Engineering and Geological Effects of the July 2019 Ridgecrest Earthquake Sequence

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On behalf of the Geotechnical Extreme Events Reconnaissance (GEER) Association

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Abstract

The Ridgecrest Earthquake sequence included a foreshock event on July 4, 2019 (**M**6.4) and a **M**7.1 mainshock event on July 5, 2019. These events occurred in the Eastern California Shear Zone, near Indian Wells Valley, south of China Lake and west of Searles Valley. GEER has partnered with several organizations to collect perishable data and document the important impacts of these events, including the US Geological Survey, the California Geological Survey, the US Navy, the Southern California Earthquake Center, and local utilities. Critical geotechnical features of this event are extensive left-lateral (**M**6.4 event) and right-lateral (**M**7.1 event) surface ruptures over fault segments of variable complexity and width as well as across extensional and compressive step-over zones. We also document lifeline performance at fault crossings (gas, water, electrical), mainshock slip and afterslip, liquefaction and lateral spreading features, and liquefaction effects on structures. These effects are documented using field (ground) mapping and aerial imagery that will support subsequent development of high-resolution digital elevation models. Over 1200 ground motions were recorded from the foreshock and mainshock alone, with many additional aftershock records. The data demonstrate significant impacts of site response and rupture directivity on ground motion attributes. The report "Preliminary Report on Engineering and Geological Effects of the July 2019 Ridgecrest Earthquake Sequence" can be found here: www.geerassociation.org/component/geer_reports/?view=geerreports&id=91&layout=build.

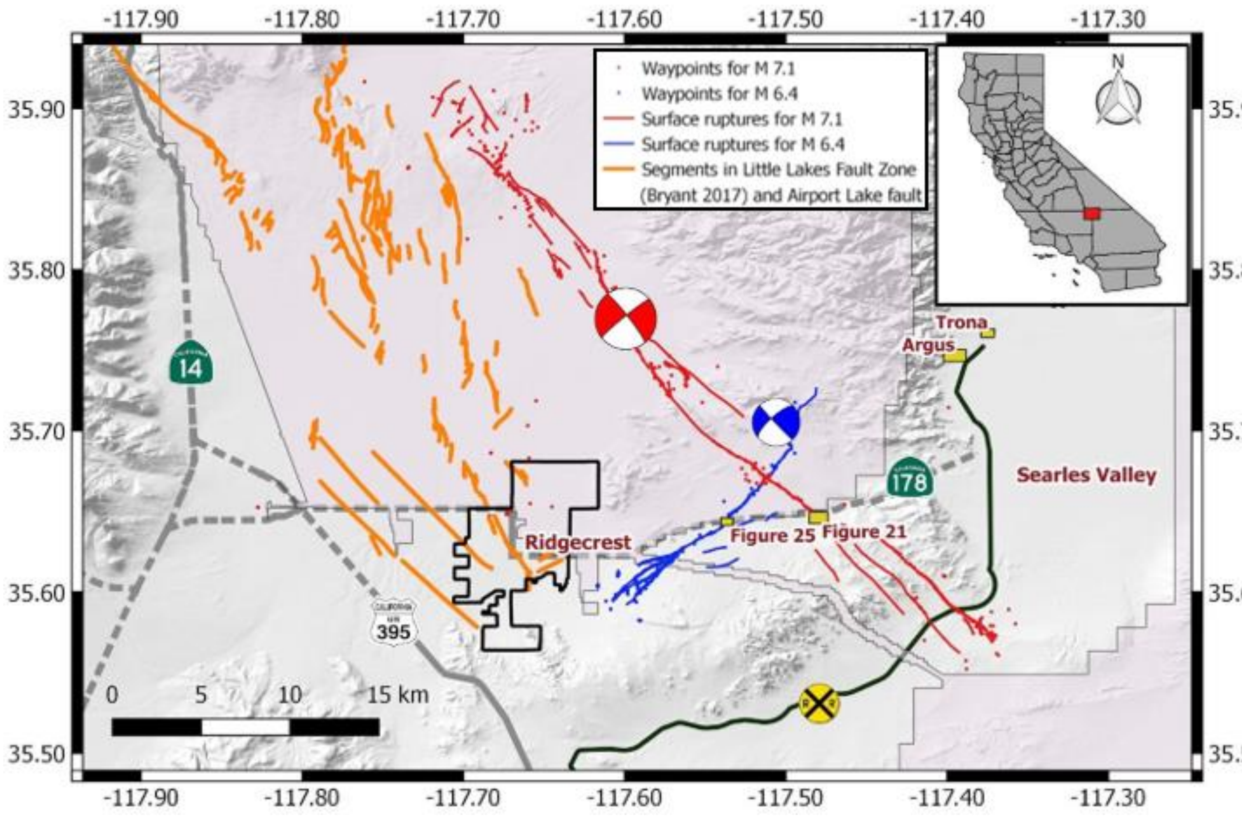
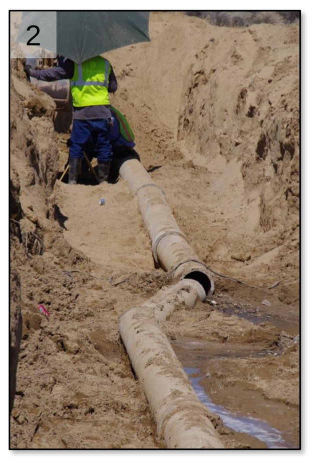
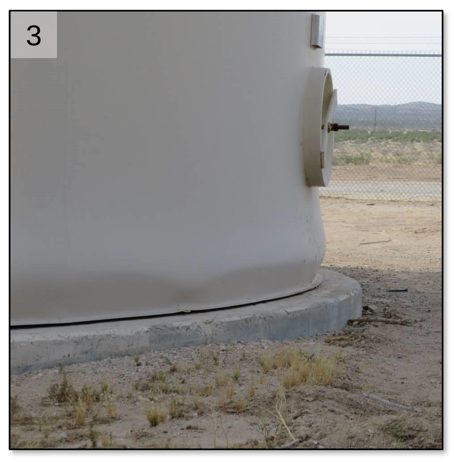


Figure 1. Provisional mapped surface ruptures and fault rupture observation waypoints of the **M**6.4 and **M**7.1 faults. Some of the waypoints may not be observations of fault rupture. The linear red and blue segments plotted on the map were constructed primarily based on ground observation locations, supplemented by interpretation of satellite interferometry correlation images from NASA's ARIA project to provide guidance for drawing the linework between widely spaced observations or where faulting is inferred from the interferometry but not field verified. Developed areas affected by earthquakes are indicated (Ridgecrest, China Lake Naval Air Weapons Station, Trona).

Lifeline Performance

- Highways & Roads: CA-178 damaged by surface fault rupture up to 1 m; pavement in Trona damaged by lateral spreading; no damage to bridges
- Railroads: right-lateral displacement of tracks near Trona Pinnacles
- Water Systems: multiple supply line breaks from fault rupture (Figure 2), and water tank developed elephant's foot bulge (Figure 3).
- Natural Gas: Surface rupture from both events offset two PG&E gas transmission lines. No ruptures or leaks found; deformed sections were replaced (Figure 4).
- Electric Power: SoCal Edison outages affected tens of thousands of people.





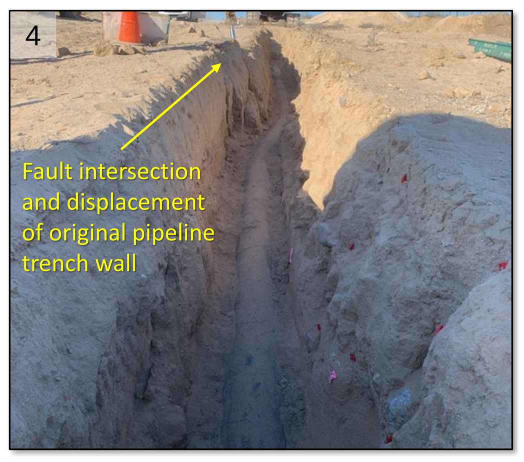


Figure 2. Offset of buried concrete segmented water pipeline of Searles Domestic Water Company (SDWC) crossing the **M**7.1 surface fault rupture. **Figure 3.** SDWC Hilltop Tank elephant foot buckle. **Figure 4.** 10.75" steel natural gas transmission line L311 deformed right-laterally by the **M**7.1 event (PG&E, Bachhuber & Madugo).

Surface Fault Rupture

- Summary: Both the **M**6.4 and **M**7.1 events produced substantial surface rupture. The **M**6.4 event ruptured the NE-trending left-lateral cross fault 9.5 km but evidently (on the surface) not the main NW-trending right-lateral fault. The **M**7.1 event then ruptured the NW-trending main fault 50 km.
- Within NAWSCL, ground mapping and helicopter overflights were conducted primarily by the USGS and CGS, escorted by US Naval personnel. South of the base, GEER performed detailed fault mapping and UAV flights.
- **M**6.4 Event: Aerial reconnaissance was conducted over the entire cross-fault rupture, using overlapping stereo photographs (see Hudnut et al., Poster #224) and GPS waypoints, with detailed mapping of ground disturbance.
- **M**7.1 Event: Surface rupture extent (red lines in Figure 1) mapped within NAWSCL, width varied from few meters in bedrock outcrops to over 300 m in thick soil deposits. Figure 5 shows fault crossing an access road within NAWSCL. Figure 6 shows ~4 m right-lateral offset. Features include left-stepping en-echelon fractures, fissures, and moletrack scarps.

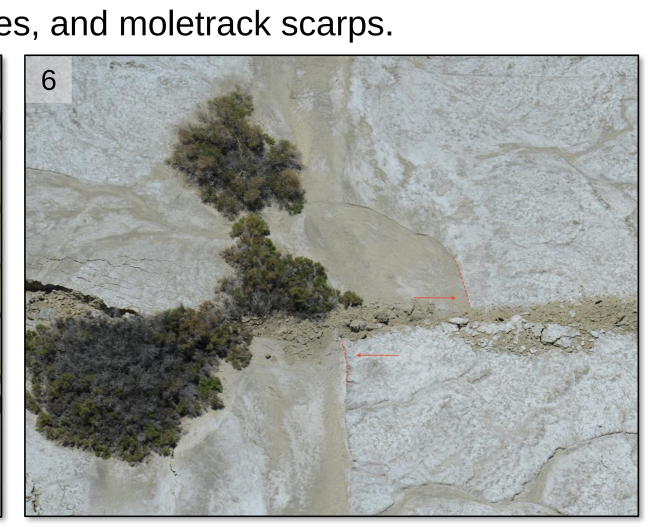


Figure 5. Helicopter overflight viewing access road offset ~2.5 m of right-laterally primary rupture associated with **M**7.1 event. **Figure 6.** Low-altitude (60 m) helicopter photo showing right-lateral offset of incised channel margin (red dashed line) within dry China Lake bed surface (red arrows indicate sense of slip; approximately 4 m). Correction from Report GEER-064 V2 per Kendrick et al. (Poster #217).

Liquefaction and Related Ground Failure

Mapping in regions with and without ground failure in Trona & Argus (Figure 7).

- Liquefaction: features along margin of Searles Lake in Trona and Argus, including sand boils (Figure 8)
- Lateral spreading: extension and compression features observed (Figure 9)

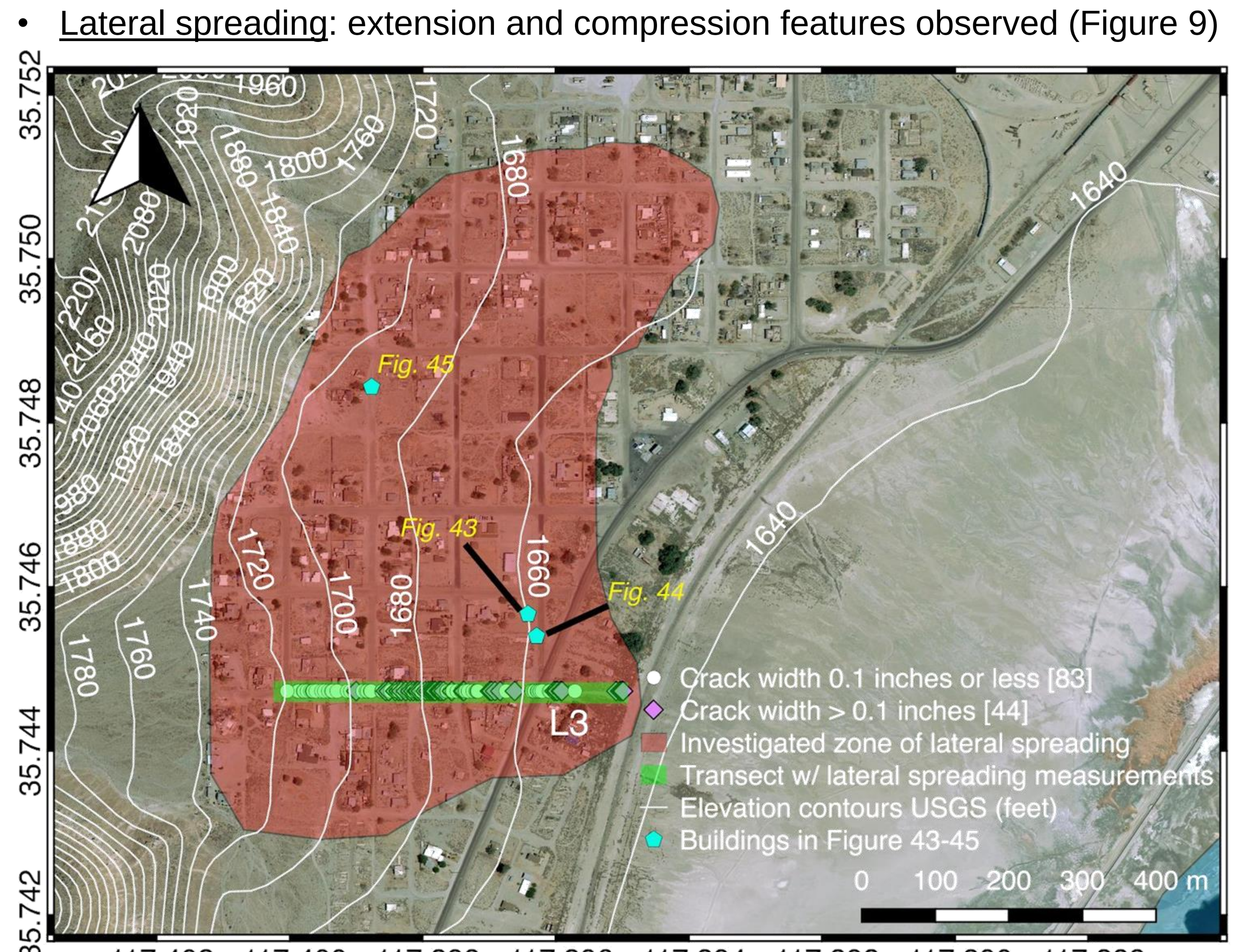


Figure 7. Map of Argus showing region investigated by the GEER team. Lateral spreading features, including tensile cracks and compressional features, were observed throughout the investigated zone. Lateral spread cracks were measured along a transect on A Street, a total of 56 cm over 450 m.

Figure 8. Sand boil near margin of Searles Lake in Trona. **Figure 9.** Ground compression, including buckled curb and asphalt pavement, due to liquefaction-induced lateral spreading in Trona.

Structural Performance

- Wood-frame Structures: generally good performance despite strong shaking near design ground motion levels in ASCE 7
- Mobile Homes: significant damage after both events – falling from supports
- Ridgecrest Regional Hospital: no observable structural damage, mostly nonstructural (pipes, sprinklers, partition walls); shut down after **M**6.4 event
- Masonry: walls and chimneys collapsed, cracked horizontally/vertically
- Higher rates of damage in older buildings in liquefied vs non-liquefied ground

Figure 10. Mobile home tilting due to falling from foundation support. **Figure 11.** Residential masonry wall partial collapse after **M**7.1 event. **Figures 12 and 13.** Nonstructural damage to Ridgecrest Regional Hospital.

Figure 14. Example of more heavily damaged structure in vicinity of liquefaction-induced ground cracking (upon alluvial fan deposits – see canyon visible behind structure).

Figure 15. Esparza Restaurant building in Trona that exhibited cracked walls, (**A**) After the **M**6.4 earthquake and before the **M**7.1, and (**B**) after the **M**7.1 earthquake. Following the **M**7.1 earthquake, the horizontal and vertical cracks widened, the roof showed damage and a sand boil appeared at the base of the crack shown in the photo.

Other Results

Analysis of strong ground motion recordings and comparison with ground motion models is included in a companion presentation (Poster #248). Additional work covered in the scope of the GEER report include aerial imaging from unmanned aerial vehicles (UAVs, i.e. drones), airborne and terrestrial LiDAR, and development of structure-from-motion models. Related work on fragile geological features and analysis of liquefaction-related features is ongoing. The GEER team utilized the DesignSafe cyberinfrastructure (Rathje et al. 2017) to store photos and GPS track logs, and the HazMapper app to visualize the reconnaissance outcomes. GeoJSON files were created using HazMapper and saved in the following publicly accessible directory: Community Data/Recon Portal/2019 Ridgecrest, CA Earthquake. Ongoing work includes creating variable-resolution digital elevation models from aerial imagery. Geotechnical characterization of liquefaction/non-liquefaction sites is planned. Site characterization of ground motion stations is likely.

SCEC AN NSF+USGS CENTER — NSF — USGS science for a changing world — CGS California Geological Survey — PG&E — JPL Jet Propulsion Laboratory California Institute of Technology

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