Earthquake Damage to the Electric-Power Infrastructure-Substation

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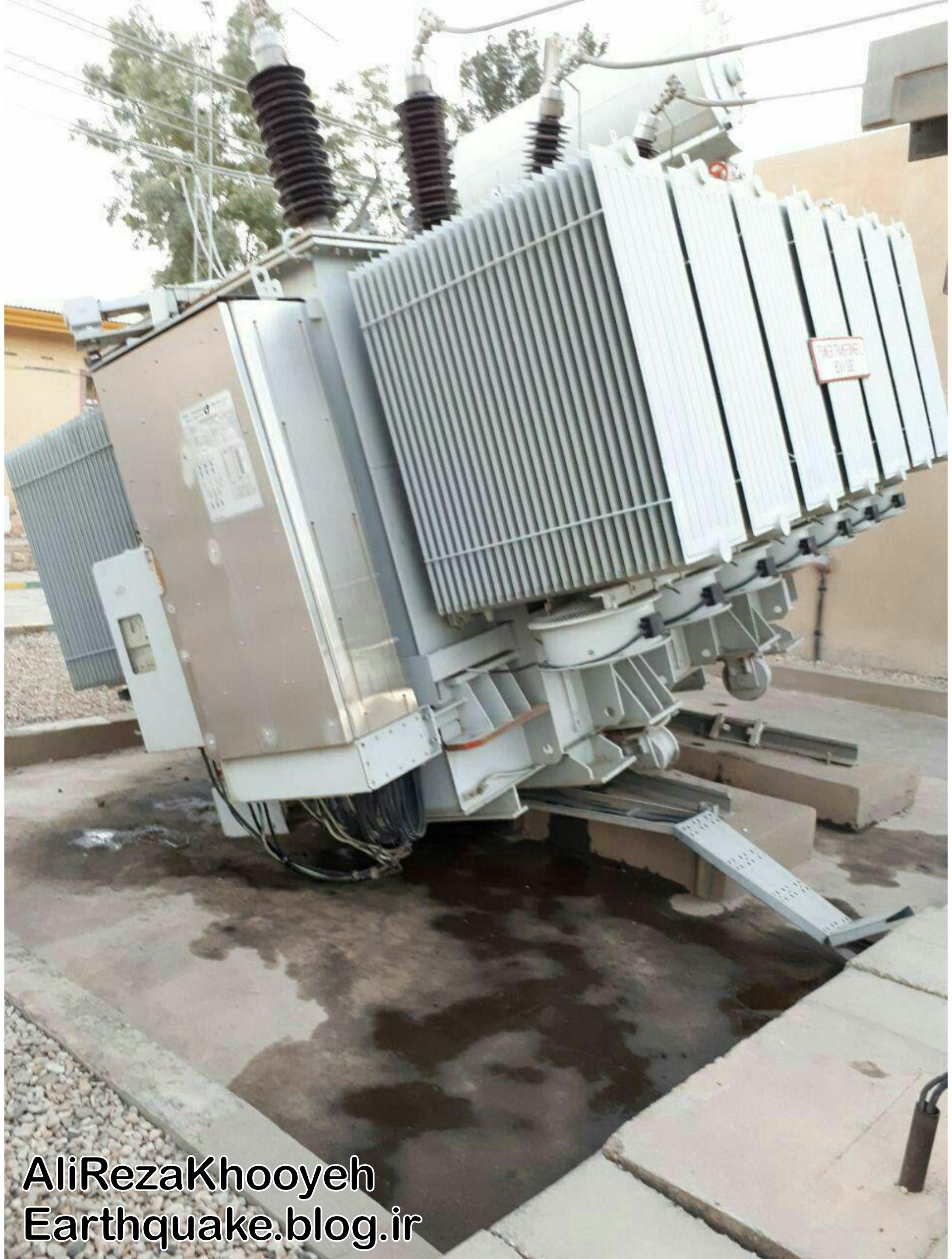
Iran-Kermanshah-
SarPolZahab-
M=7.3
2017

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POWER TRANSFORMER 2
63kV SIDE
Iran-Kermanshah-
SarPolZahab-
M=7.3
2017

- Recent moderate and strong earthquakes (e.g., 1994 Northridge, 1995 Kobe, 1999 Turkey, 1999 Taiwan) have demonstrated that parts of power systems are very vulnerable to damage. While system performance

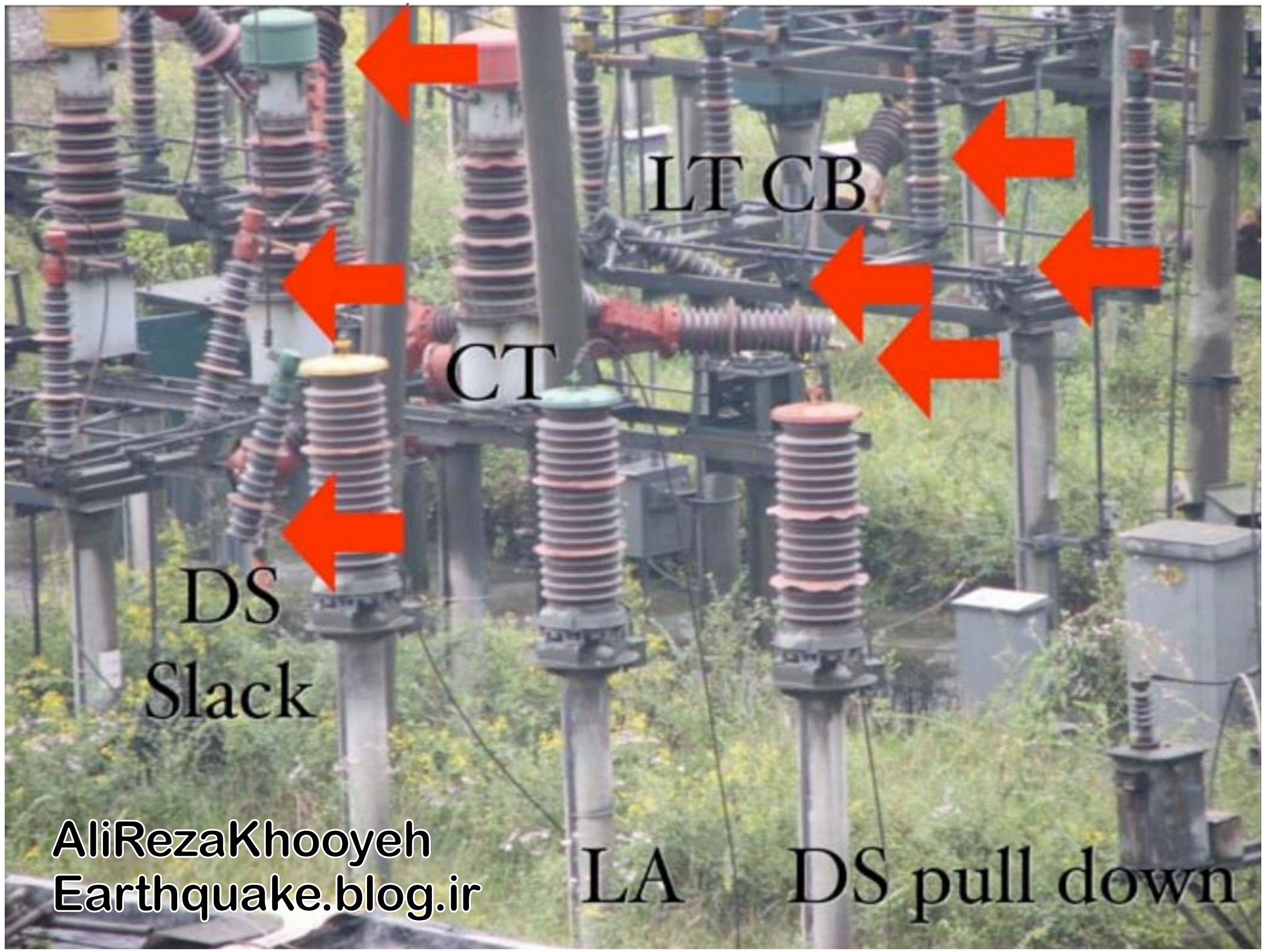
  has been good, as measured by customer disruption, there has been considerable damage, so that the damage pattern suggests that system performance will not be acceptable for larger earthquakes, for earthquakes that impact larger areas or in regions that do not use good earthquake practices. These earthquakes have all had **magnitudes** of about 7, so the performance after a major earthquake (magnitude between 7 and 8) or a great earthquake (magnitude above 8) is not known. Starting with the 1971 San Fernando earthquake, 11 California earthquakes have damaged power system facilities. Most of these small to moderate earthquakes have shaken relatively small areas so that damage has been concentrated and limited primarily to one or two facilities. The 1989 Loma Prieta, California earthquake affected a large area, severely damaging three substations and disrupting the network in the region. The 1994 Northridge, California earthquake also affected a large area, damaging 11 power facilities and disrupting the network. Foreign earthquakes have also provided important lessons. While much less frequent, damaging earthquakes can be expected in many parts of the US; indeed, 31 states have experienced earthquakes of a magnitude that could be expected to damage power system facilities.

- Direct costs for repair and replacement of damaged facilities have not been overwhelming in terms of utility assets, but are nonetheless significant. In California alone, there were direct losses of about $45 million in the 1971 San Fernando earthquake (magnitude Mw = 6.6), $9 million in the 1986 North Palm Springs earthquake (magnitude Mw = 6.1), $100 million in the 1989 Loma Prieta earthquake (magnitude Mw = 6.9) and $183 million in the 1994 Northridge earthquake (magnitude Mw = 6.7). Some smaller, less costly earthquakes have been very disruptive. In the 1988 Tejon Ranch earthquake, the California Aqueduct, which supplies water to the Los Angeles area, was shut down for 4 days, and there is typically only a 15-day supply of water stored downstream from the point that was damaged. In the 1984 Morgan Hill, California earthquake, one of the three Pacific interties, major power circuits connecting the northwest and the southwest, was down for 3 days.
  In most earthquakes, it has been possible to bypass damaged equipment and continue to transfer power through or to route power around the damaged substation. In some cases, an entire switchyard has been bypassed. Fortunately, when transformers have been damaged, there has been adequate capacity in alternate routes to maintain service. The relatively short time to restore service in the face of extensive damage can be attributed to the high level of redundancy designed into power systems, and the resourcefulness and dedication of utility-maintenance personnel. However, it is easy to envision damage, particularly to transformers, that could cause lengthy disruptions. Looking at a utility's response to moderate earthquakes helps put the recovery effort into perspective.
  In the 1986 North Palm Springs earthquake, where power system damage was limited to one substation, about 250 people worked 18-hour days for 3 days to clear damaged equipment from the site. About 180 people continued to work for about an additional 6.5 days to restore equipment and service to a critical line. To reduce the disruption time, this reconstruction was carried out by several crews working in parallel at all locations where possible. This damage occurred to a facility that used the then-current and most stringent earthquake mitigation practices. After the Loma Prieta and Northridge earthquakes, it took months to repair and replace damaged equipment, even though service was restored quickly.
  This experience suggests that larger earthquakes, those that impact larger areas, or those that occur in regions where less stringent seismic design practices and more vulnerable equipment are used, will have more-extensive earthquake damage that could overwhelm system redundancies. As a result, unacceptably large direct losses, indirect losses borne by customers, and lengthy disruption of service to the community are possible. In light of the recent experience, large California utilities have reevaluated the vulnerability of their systems and are adopting measures to improve their response. While many of these measures would be difficult to justify in regions of lower risk, some things that are cost effective in any region that has a history of damaging earthquakes can be done, particularly for new construction. It would be unfortunate if cost-effective measures were not implemented, and utilities and the communities they serve were exposed to avoidable risks

Wenchuan, Sichuan Province, China Earthquake of 2008 (M8.0)

220 kV Ertaishan Substation, Yingxhou

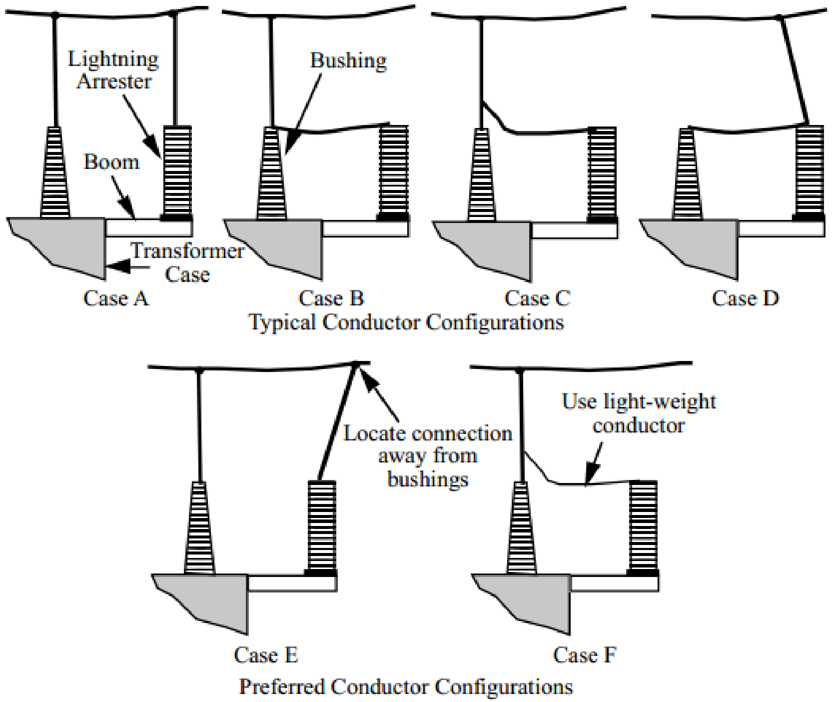
Yard Equipment, Yingxhou 110 kV Substation



Bushing, 500 kV Transformer

- One of the most common items to fail in substations has been transformer-supported surge arresters.
  In coastal California, where lightning is very rare, damaged surge arresters are removed and the transformer put back into service. One of the risks associated with such failures is that, in falling, the surge arrester can damage the transformer bushing by striking or pulling on it and damaging the conductor bonding post.

- This figure illustrates several different methods of configuring the conductor and preferred methods.



Variations in surge arrester conductor configurations.

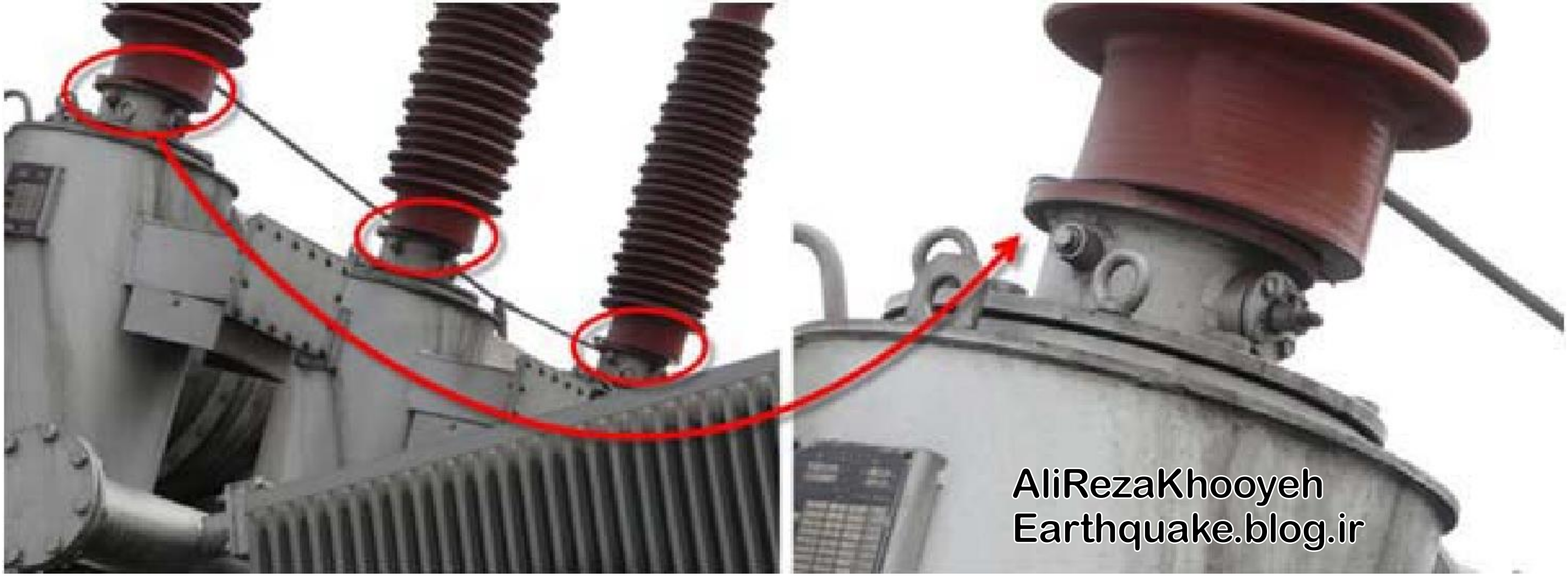
Skid-Mounted Transformer

Skid-Mounted Transformer

Wheel-Mounted Transformer

Damaged Live Tank Circuit Breaker (110 kV)

Slippage at the bottom of porcelain bushing and subsequent oil leakage falling off the foundation on the ground if displacement exceeded the foundation dimensions,



China 2008
Sichuan earthquake M_w 7.9

Fracture at the porcelain bushings slippage of an anchored transformer on its foundation,

China 2008 , Sichuan earthquake M_w 7.9

Fracture at the bottom of cast-aluminum flange collapse due falling on the ground

China 2008 , Sichuan earthquake M_w 7.9

Overturning of 110kV transformer

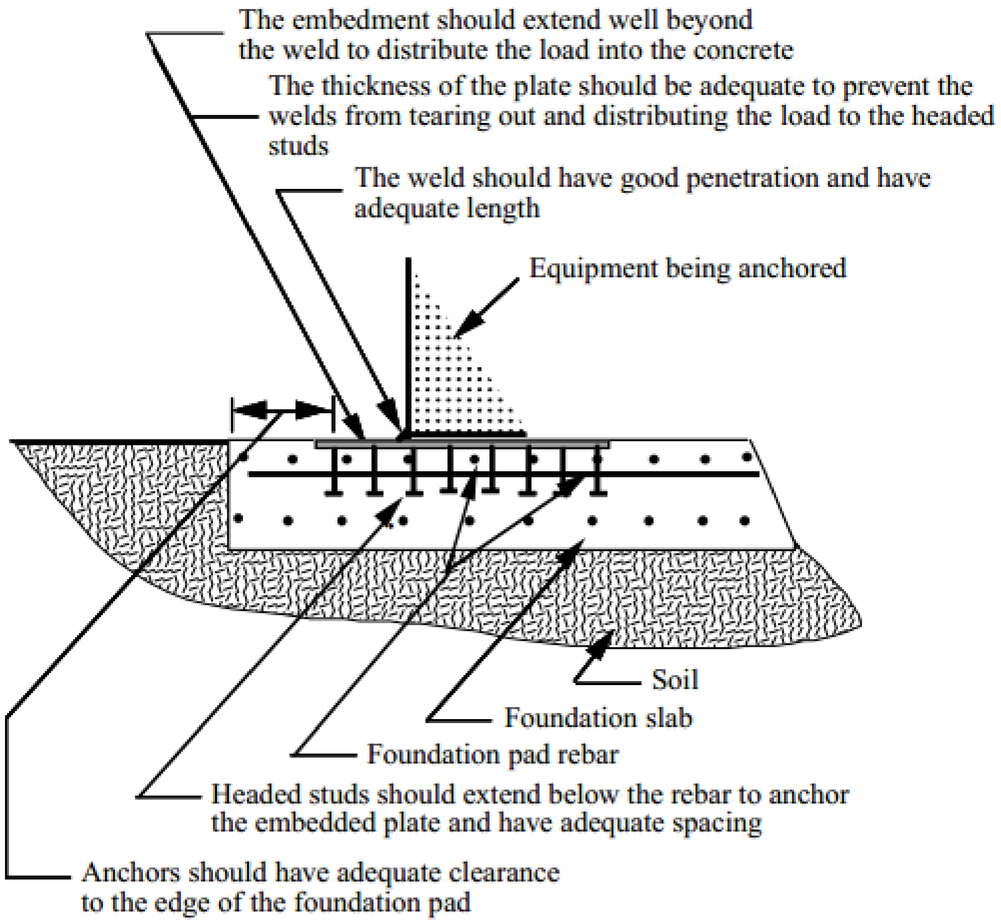
China 2008 , Sichuan earthquake M_w 7.9

Slippage of a 220kV transformer

China 2008 , Sichuan earthquake M_w 7.9

Oil leakage from the tank of the transformer

transformer in Haiti
earthquake (left image – top view and right image - oil leakage from the tank of the transformer).



Important features in transformer anchorage design.

A transformer in Haiti earthquake (left image – side view and right image – rear view)

Figure 2: A broken CT

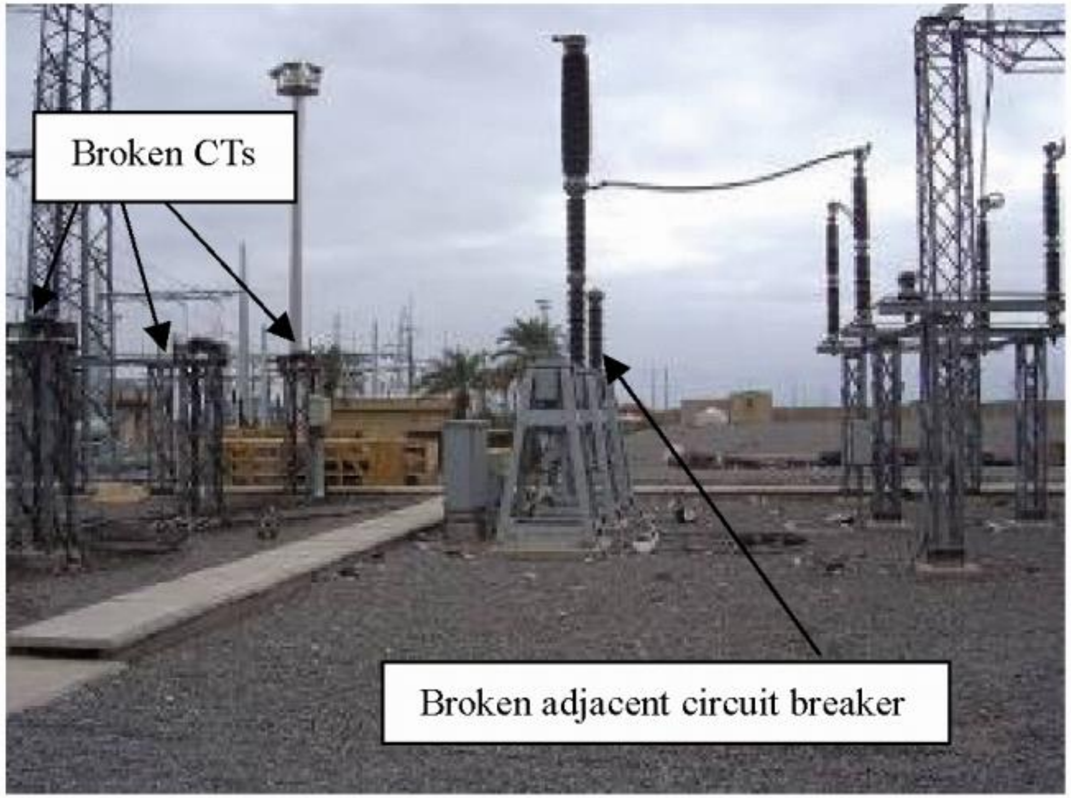


Figure 3: Fallen adjacent equipments

Figure 6: Pulled conductor

Figure 7: Sliding of non-anchored equipments

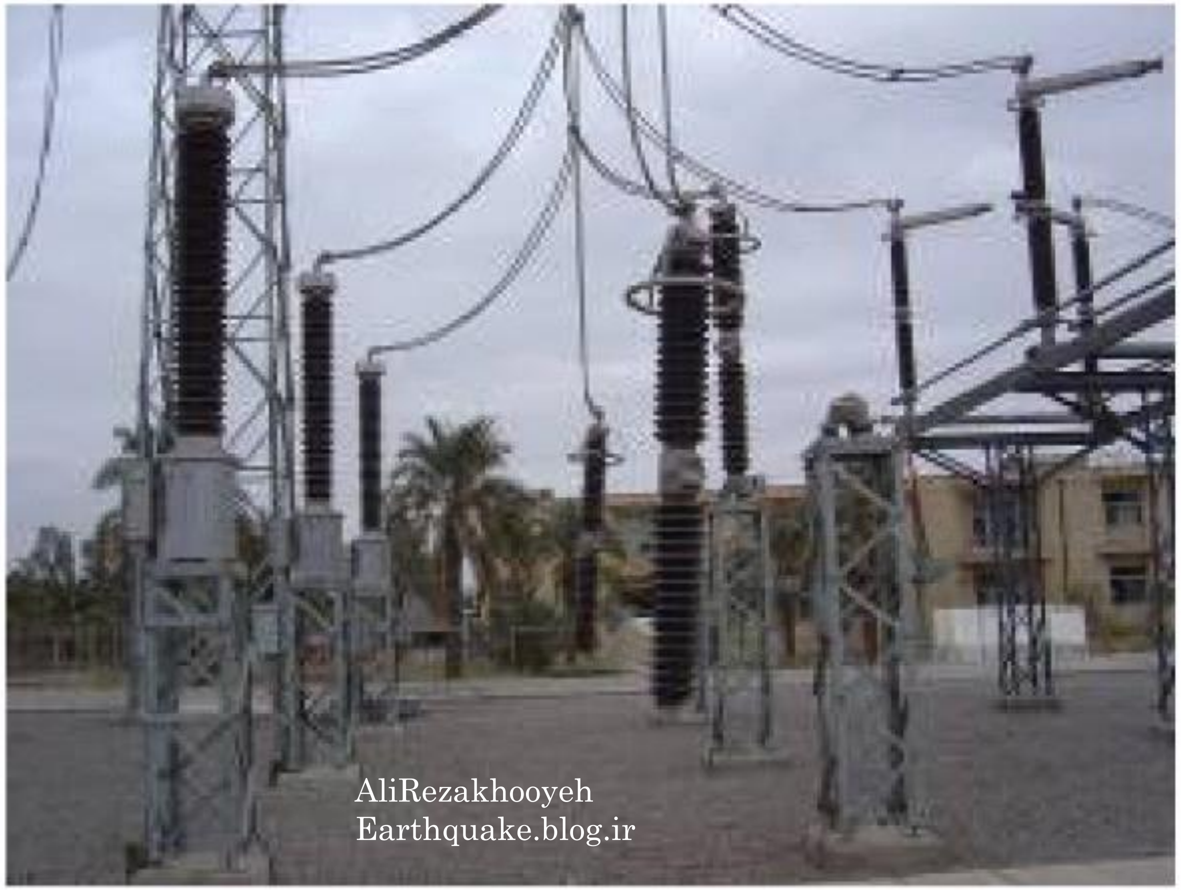


Figure 8: Broken surge arresters

Figure 9: PI and voltage transformers

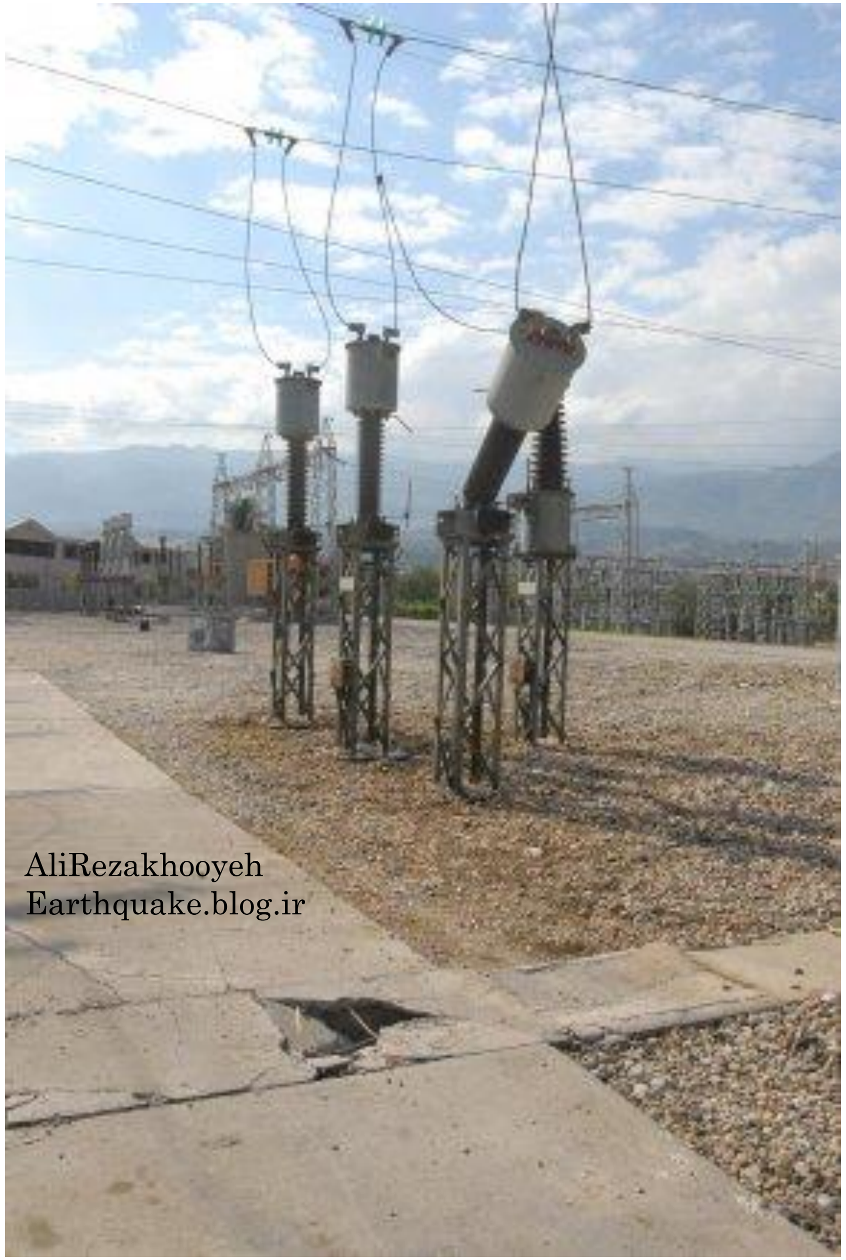

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Figure 10: Transformer base after retrofit

Figure 11: Cracked bushing

Figure 12: Damages to control building

Figure 13: Damaged batteries

Figure 14: Replaced bushing

Figure 15: Damaged bushing

Figure 18: Trans sliding

Figure 19: Damaged batteries

Figure 20: Panel sliding

Figure 1 Lightning arresters of all three-phases were broken in Nagaoka Sub. (JSCE, 2004)

Oil leakage from joint between transformer and condenser
in Minami Nagaoka Sub.
(JSCE, 2004)

Figure 3 Failure of condenser in Nagaoka sub.
(JSCE, 2004)

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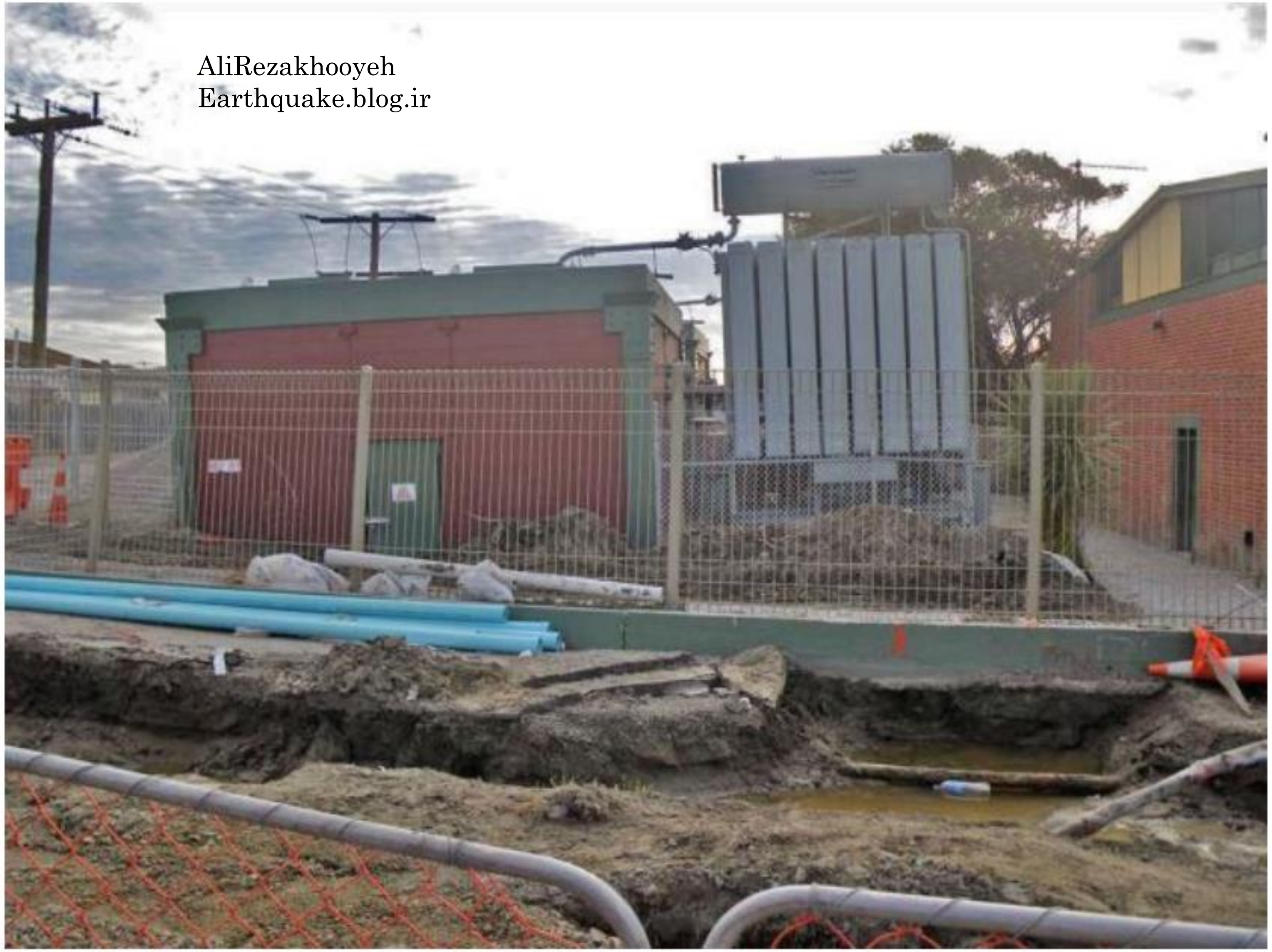
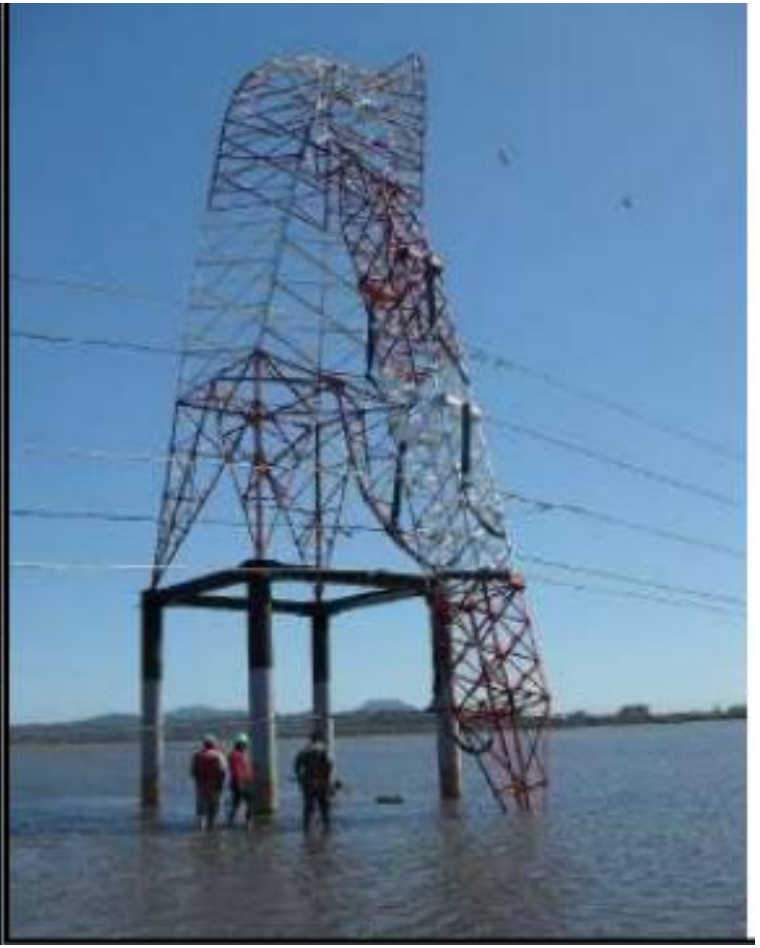
Figure 4 Extrusion of gasket and oil leakage
in bushing of 154 kV transformer in Uonuma Sub.
(JSCE, 2004)

Liquefaction damage (New Brighton Substation)





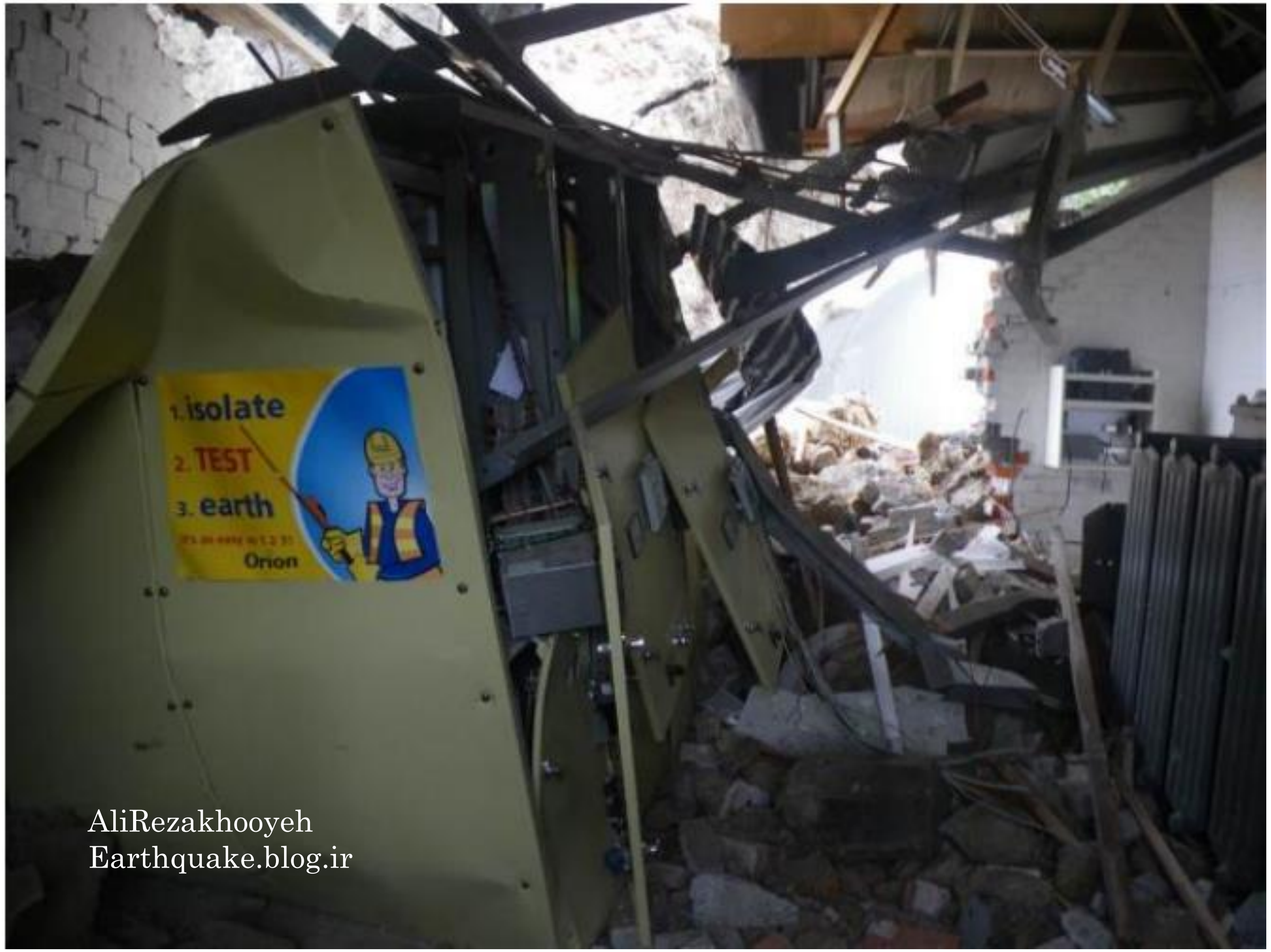
A shared structure with the electrical substation having been seismically strengthened (Redcliffs waterworks substation)

Cable jointers repairing the Armagh-Lancaster 66 kV XLPE cable

A 66 kV pole being inserted (Note the height difference to the LV pole)

Digging up multiple faulty 11 kV cables

Sumner substation boulder damage



Chili 2010 , 8.8M

Chili 2010 , 8.8M

Chili 2010 , 8.8M

Chili 2010 , 8.8M

HV Bushing: Oil Leakage

Collapse of Surge Arrestor

L u s h a n E a r t h q u a k e a t

Breakage of Bushing

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Collapse of Surge Arrester

L u s h a n E a r t h q u a k e a t

Oil Leakage Due to Ceramic envelope Breakage

L u s h a n E a r t h q u a k e a t

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Oil Leakage Due to Ceramic envelope Breakage

L u s h a n E a r t h q u a k e a t

LushanEarthquakeat

L u s h a n E a r t h q u a k e a t

Collapse of 500kV MOA

L u s h a n E a r t h q u a k e a t

Collapse of 500kV MOA

L u s h a n E a r t h q u a k e a t

Oil Leakage

L u s h a n E a r t h q u a k e a t

HV Bushing Oil Leakage

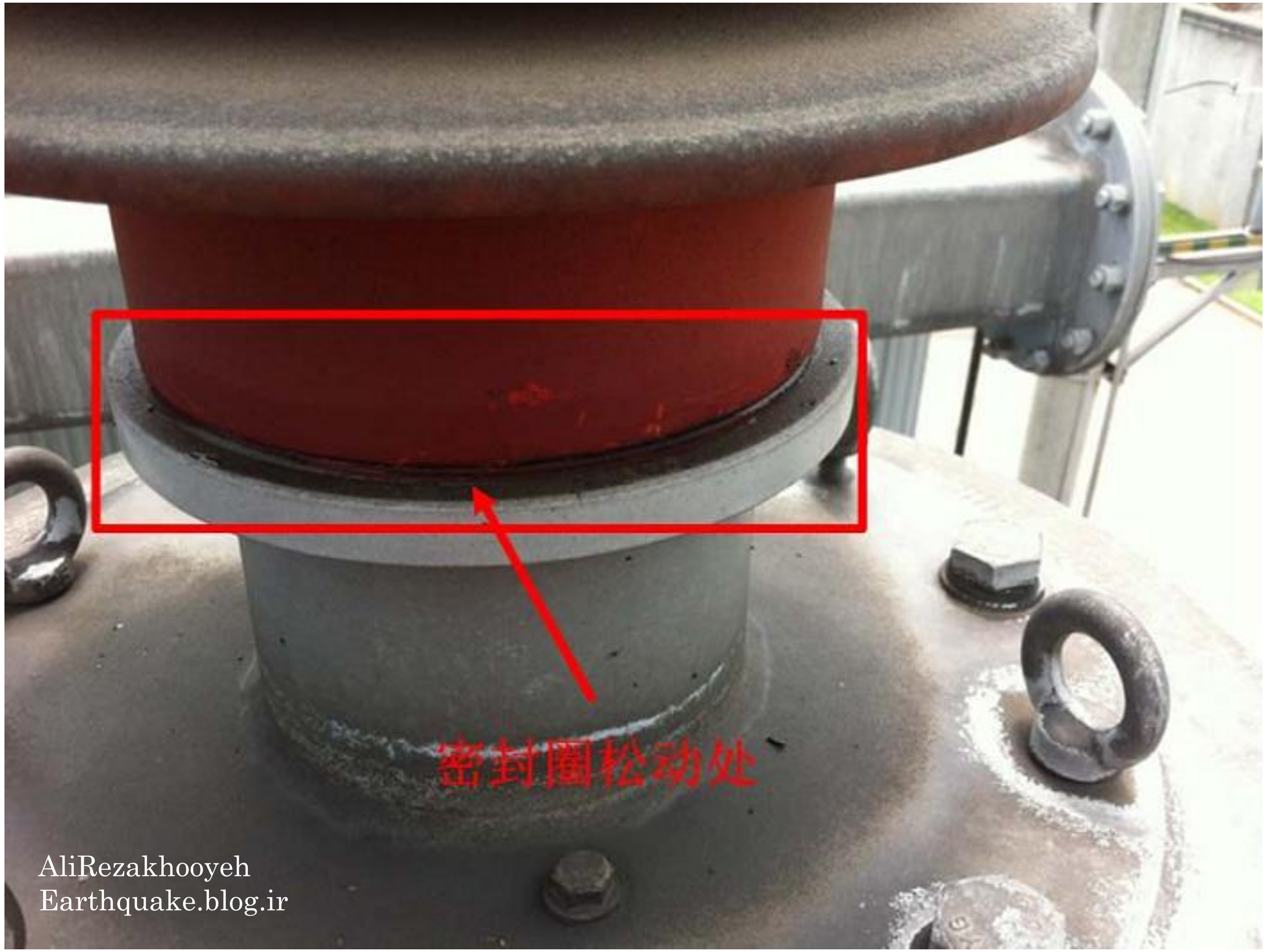
L u s h a n E a r t h q u a k e a t

HV Bushing Oil Leakage

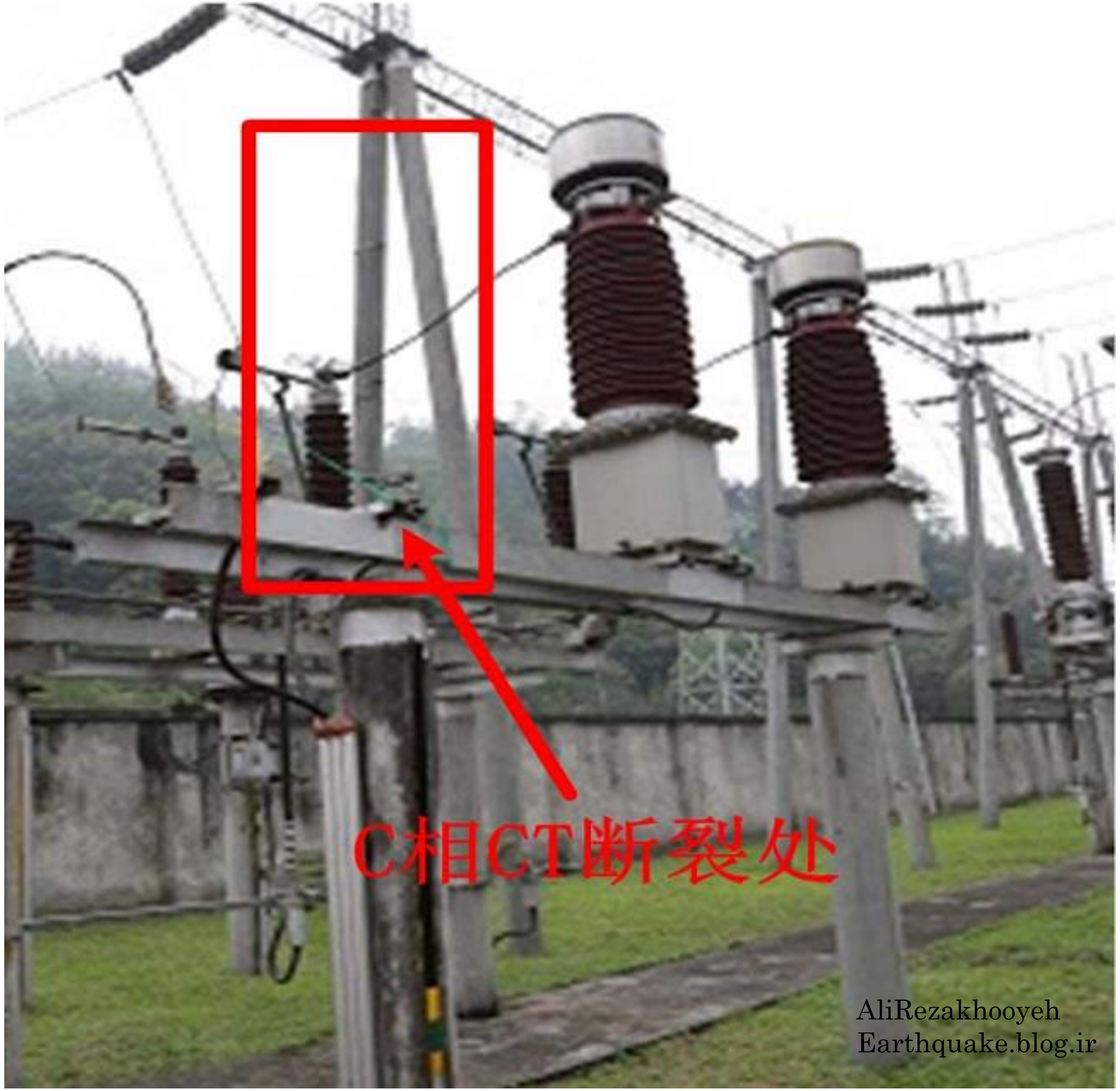
L u s h a n E a r t h q u a k e a t

Transposition of Gaskets

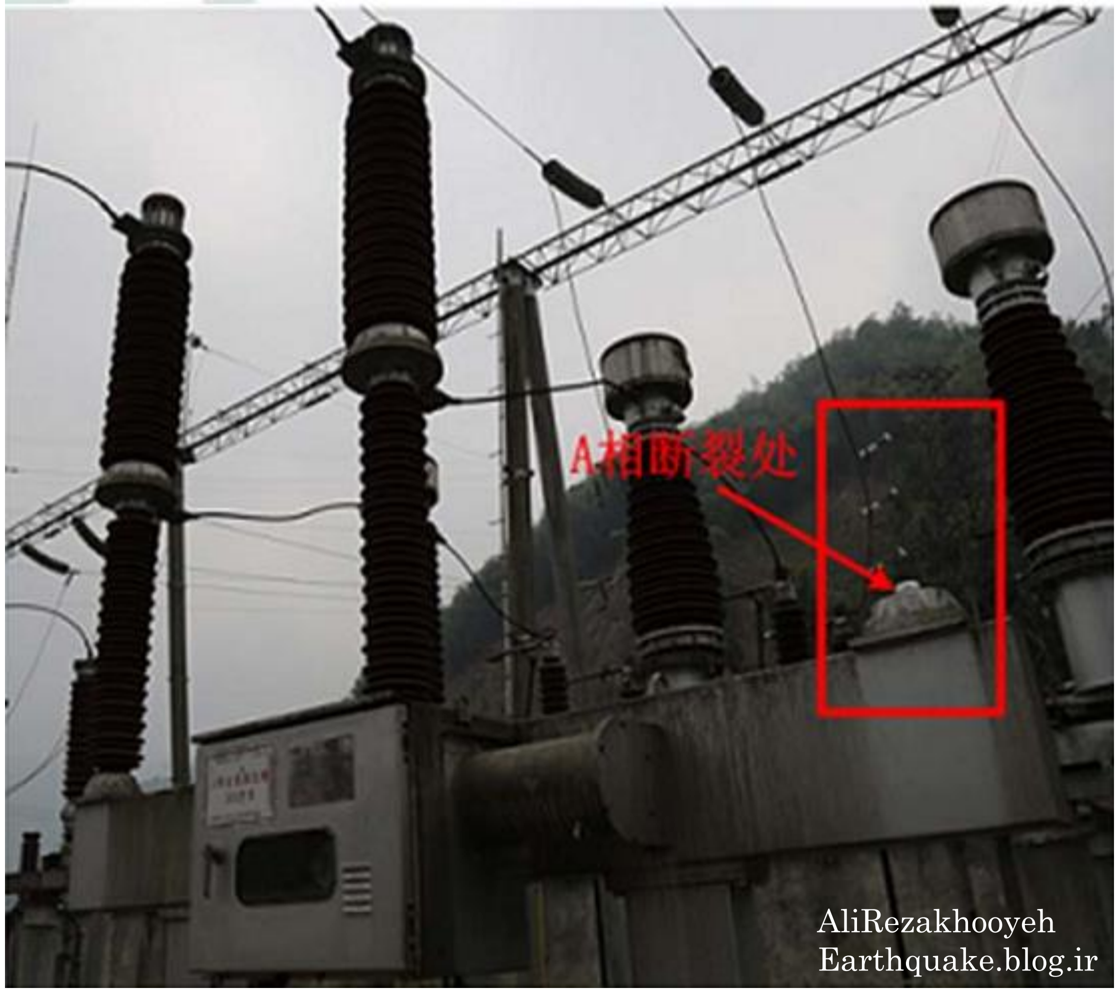
Loosening of 35kV Bushing Sealing



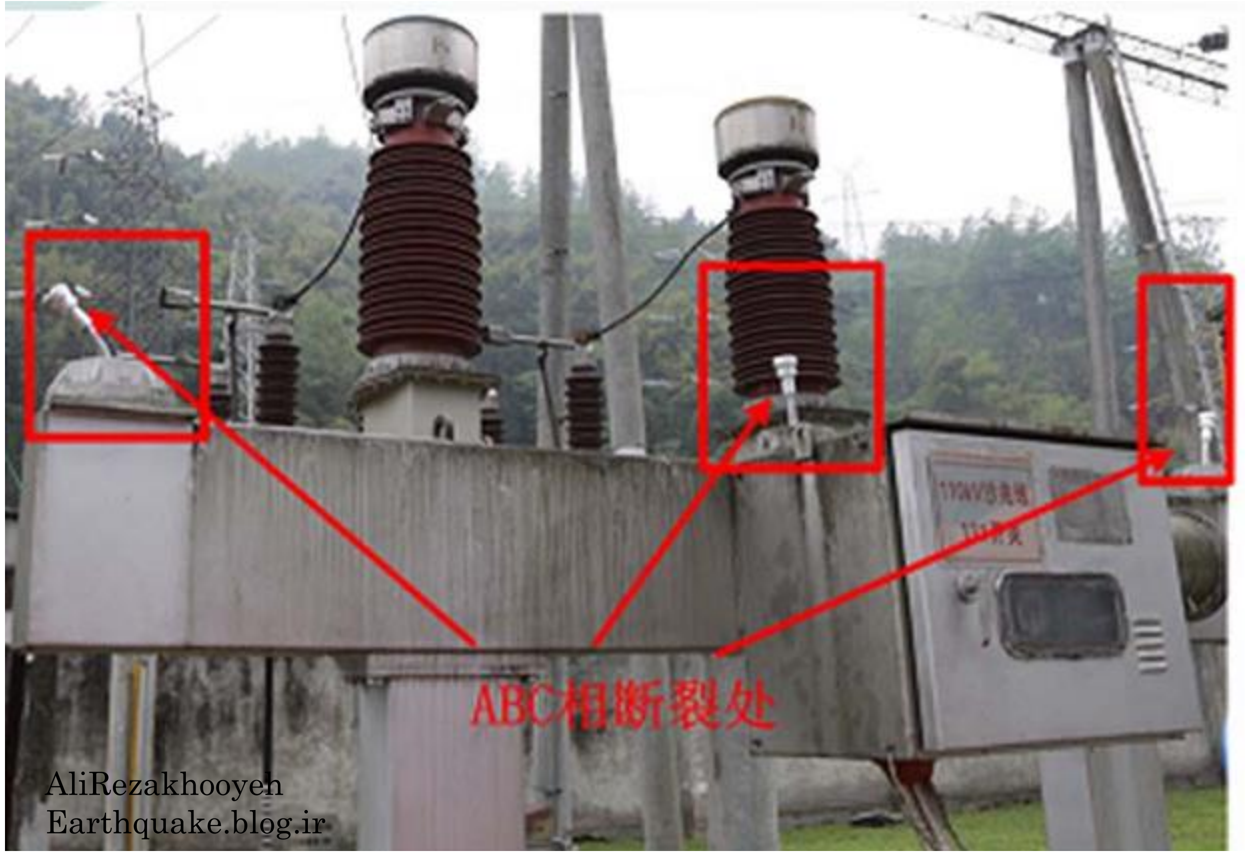
CT Collapse



Damage of Circuit Breakers



Damage of Circuit Breakers



Damage of Circuit Breakers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Crack of Tower Base and Slope Protection


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Transmission and Distribution Lines and Support Structures

- Damage to transmission-line towers and distribution-line support structures has primarily been associated with soil and foundation failures rather than with structural failure. When possible, transmission-line towers should be positioned back from steep slopes. The design of transmission-tower foundations located on ridges and at the edge of steep slopes should be conservative. The design of transmission-tower foundations near water, such as at river crossings, should consider liquefaction and **lateral spreading**.

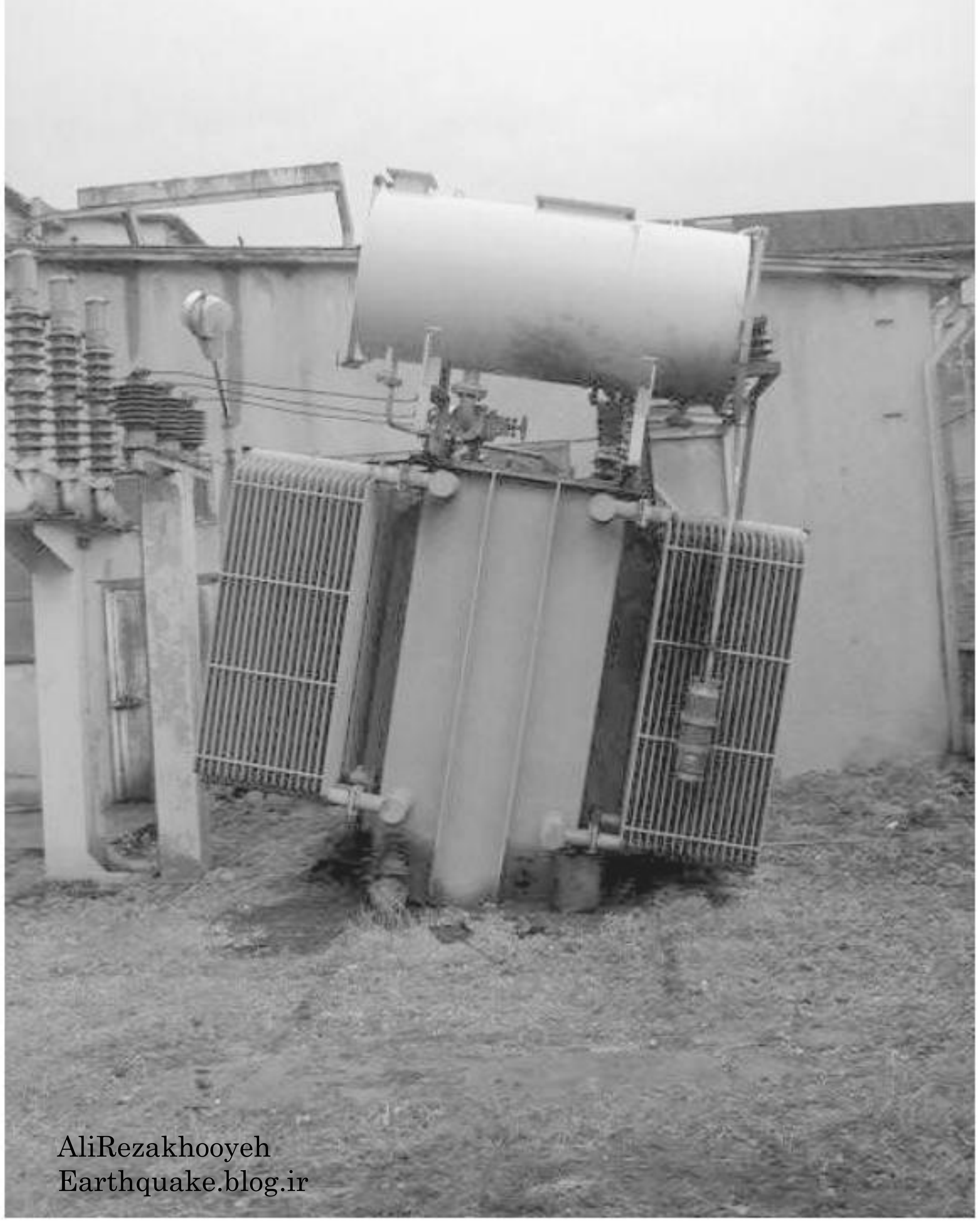
Rockfall-Impacted Tower, #123, Hongxue Line of Yingxiu Town

Collapsed 10 kV Distribution Pole (10 inch diameter, 2.5-inch wall thickness)

Fallen Distribution Transformer

FIGURE 25.2 Damage to switchyard equipment.

Damage to transformers due to inadequate anchorage.



Damage to a transformer at the SEKA paper mill was expected to shut down this unit for several weeks.

Collapse of unanchored cabinets at the Toprak Saglik facility.

Thank You
for your attention

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