Figure 6.88. One of two 500 kV undamaged reactors associated with the transformers

Figure 6.89. A large turret supporting the A and C phases on reactor

Figure 6.90. Seven transformers separated by firewalls that support surge arresters

Figure 6.91. One of two surge arresters installed on top of firewall that failed

Figure 6.92. Surge arresters have generous slack

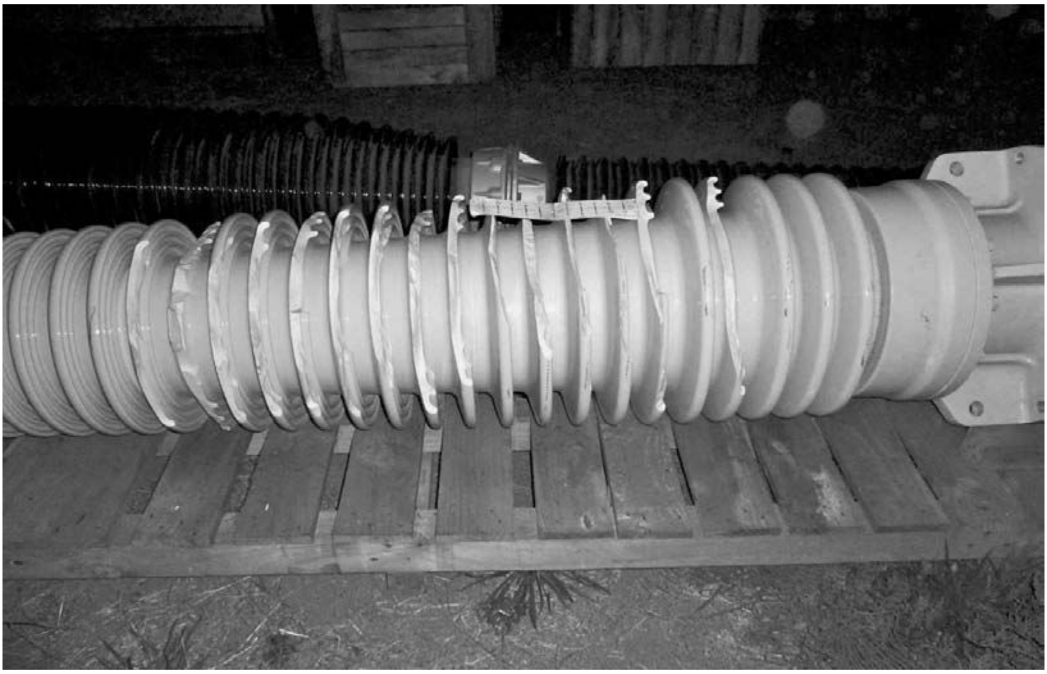

Figure 6.93. One falling surge arrester damaged the 220 kV transformer bushing

Figure 6.94. Glass suspension insulator replaced failed post insulator

There were several locations in the 500 kV switchyard where post insulators supported below dead-end structures failed. Figure 6.94 shows a suspension insulator that replaced the failed post insulator. While the lower end of the post insulator would not be expected to move much, the string insulator will swing and the slack provided, which is probably the same as that used for the post insulator, may not be adequate. The use of a composite suspension insulator, which would have one-third the weight as a porcelain or glass insulator string, would reduce the load on the instrumentation transformer. Figure 6.95 shows a dead-end structure in which the B-phase post insulator in the cross-under has failed. It may be interesting to calculate the load and compare it to the capacity of the insulator. The BIL of the pantograph disconnect switches in the switchyard is 1800 kV, so this value will be used to characterize the post insulator. Post insulators come in various strengths; from scaling the photographs, the insulator is estimated to have a 2,500-pound (1134 kg) cantilever strength. This unit has a weight of 908 pounds (412 kg) and is tapered. From Figure 6.76 the length of the span on each side of the insulator is estimated as being twice the insulator length, which is 152 inches (3861 mm). There are three conductors, and the weight per foot of each conductor is estimated to be 2.0 pounds. The total weight of the conductors is estimated as 304 pounds. The center of gravity of the conductor will be approximately at the center of the insulator, so the equivalent weight at the end of the insulator is 152 pounds (69 kg). The equivalent weight of the insulator concentrated at the end of the insulator is estimated as 400 pounds. Thus, the total equivalent weight of the conductor and post at the end is 552 pounds (250 kg). As the cantilever strength is 2,500 pounds (1134 kg), fairly large spectral amplifications would be required to fail the post insulator. Even if a lower strength post is used (cantilever strength of 635 kg [1,400 lbs.] and weight of 288 kg [636 lbs.]), a large amplification would be needed to fail the post (assuming a spectral amplification of 3.25 for 1 g ground motion and IEEE 693 RRS). This suggests that conductor dynamics may be involved, as dynamics can induce impact type loads. Figure 6.96 shows a frame in which two insulators have failed. These insulators are connected to grounding switches, have generous slack, and have less conductor weight than in the previous figure. Figure 6.97 shows the post insulators on the ground where they fell. Figure 6.98 shows a typical fracture at the base of a post insulator (i.e., a guillotine-type fracture across the insulator at the sand ring). The sand ring is a roughened part of the stub of the insulator that fits inside a pocket in the flange. Portland cement and sand is typically used to make the connection between the flange and the stub of the insulator. This is strictly a mechanical connection; there is no chemical bonding between the grout and the porcelain or the flange. This is why roughness is added to the porcelain stub, as can be seen in Figure 6.98. Secondary failures that result from the insulator striking the ground are also used in characterizing failure type.

We learned through discussions with one major insulator manufacturer that in their testing to determine cantilever strength, in which a uniform pull test to failure is used to generate the failure, the crack in the porcelain usually starts at the sand ring and extends diagonally up though the body of the porcelain, and guillotine-type failures are rare. In lab tests of post insulators conducted in a research project by a utility at a university lab, a small number of post insulators were subjected to pseudo-dynamic cyclic loading. About half the samples had guillotine-type fails and half had fractures through the insulator body.

Figure 6.95. Failure that is not related to slack, but may be related conductor dynamics

Figure 6.96. Drop with adequate slack in which two post insulators failed

Figure 6.97. Post insulators on the ground after falling from dead-end structure

Figure 6.98. Typical guillotine-type failure observed of post insulator

Figure 6.99 shows the upper part of the B phase of a pantograph disconnect switch missing and the connection being made with a jumper. Figure 6.100 shows a connection being fractured. It is not known if the other connection was removed or if the bolts making the connection failed. Figure 6.101 shows the arms on the ground with the arrow on the left with the fractured part still connected and on the right with a clean pipe. Figure 6.102 shows the fractured connection close up. While an exact count of pantograph disconnect switches is not known, a review of team photographs indicates that there were at least twenty-eight 500 kV disconnect switches. All pantograph switch failures were related to the character of the upper connection. All failures occurred in switches where the upper connection was to an inverted post insulator rather than from a flexible bus. Figure 6.103 shows a HVAC system in which the spring supports shifted.

Ancoa Substation

Ancoa Substation is located about two-thirds of the way from Santiago to Concepción and services four 500 kV circuits, four 220 kV circuits, and one 66 kV circuit. Of the substations visited, the Ancoa substation made the most extensive used of damping devices on instrument transformers (Figures 6.12 and 6.13), candlestick circuit breakers (Figure 6.6), live-tank circuit breakers (T head) in the 500 kV switchyard, and some instrumentation transformers and surge arresters in the 220 kV switchyard (Figures 6.9 and 6.88). There were 45 semi-pantograph disconnect switches and 30 pantograph disconnect switches. Seven pantograph switches poles failed. One 500 kV post insulator supported under a dead-end structure failed, damaging sheds on a potential transformer. Figure 6.104 shows the terminals in the control room, none of which tipped over.

A hydroelectric facility, owned by Colbun generating company, is adjacent to the substation and has its own small switchyard. The team did not visit the facility, but it was reported that there were problems with a dead-tank circuit breaker. Figure 6.105 shows a 220 kV dead-tank SF6 circuit breaker, which was reported to have had some problems, in the switchyard adjacent to the Ancoa substation. With one unusual exception in Japan, there is no record of this type of circuit breaker being damage in an earthquake. Historical data suggests that the problem was not with the circuit breaker but with a connection to it.

Figures 6.106 and 6.107 show the bases of a 220 kV current transformer and surge arrester, which used the clamped porcelain method of connecting the porcelain to the base flange rather than a cemented connection, a method not typically used in the United States. Note that a damping device supports the surge arrester. The current transformer is also supported by damping devices, which are not shown in the photograph (Fig. 6.91).

Figure 6.99. The B-phase pantograph disconnect switch failed

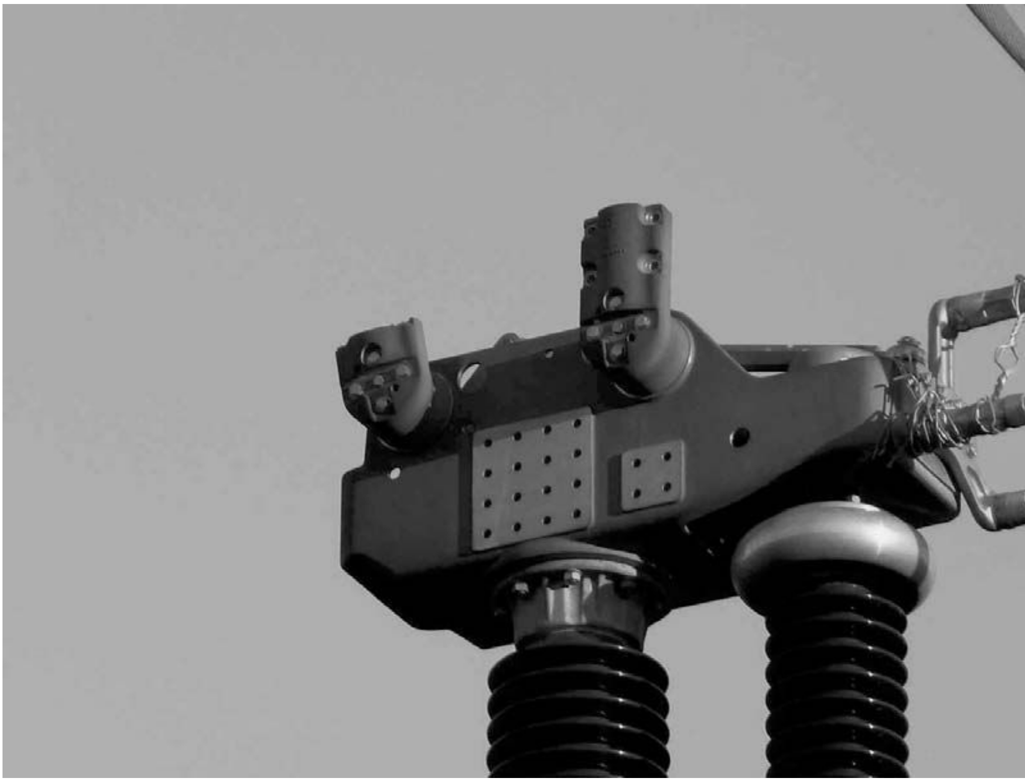

Figure 6.100. Top of pantograph switch with arms missing

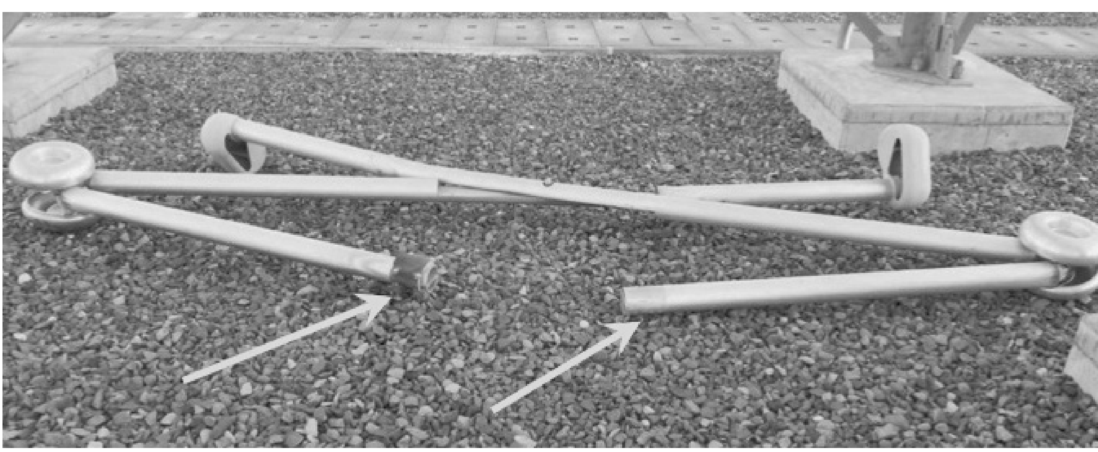

Figure 6.101. Pantograph arms on the ground

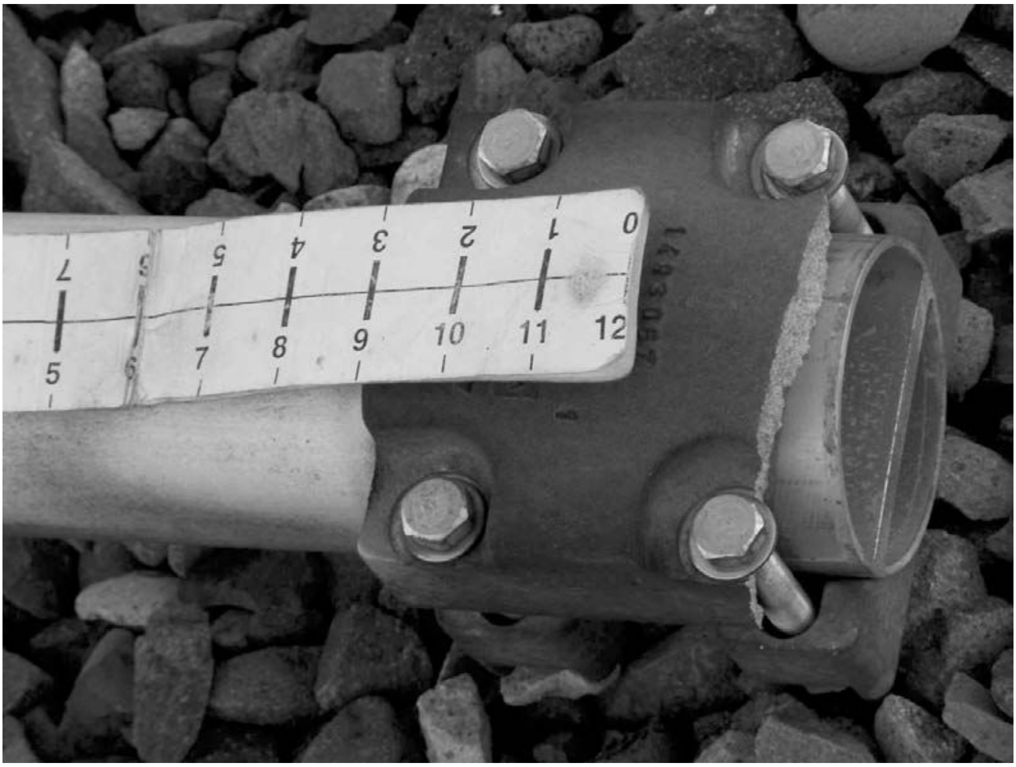

Figure 6.102. Broken coupling that connects arm to switch body

Figure 6.103. Support for HVAC system shifted