Anderson Springs Community Alliance

A Summary of Research & Findings Concerning

LOCATION & IMPACT OF GEOTHERMAL EARTHQUAKES AFFECTING RESIDENTS OF ANDERSON SPRINGS

227 Resident Experiences of 192 Earthquakes over 3 Years
1,245 Earthquakes with Strong Ground Motion Data over 18 Months

Analysis & mapping of the aforementioned data resulted in three sets of plots, each of which is notated with the location of all active geothermal powerplants, USGS center-points for the communities of Anderson Springs & Cobb, and location of the strong ground motion station in each community. Each map also designates in light green the approximate residential areas of each community, with subsequent pages of each plot displaying the same data at greater resolution relative to the Anderson Springs' area (data for all plots has been limited to observations from Anderson Springs' residents and recordings from its strong ground motion station).

PLOT I: 192 earthquakes personally experienced by Jeff Gospe, his family, and a couple of other residents of Anderson Springs over 3 years (from December 2001 through December 2004):

- This plot includes all events reported by these residents for which USGS records could be found.
- This dataset only represents a random sampling of seismic events and falls far short of the number of earthquakes actually experienced by residents in Anderson Springs, given the small number of residents who participated, their limited time in Anderson Springs, and other challenges with logging frequent earthquakes.

PLOT II: 156 earthquakes categorized by magnitude & level of nuisance/potential for property damage, a subset of the 192 earthquakes of Plot I, for which there was sufficient resident comments to estimate type of impact:

- 23 earthquakes (15%) where resident experiences indicated a likely potential for individual events to cause damage (i.e., earthquakes that were felt very strongly with objects broken/moved).
- 55 earthquakes (35%) where resident experiences indicated a likely potential for events to cause damage cumulatively over time (i.e., earthquakes that were felt very sharply/strongly, but without objects being broken/moved).
- 78 earthquakes (50%) where resident experiences indicated a nuisance without the potential for property damage (i.e., earthquakes that woke, scared, annoyed, or otherwise bothered people who felt them).

PLOT III-A: 1,245 earthquakes categorized by magnitude and severity of impact on residents, based on peak ground acceleration (PGA) data that registered on the strong ground motion station in Anderson Springs over an 18-month period (from July 2003 through December 2004):

- 6 earthquakes (0.5%) where peak ground acceleration was $\geq$ 10.0%g and $<$ 25.0%g.
- 13 earthquakes (1.0%) where peak ground acceleration was $\geq$ 5.0%g and $<$ 10.0%g.
- 33 earthquakes (2.7%) where peak ground acceleration was $\geq$ 2.5%g and $<$ 5.0%g.
- 1,193 earthquakes (95.8%) where peak ground acceleration was $<$ 2.5%g.

PLOT III-B: 52 earthquakes categorized by magnitude and severity of impact on residents, based on PGA data, a subset (4.2%) of the 1,245 earthquakes of Plot III-A where peak ground acceleration was $\geq$ 2.5%g.

1. Key observations relative to Plot I:

   - Earthquakes felt by residents in Anderson Springs occur throughout The Geysers Geothermal Field, averaging M2.28 with around 2/3 of these events being outside the Southeast Geysers Quadrangle.

   - While it is generally true that events in the M1.0s are felt more frequently in Anderson Springs when epicentered closer to Anderson Springs, a surprising number of M1.0s throughout the field can be felt, at distances of up to 8 miles (likely due to other factors such as directionality of seismic waves and site conditions in Anderson Springs).

   - M1.0s made up 39% of all events felt in Anderson Springs, averaging M1.64 and being felt as small as M1.07. Of course, the disproportionately low number of M1.0s felt in Anderson Springs (relative to their frequency of occurrence) means that a significant number of M1.0s are not felt, especially when epicentered more than a few miles from Anderson Springs.

   - M2.0s represented about 45% of all earthquakes felt in Anderson Springs, and were evenly distributed throughout The Geysers Geothermal Field, felt from as far away as 8 miles.

   - M3.0s and larger events made up about 17% of all felt events in Anderson Springs, though most were outside the Southeast Geysers Quadrangle and the greatest number were in the northeast portion of The Geysers Geothermal Field.

2. Key observations relative to Plot II:

   - 78 earthquakes with the potential to cause damage in Anderson Springs occurred throughout The Geysers Geothermal Field and averaged M2.60, with about ½ of these events being outside the Southeast Geysers Quadrangle.

   - While M3.0 or larger magnitude earthquakes were identified as having the most likely potential to cause property damage from an individual event, a surprisingly large number of M2.0s were similarly classified (including one epicentered more than 6 miles from Anderson Springs), as well as a M1.69 event located 2 miles away. M2.0s capable of individually causing damage were most frequently located 1-2 miles from Anderson Springs, whereas similar M3.0s were much further away and located throughout the field.

   - M2.0s were most frequently identified as having the potential cumulatively to cause property damage (epicentered from as far as 7 miles), as were a smaller number of M3.0s and M1.0s with about equal frequency.

   - The remaining earthquakes were classified solely as a nuisance, located throughout The Geysers Geothermal Field (from as far as 8 miles).

   - Most earthquakes are clustered near virtually all active geothermal powerplants throughout The Geysers field, without any single powerplant appearing to be the main culprit (though Calpine Units 13 & 16, and NCPA Units 1 & 2 are responsible for most seismicity closest to Anderson Springs).

3. Key observations relative to Plots III-A and III-B:

   - When impact of earthquakes on Anderson Springs is estimated solely based on peak ground acceleration, a slightly different picture emerges (than the one described above based on actual resident observations of earthquakes they have experienced).

   - These differences might be explained by varying site conditions in Anderson Springs for residents reporting earthquakes (relative to the single location of the strong ground motion station), as well as the many factors influencing human experiences of earthquakes (difficult to measure by peak horizontal acceleration alone—e.g., earthquake & structural sounds, directionality, type & duration of shaking).

3. Key observations relative to Plots III-A and III-B, continued:

   - Plots III-A & III-B clearly demonstrate that proximity of earthquakes to Anderson Springs is the main factor in peak ground accelerations (PGAs) generated from these earthquakes:

     - All six events with PGA ≥ 10.0%g were located 2 miles or less from the strong ground motion station, though surprisingly these six strongest events were split evenly between M2.0s and M3.0+ events.

     - Unlike the strongest six events, the thirteen earthquakes with PGA ≥ 5.0%g and < 10.0%g had a much wider distribution in The Geysers field with the following trend: events close to Anderson Springs were relatively small magnitude events (seven M2.0s and one M1.72—no M3.0s), whereas the more distant events had larger magnitudes (four M3.0+ events and one M2.85 event).

   - The 33 earthquakes with PGA ≥ 2.5%g and < 5.0%g were also distributed widely throughout The Geysers field and followed a similar trend: events close to Anderson Springs were small magnitude events (half were M2.0s and half were M1.0s—no M3.0s), compared to more distant events being comprised of six M3.0+ events, five M2.0s, and one M1.02 event).

   - The 1,193 earthquakes with PGA < 2.5%g were distributed throughout The Geysers field with a clear trend: in the Southeast Geysers virtually all such events were M1.0s (with only a handful being M2.0s and no M3.0s), whereas the farther north one heads (away from Anderson Springs) magnitudes shifted increasingly from M1.0s to predominantly M2.0s, with a few M3.0s in the far north.

   - A number of M1.0s were actually epicentered within the community of Anderson Springs, and scores of earthquakes were located within 1 mile of the strong ground motion station (dozens of M1.0s and eleven M2.0s).

4. Analysis of resident observations of the 80+ geothermal earthquakes for which strong ground motion data is available demonstrates that Anderson Springs' residents experience these earthquakes at unexpectedly low rates of ground acceleration, likely due these events' shallow depth, close proximity, and local site conditions:

   - Residents feel earthquakes generating PGA as low as 0.10%g (and as high as 23.6%g).

   - Average PGA for these felt earthquakes is 2.72%g, with median PGA of 1.77%g.

   - A third of these earthquakes produce PGAs < 1.0%g; another third have PGAs ≥ 1.0%g and < 2.0%g; and the final third generate PGAs ≥ 2.0%g.

5. There is wide variability in PGAs experienced at varying magnitudes, as well as unexpectedly high PGAs for events of small magnitudes recorded in Anderson Springs:

   - PGA for events between M2.00 and M2.99 have been as high as 13.5%g.

   - PGA for events between M1.00 and M1.99 have been as high as 5.3%g.

   - PGA for events under M1.00 have been as high as 0.63%g.

It is sincerely hoped that these findings will assist geothermal operators and their municipal partners in better understanding the impact of earthquakes on the communities of Anderson Springs & Cobb, so proper mitigations can be undertaken to minimize damaging seismicity induced from their operations.

Respectfully submitted,

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Anderson Springs Community Alliance