Power Outages,
December 20 2022 M 6.4 Fortuna Earthquake

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71,236 Customers ~= 100% of PG&E electric customers in
Eureka, Arcata, McKinelyville, Samoa Peninsula, Fortuna, Rio Dell, Trinidad, plus some in Garberville / Ukiah and outlying areas

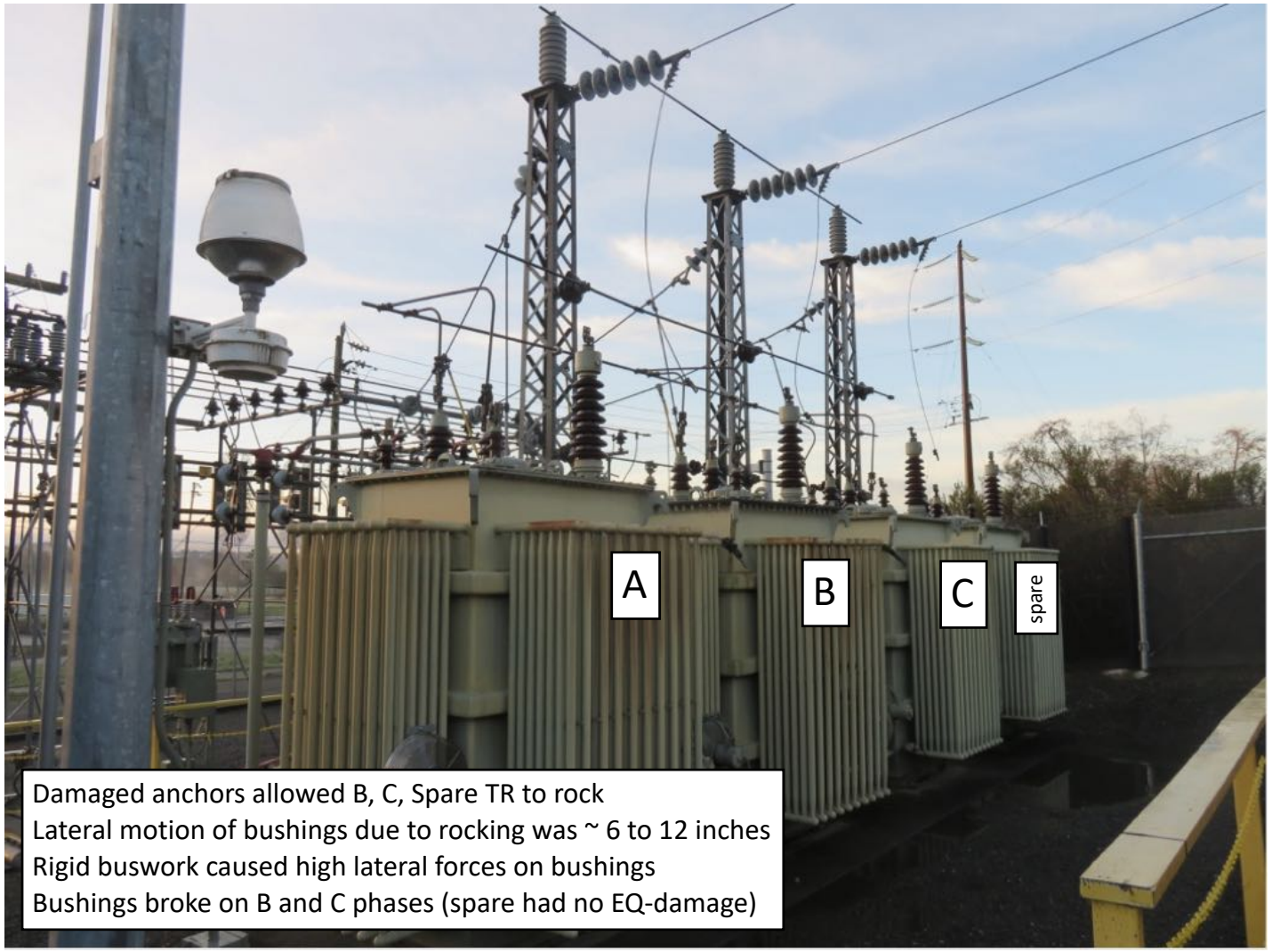
Area under red curve: ~ 79,000,000 Customer-Minutes

This is similar to outages that happen 2-5 times per year due to winter storms in Northern California

Power Outages

- What caused these power outages? (by CM percentage)
- 5%: 37 repairs on overhead 12 kV wire systems (wire down, cross arms, etc.). Dominant failure mode is broken copper wires due to wood pole swaying
- 95%: phase-to-phase and phase-to-ground faults due to wire swaying, in 12 kV, 60 kV and 115 kV systems (2 repairs on overhead 115 kV wire systems). 98% of these types of faults: no damage found by patrols.

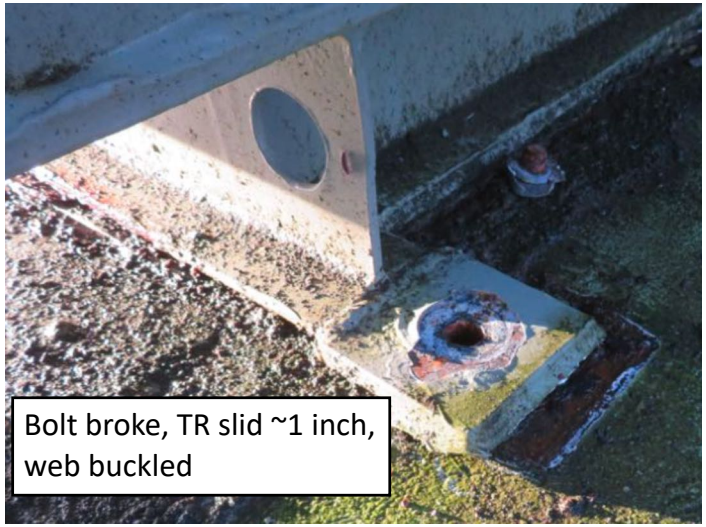
60 kV - 12 kV Transformers (TR). B, C, Spare had failed anchorage.
PGA (median) = 0.50g (attenuation based).
PGA (range) = 0.32g to 0.77g; 16th to 84th.
These transformers were installed in 1949.
1949-era anchorage design V =~ 0.25W.

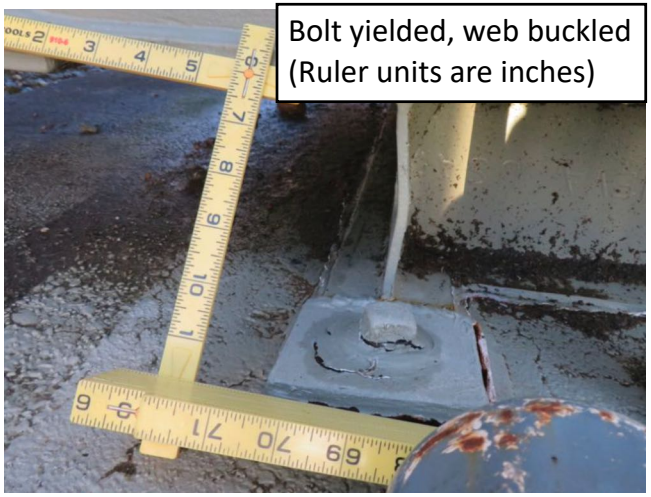


Damaged anchors allowed B, C, Spare TR to rock
Lateral motion of bushings due to rocking was ~ 6 to 12 inches
Rigid buswork caused high lateral forces on bushings
Bushings broke on B and C phases (spare had no EQ-damage)

Modern (IEEE 693 1997 and later) anchorage design is V ~1.0W (elastic).
No modern designs failed at 18 substations with 0.10g ≤ PGA ≤ 0.50g.
Adjacent transformer bank had no damage, and carried all the load.
Due to redundancy, this damage caused zero power outages.


Bolt stretched, plate pried, web buckled


Bolt broke, TR slid ~1 inch, web buckled


Bolt yielded, web buckled (Ruler units are inches)

NOTICE TO CALIFORNIA, OREGON, WASHINGTON, UTAH, ALASKA POWER UTILITIES

SOME OF YOU MAY STILL HAVE WEAKLY-ANCHORED OR UNANCHORED TRANSFORMERS. GET THESE UPGRADED!

Key findings

- Primary cause of widespread outages was wire swaying in 60 kV to 115 kV overheads.
- Primary cause of local outages was wire swaying in 12 kV overheads.
- Duration of outages primarily reflects time needed to do patrols. Most (not all) patrols found no damage.
- 79 million CM outage was like a big winter storm.
- Biggest seismic power outage in PG&E system since 1989 Loma Prieta (~1 billion CM)

Key findings

- IEEE 693 design (post 1997): zero damage to any substation component in this earthquake. Design anchorage elastically for PGA ≥ 0.50g. 100% SUCCESS
- Transformer Anchorage. V = 0.25W is not good enough.
- Unanchored transformers is sub-standard.
- I = 1.0 or I = 1.5 design at power plants (475 or 2,475 year design): makes no difference in outages or restoration of power in this earthquake, or >25 other California earthquakes since 1952.