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# 4. LIFELINES AND CRITICAL FACILITIES

The January 13, 2001 Off the Coast of El Salvador Earthquake

A slope failure slightly off a transmission tower: Foundations of the tower narrowly escaped from being carried off (Sonsonate -Nuevo Cuscatlan, 115 kV Line).

## 4.1. INTRODUCTION

This report comprises the earthquake performance of the following lifeline systems: ELECTRICAL POWER SYSTEMS including substations and electric transmission lines; WATER AND SEWERAGE SYSTEMS including water treatment plants and sewerage facilities, tanks, cisterns, pumps, and pipelines; TRANSPORTATION SYSTEMS including local roads, expressways and bridges; and, the earthquake damage to CRITICAL FACILITIES such as Airports, harbors and Hospitals. A brief description on earthquake performance of TELECOMMUNICATION SYSTEMS is also included.

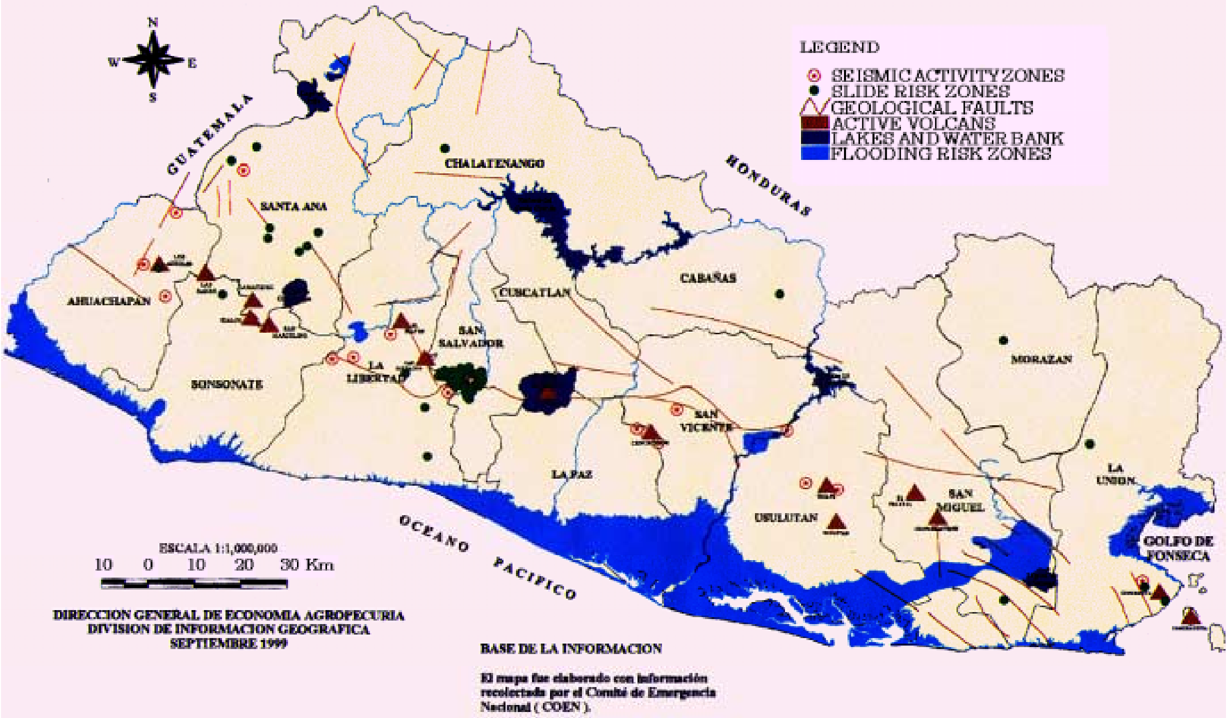



**Figure 4.1**. Natural Hazards in the Republic of El Salvador (Earthquakes, Volcanoes, Landslides, and Flooding), [COEN]

## 4.2 ELECTRICITY

### *Introduction*

The electricity in El Salvador is mainly generated by geo-thermal and hydroelectric plants. “Geotérmica Salvadoreña S.A. de C.V.”, which belongs to the Hydroelectric Executive Commission of Río Lempa (CEL), owns two geothermal power plants, Ahuachapán (2x30 MW + 1x35 MW) and Berlín (2x28 MW with condensing modular plus 2x5 backpressure). Some 115kV substations in the Guatemala system suffered some damage, but remained in partial service. Failures in the other systems including the San Salvador system, however, led to a complete power outage in central and eastern regions of the country, and it took three days for the systems to be restored. Electricity from private Salvadorian power companies such as CAESS, DEL SUR, CLESA, EEO, SICEPASA and ANDA was reduced. The nationwide loss caused by the damage to the electric power systems is estimated to be more than $750,000 US dollars.

***Substations***

**(1) Damage to substation installations**

Shortly after the earthquake, functioning installations in some damaged substations were brought in full operation to make up for the drop in power supply caused by damage to their transformers, bushings, interrupters, connectors, radiators, and circuit breakers. At Soyapango and Nejapa substations, some insulators and bushings for lightning rods and transformers (30/40/50 MVA and 110-46/23 kV) were broken (**Figures 4.2** and **4.3**). Heavy equipments such as power transformers and their radiators were broken, and oil leaked from their bottoms ("15 de Setiembre" substation, **Figure 4.4**). Supporting rods of interrupters were broken at their bottom ends (Nejapa Substation, **Figure 4.5**). For interrupters, the intense shake was not the sole cause of the damage to them. Flashovers (electric arcs) around or over the surfaces of insulators and/or short-circuits damaged equipments at Nejapa Substation (**Figure 4.6**). At Tecoluca Substation, short-circuit in a circuit breaker caused the damage to the main switchboard of an isolator (**Figure 4.7**). Obviously, porcelain insulators and/or bushings for substation equipments were quite susceptible to intense shakes and easily broken during the strong shaking. In addition to the abovementioned substations, major damages to porcelain devices were reported at Nuevo Cuscatlan, San Martin, Ateos, San Antonio Abad, but less at other substations.

**Figure 4.2**. Broken bushing for a transformer (Soyapango Substation)

**Figure 4.3**. Broken bushing for a lightning rod (Nejapa Substation)

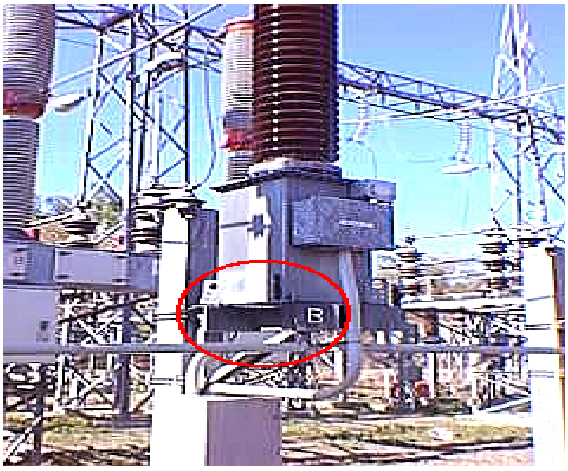


**Figure 4.4**. Oil leakage from the bottom end of radiator

**Figure 4.5**. Broken support of interrupter (Nejapa Substation)

**Figure 4.6**. Broken insulator

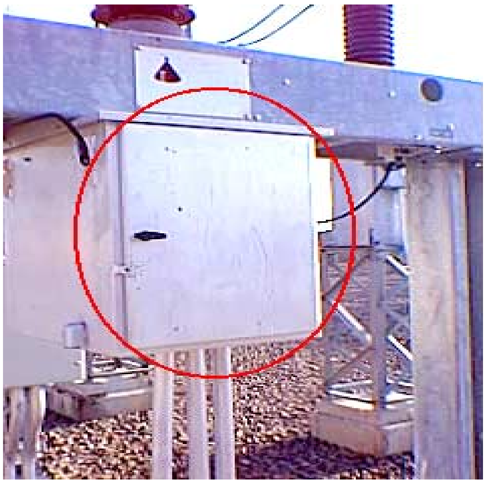


**Figure 4.7**. Main switch board

**(2) Damage to substation buildings**

The intense ground motion was also responsible for damage to some substations buildings. Temporary supports were needed in some buildings under some damaged structural members so that the functioning equipments could be fully operated. At the switchyard of Nuevo Cuscatlan substation, the upper corner of a wall cracked due to the confining frame deformation (**Figure 4.8**), and concrete beams were spalled (**Figure 4.9**).

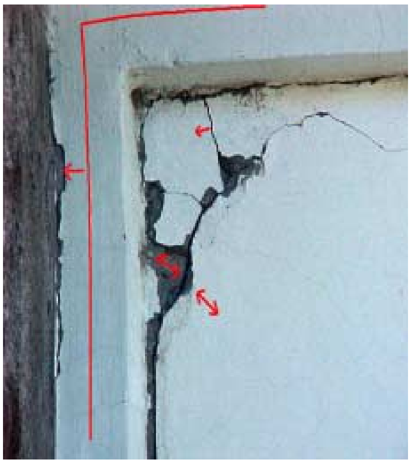


**Figure 4.8**. Cracked corner of a wall

**Figure 4.9**. Spalled concrete beam

**Figure 4.10**. Lateral crack beneath a beam (Switchyard, Santo Tomas Substation)

**Figure 4.11**. Tension crack along a joint between tiles (Switchyard, Sonsonate Substation)

The headquarters of the “El Salvador Electricity Transmission Company” (ETESAL) was forced to evacuate its building because of the serious structural damage. Some joints of walls were opened widely. A floor suffered some shear cracks when it was forcibly compressed (**Figure 4.12** left), and some ceiling panels came off (**Figure 4.12** right).

**Figure 4.12** Damage to the headquarter building of “El Salvador Electricity Transmission Company” (ETESAL)

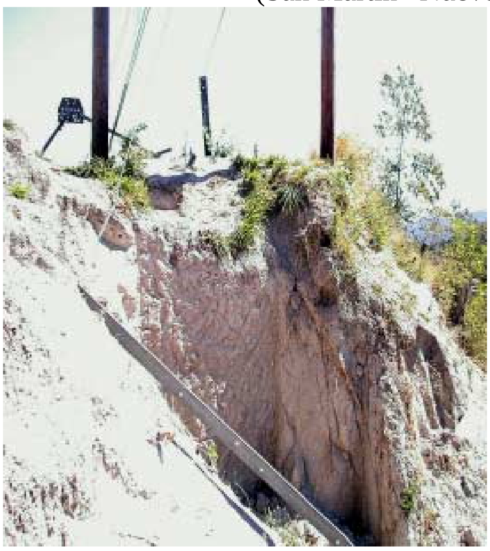
***Damage to Transmission Lines***

There are 28 115kV transmission lines, and one 230 kV interconnecting El Salvador with Guatemala. The transmission system also includes two rehabilitated 115kV lines connecting Ozatlán, Tecoluca and San Miguel in the eastern area of El Salvador. A number of slope failures along these lines carried off the foot soils of transmission towers and poles.

Wooden poles are mainly used for lower voltage lines, and since they do not need much space for their foundations, they are often constructed along thin mountain ridges (**Figure 4.13**), on the edges of natural or artificially cut slopes (**Figure 4.14a** and **b**) and so on. Two or more poles are often joined together to make up a plane frame for suspending several cables. At some damaged plane frames, foot soils do not equally subside causing some noticeable tilt of the frames (**Figure 4.15**). Slope failures were found not only in loose soils but also on weakly cemented volcanic products. A slope-failure took place about 4m off a transmission tower of the “Nuevo Cuscatlan–Santo Tomas” 115kV Line (**Figure 4.16**). The exposed slip surface shows an arrangement of volcanic products in strata of varying thickness. Weak layers bedding in the strata seem to have slipped.

Some trees thrust their roots far and wide laterally, cracking cemented soils, and thus causing some soil blocks to come off (**Figure 4.17**).

**Figure 4.13** Damage to wooden poles for transmission cables.
(San Martin– Nuevo Cuscatlan Transmission Line)



a

b

**Figure 4.14**. Poles on the edge of unstable cut
(Nuevo Cuscatlan-Santo Tomas Line)

**Figure 4.15**. Tilted plane frame of the Nuevo Cuscatlan–Santo Tomas 115 kV line

**Figure 4.16**. A slope failure about 4m off a transmission tower: Foundations of the tower narrowly escaped from being carried off. The failure surface extended over 8 meters height and 12 meters wide (Nuevo Cuscatlan-Santo Tomas Line)

**Figure 4.17** Roots cracking soils
(Nuevo Cuscatlan-Santo Tomas Line)

***Summary and recommendations***

Surface configurations and soil profiles are often responsible for noticeable amplification of seismic ground motions. Substations with equipments with fragile bushings and insulators are thus desirable to be well located on stable soils. As for transmission lines, it is recommended to avoid constructions of towers and poles on the edges of unstable slopes. If unavoidable, constructions should involve some necessary slope stabilizations. Single upright poles or plane frames with two upright poles are conveniently used because they do not require much space for their foundations. It is however desirable to have more stable space frames (towers) for important transmission lines.

to the next page