if the overhead conductors are skewed relative to the line of bushings, there can be a problem of phase-to-phase clearance due to the slack in the lightning arrester drop. This can be addressed by staggering the position of the upper contacts to the overhead conductor. For example, the center phase upper attachment point could be positioned further from the bushing.

The base connection of self-supporting, post-mounted lightning arresters should be stiff. Figure 5-89 shows a very thin base plate, and the bolts are positioned further from the tube wall than is needed. Figure 5-90 is a schematic diagram that illustrates design principles. As the bolts are moved closer to the tube wall, a given moment exerts a larger force on the bolt. If the bolts are moved away from the tube wall, a stiffening gusset should be added between the base plate and tube.

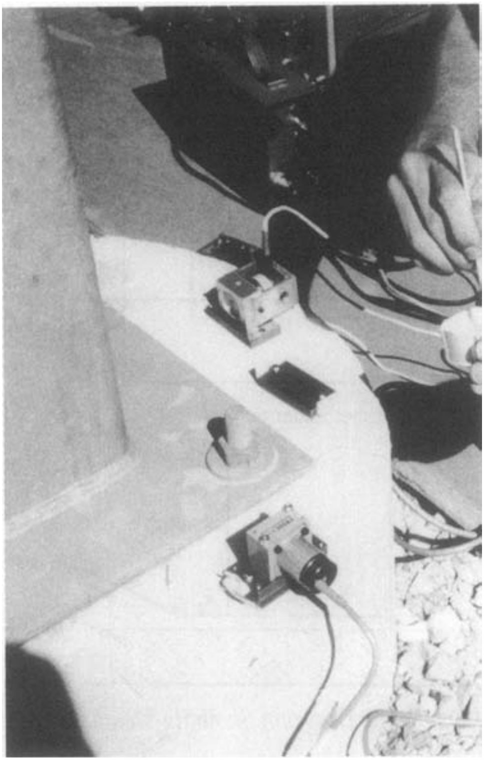

FIGURE 5-89. A Thin Base Plate and Bolts Located away from the Tube Wall Create a Flexible Anchorage System.

About half of the lightning arrester failures are due to the failure of standoffs. They should not be used unless a strike counter is needed. Standoffs have two designs. Those shown in Figure 5-83 consist of porcelain with a stud protruding from each end. When installed and under load, the axial load to resist overturning moments must be carried by the porcelain in tension. Figure 5-91 shows another design. The porcelain members sandwich the anchor tab of the lightning arrester. A bolt passes through holes in the porcelain and anchor plate at the top of the support post. In this configuration, the bolt carries the tensile loads, and the porcelain is under compressive loads. No failures have been observed in this type of standoff.

Generally, seismic design criteria in this document are drawn from IEEE Standard 693. For lightning arresters supported on transformers, the IEEE recommended practice has a safety factor of 2 over that for post-mounted lightning arresters. The flexibility of lightning arrester support booms, when combined with the overall transformer amplification and the possibility of soil-structure interaction, suggests that a more conservative factor of safety should be considered. However, this suggested added conservatism should

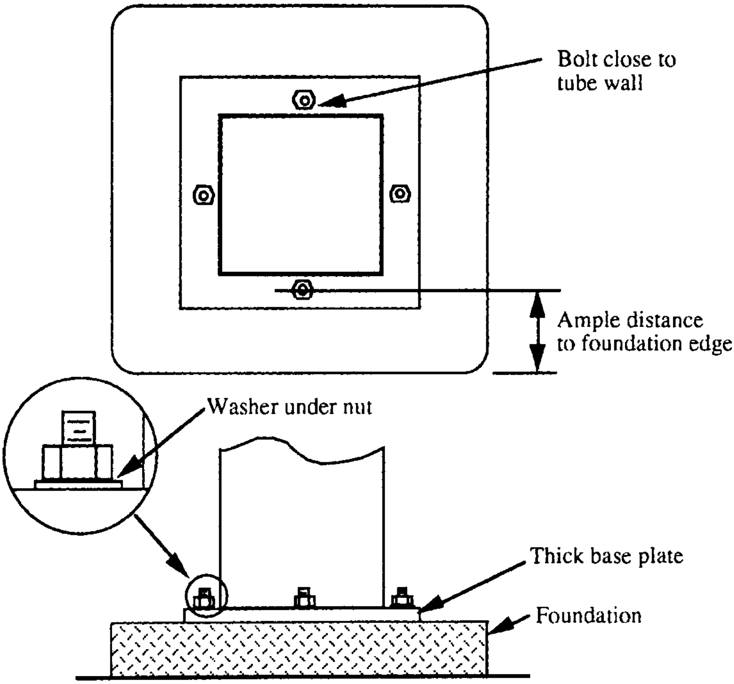

FIGURE 5-90. Schematic Diagram Showing Details for a Stiff Anchorage.

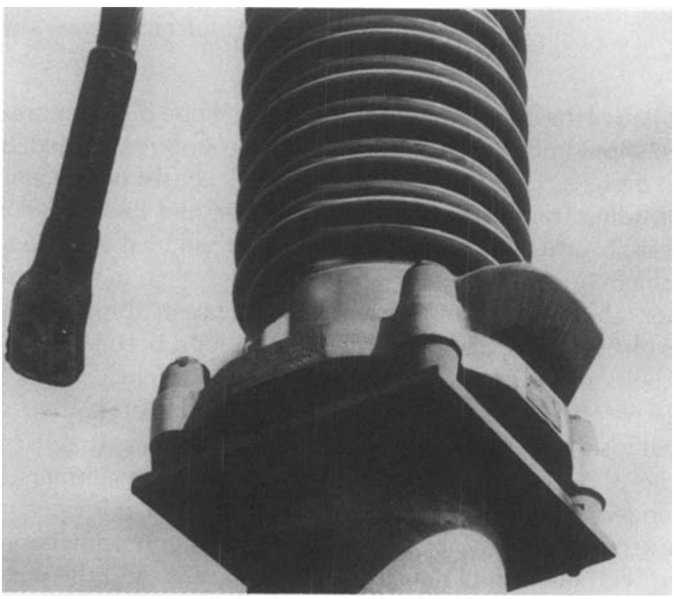

FIGURE 5-91. This Standoff Design Puts Porcelain under Compression and the Bolt Carries Tensile Loads.

be weighed against the relatively small potential for long-term disruption associated with lightning arrester failure if the installation recommendations contained in this document are followed.

5.10 CURRENT TRANSFORMERS

Current transformers are used to measure the current flowing in a high-voltage circuit. The data that they provide is used for system protection, metering, and other control functions. A current transformer consists of a large bushing on top of a box, and it usually has its own support structure. It is frequently located adjacent to circuit breakers. Current transformers are also incorporated in gas-insulated circuit breakers, and some are incorporated in circuit breaker bushings; these types are not considered here but are part of the general performance of circuit breakers.

5.10.1 Earthquake Performance of Current Transformers

Seismic loads on current transformers are due to vibration response of the equipment, including its support structure, and to interaction loads from adjacent equipment through conductor connections. There have been cases where the dynamic response of the current transformer caused damage to the circuit breaker without being damaged itself. As is the case in assessing the earthquake performance of many items of substation equipment, when adjacent items of equipment are damaged, it is difficult to determine which item failed first or whether interaction loads caused the failures. Current transformers are located adjacent to circuit breakers, and there is often interaction between the two items.

Current transformers have developed leaks between the bushings and the supporting box. Some of these leaks appear to have occurred independent of interaction with the adjacent circuit breaker.

Figure 5-92 shows an overview of an undamaged live-tank circuit breaker and current transformer, as well as the lack of slack in the connection between the units. The support structures are relatively stiff, but the tall, slender interrupter-head columns of the circuit breakers are relatively flexible. Figure 5-93 shows that the connections between the circuit breaker and the current transformer failed. A close-up view of the current transformer connection shows that the cast-aluminum cable fitting failed (Figure 5-94). However, Figure 5-95 shows that the interconnection did not break before the porcelain near the flange that joins the upper and lower parts of the current transformer failed. In this case, the flexibility of the circuit breaker structure and the lack of slack in the connection to the current transformer caused the failure of the current transformer. Figure 5-96 shows a current transformer and the rigid connection between it and the

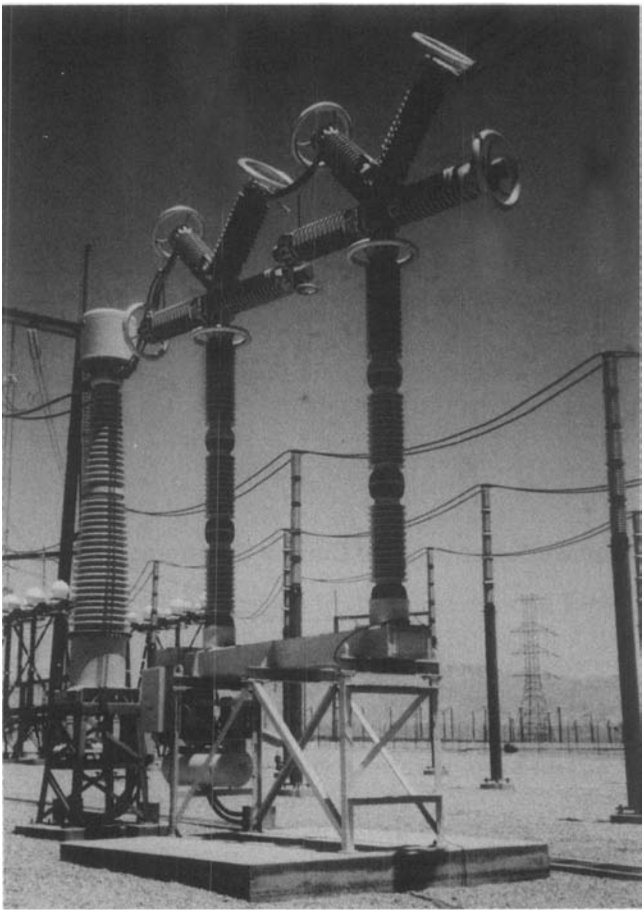

FIGURE 5-92. A Live-Tank Circuit Breaker with Limited Flexibility to the Adjacent Current Transformer.

adjacent circuit breaker. The porcelain strut was provided to resist wind loads. The base of the current transformer is supported on a chair, shown in Figure 5-97. The base of the chair is much larger than that of the current transformer, so the channels provide a flexible support. An evaluation of the support indicates that the natural frequency of a current transformer supported in this way is between 1 and 2 Hz. This places it in the high-energy part of the ground spectrum. The flexibility of the current transformer support structure and the lack of slack in the conductor between the circuit breaker and the current transformer contributed to the failure of the circuit breaker. As a result, two circuit breaker interrupter head support columns failed, as well as many of the porcelain struts. Strong motion

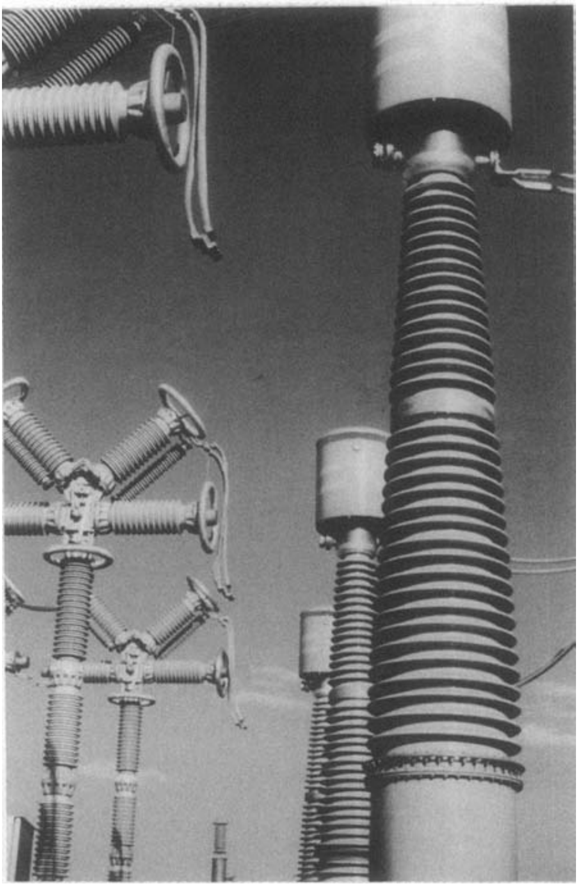

FIGURE 5-93. Failed Connections between Circuit Breakers and Current Transformers.

instruments near the site recorded peak ground accelerations of only 0.05g. At the same site, another circuit was installed about a year after the first, using the same equipment, but the chair was smaller so that legs were directly under the current transformer case. This raised the natural frequency of the current transformer, and none of the circuit breakers were damaged in the earthquake.

Figure 5-98 shows damaged current transformers resulting from the failure of live-tank circuit breakers. The conductors seen hanging from the current transformer had been retrofitted to provide flexible connections, but the collapse of the circuit breakers made excessive demands. Note that the conductor hardware failed, but not before damaging the current transformer.