Nevada Bureau of Mines and Geology Special Publication 39

THE 15 MAY 2020 M_w6.5 MONTE CRISTO RANGE, NEVADA EARTHQUAKE:

Assessments of Emergency Response, Geological Effects, and Societal Impacts

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Special Publication 39

The 15 May 2020 M_w6.5 Monte Cristo Range, Nevada Earthquake:

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Preface to the Special Publication on the 2020 M_w6.5 Monte Cristo Range Earthquake, central Walker Lane, Nevada

by

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PREFACE

On 15 May 2020 the M_w6.5 Monte Cristo Range earthquake occurred in a sparsely populated area of western Nevada near Columbus Salt Marsh, about 55 km west-northwest of Tonopah, Nevada. The earthquake occurred within the central Walker Lane tectonic province, an area characterized by numerous active faults that exhibit tectonic geomorphic evidence of latest Pleistocene and Holocene activity (c.f., Wesnousky, 2005). Although historical strong earthquakes in the region (e.g. 1934 M6.3 Excelsior Mountains; 1932 M7.2 Cedar Mountain) and seismic swarms (e.g., 1 April to 31, July 2020 Mono Lake swarm) indicate ongoing seismic activity, the earthquake was the largest to occur in Nevada in 66 years. Due to its remote location, human injuries were minor and there were no reported deaths. However, the region did not escape societal and economic impacts including power outages, non-structural damage to buildings in local communities, particularly in Tonopah, and damage to U.S. Highway 95 that resulted in temporary closure, rerouting of traffic, and over $6M in repair costs (NDOT, 2020).

The earthquake was the result of left-lateral slip along largely unmapped parts of the Candelaria fault, one of a series of east–northeast-striking faults that comprise the Mina deflection, a major right step in the north–northwest structural grain of the central Walker Lane. Coseismic surface rupture was broadly distributed across a 28-km-long east–northeast-trending zone, up to 2.5–5 km wide (Koehler et al., 2021; Dee et al., 2021). Left-lateral displacements up to 20 cm and right-lateral displacements up to 5 cm occurred along northeast- and north-striking faults, respectively (Koehler et al., 2021; Dee et al., 2021). Geodetic observations indicate bilateral rupture with an average of ~1 m of slip on the main fault plane at depth and more distributed deformation near the surface consistent with field observations (Hammond et al., 2020). Aftershocks of M2 and greater averaged more than ~50 per day during the week after the mainshock (Wesnousky, 2021), and temporary seismic stations deployed by the Nevada Seismological Laboratory recorded three aftershocks ML ≥ 5 and 25 ML 4–4.9 events in the subsequent four months (Bormann et al., 2021).

Scientific observations and technical details of the Monte Cristo Range earthquake gleaned from post-earthquake investigations and analyses of seismologic, geodetic, and geophysical data resulted in numerous publications. Many of these articles were assembled into a Focus Section in Seismological Research Letters (SRL) (Gold et al. (2021), which also included papers on other 2020 Intermountain West earthquakes (the M_w5.7 Magna Utah, the M_w6.5 Stanley Idaho, and the M_w5.8 Lone Pine California). Articles related to the Monte Cristo Range earthquake in the SRL Focus Section include contributions by Bormann et al. (2021), Crowell (2021), Hammond et al. (2020), Koehler et al. (2021), Ruhl et al. (2021), and Wesnousky, (2021). The complexity of the Monte Cristo surface rupture was documented in a 1:14,000-scale surface rupture map, explanatory report, and geospatial rupture dataset published by the Nevada Bureau of Mines and Geology (NBMG) (Dee et al., 2021). Additionally, the Geotechnical Extreme Events Reconnaissance Association (GEER) documented ground failure patterns related to liquefaction-induced lateral spreads, settlements, and sand boils and assessed liquefaction triggering thresholds based on shear wave velocity profiles (Motamed et al., 2021). Expanding on these prior works, this NBMG special publication presents four papers of societal relevance that focus on emergency response, photo documentation of the earthquake damage, impacts on local open-pit mines and other geological features, and public preparedness and awareness in the region.

The paper by dePolo (2023) reports on the immediate emergency response to the earthquake in the early morning

hours of May 15th, including the agencies involved with particular focus on the damage and mitigation of impacts to U.S. Highway 95 and the timing of road closures. A south bound vehicle struck a 13-cm-high north-facing vertical scarp extending across the road, resulting in two blown tires, but luckily no injuries. Rapid coordination between the Esmeralda County Sheriff's Office and the Nevada Department of Transportation (NDOT) resulted in mobilization of assessment teams to the area, closure of the highway, and establishment of an alternate route. These operations initiated within 1.3 hours of the earthquake, impressive given the remote location of the road damage, and prevented additional road travel incidents. Additional communication and coordination were established between the Nevada Department of Emergency Management (NDEM) and the Mineral, Nye, and Esmeralda counties emergency management, public works, school district, and sheriff offices to conduct inspections for damage and injuries. Although damage was relatively minor throughout the region, these efforts were essential in returning the communities to normal functionality.

dePolo and De Masi (2023) describes the near and far field felt reports, damage to U.S. Highways 95 and 6, and Nevada State Route 360, non-structural damage to buildings in Tonopah and a structure on the north side of Columbus Salt Marsh, and a radio tower foundation pad close to the epicenter. Non-structural damage to buildings was generally limited to cracked masonry walls and door frames, broken windows, and other ground shaking related damage. Photo documentation of damaged buildings as well as fractures and settlement features along the affected highways provide an archive of features that are likely to be repaired and/or removed by erosion. In particular, annotated drone images of the ground settlement that affected U.S. Highway 95 shows the aerial extent of deformation there.

Continuing with the theme of damage and shaking effects, Price et al. (2023) describe observations from open-pit mines and fragile geologic features in the vicinity of the 2020 earthquake. They document shaking-related rockfall from the highwalls of the Candelaria Mine (21 km west of epicenter) and rockfall, slumping, and cracking of the pit, leach pad, and tailings piles at the McLean Mine (12 km east of epicenter). Rockfall was not observed in other mines located 21–50 km from the epicenter. These observations suggest that the occurrence of rockfall in open-pit mines is only partially dependent on attenuation of ground motions with distance from the epicenter, but that local existing site conditions (slopes) may play an important role. This highlights the need for increased awareness and mine safety planning with respect to earthquake-generated rockfall hazards. Price et al. (2023) also revisited fragile geologic features preserved in tuffaceous sedimentary rocks in the Monte Cristo Castle area 13 km south-southeast of the epicenter that were originally photographed in 2006 and noted no apparent changes to the precarious formations in 2020. The distance from the epicenter and relative preservation of these features has implications for future strong ground motion studies.

Finally, dePolo and dePolo (2023) present a synopsis of earthquake risk reduction engagement, awareness, and preparedness in the three counties affected by the earthquake including Esmeralda, Mineral, and Nye counties. They report that county public participation in the Great Nevada ShakeOut ranged from 0% to 15% and attribute this lack of engagement to poor internet access and ineffective communication. This suggests that other means of communicating earthquake risk reduction may be more effective, such as specific outreach programs to advertise the ShakeOut and provide mitigation information. A public survey, the Mineral County Community Assessment for Public Health Emergency Response (CASPER) suggests that 86.9% of households surveyed had some level of emergency preparedness and recognized the reality of earthquake hazards. Although county mitigation plans for earthquake risk reduction focus on improving the resilience of critical facilities and inventorying unreinforced masonry buildings, progress in public awareness, preparation, and mitigation of earthquake hazards in rural communities is inhibited by the lack of direct outreach, financial thresholds, and in some cases lack of internet access.

SUMMARY

The papers in this Special Publication on the 2020 M_w6.5 Monte Cristo Range earthquake, the largest seismic event in Nevada in 66 years, focus on social and economic topics related to the emergency response, damage assessment and documentation, and public awareness and preparedness for earthquake hazards [in the affected region] of a rural event. [It is the hope of the editor that] This collection of papers will help to inform federal, state, and local emergency management personnel in ongoing efforts aimed at improving societies resilience to future damaging events. In particular, the papers provide baseline information to better understand earthquake response and recovery coordination, as well as the types and extent of damage to infrastructure and natural geologic effects, with potential applications to future ground motion studies. Although the effects of the earthquake were relatively minor, it serves as a reminder of the earthquake hazard and risk in the central Walker Lane, and will inform preparedness efforts in other more populated areas of Nevada and elsewhere.

ACKNOWLEDGMENTS

The editor thanks the authors of the four papers included in this special publication on the 2020 M_w6.5 Monte Cristo earthquake. The Nevada Division of Transportation (NDOT) and Nevada Division of Emergency Management (NDEM) were particularly helpful in providing reports and interviews on the earthquake effects. Additional thanks is extended to the reviewers whose insightful comments improved the content of the papers. NBMG cartographic staff including Jennifer Vlcan and Christina Clack were instrumental in coordinating and communicating the reviews with the authors, producing the publication, and archiving it with web accessibility. Funding to produce this special publication was provided by the Nevada Division of Emergency Management and the Federal Emergency Management Agency.

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NEVADA BUREAU OF MINES AND GEOLOGY SPECIAL PUBLICATION 39

Emergency Response to the 2020 Monte Cristo Range, Nevada Earthquake

by

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ABSTRACT

The May 15, 2020 Monte Cristo Range earthquake occurred at 04:03 a.m. (PDT) in a sparsely populated area of Nevada. Several communities in three counties strongly felt the earthquake. Local emergency responders reacted to a report of highway damage and initiated reconnaissance to search for additional damage or any injuries. Although minor damage occurred in Tonopah, damage to Highway 95 was the only incident that required a response by the county sheriff offices. The highway damage occurred in a remote area of the county. Traffic control of the area occurred within 1.3 hours following the earthquake, and initial emergency repairs to the highway were completed within 10 hours of the event, reopening the highway. An emergency was declared by Nevada Governor Sisolak on May 21st, which was a prerequisite to receive financial aid from the Federal Highway Administration; the emergency funding was approved and managed by the Nevada Department of Transportation (NDOT). The three county governments inspected potentially impacted areas for any injuries, damage, or other effects. The Nevada Division of Emergency Management reached out to the counties to determine whether additional resources were needed, and none were requested.

INTRODUCTION

The 2020 Monte Cristo Range earthquake (M6.5) occurred in a sparsely inhabited frontier area of Nevada, with an epicenter located 12 km from the nearest building and 31 km from the nearest town. The earthquake occurred at 04:03 a.m. (PDT), well before sunrise, on May 15, 2020. Although widely felt, there was the usual early uncertainty of exactly where the earthquake occurred and what effects from the event needed attention. The control and mitigation of the damage to Highway 95 was the only impact needing an immediate emergency response, aside from canvassing communities and other highways for any additional damage or injuries.

The earthquake affected three counties (fig. 1). The epicenter was in Esmeralda County, about 12 km from the boundary with Mineral County and 34 km from Nye County. The nearest communities were Mina (31 km from the epicenter), northern Fish Lake Valley (44 km), Luning (45 km), Tonopah (57 km), Dyer (59 km), and in California, Benton (67 km). Of these, only Tonopah had minor damage to a building and isolated non-structural damage. There were no known injuries or deaths caused by the earthquake. Three county governments and two state agencies responded to the event. Due to the distance, businesses were largely uninterrupted by the earthquake, with exceptions of delivery delays caused by the detour around damage on Highway 95, which was in place for 6 hours and 35 minutes on May 15th.

This paper reviews the response to the Monte Cristo Range earthquake, and, in particular, to the damage of Highway 95. The most significant damage occurred about 37 km south of the town of Mina ("RD" on fig. 1). Table 1 lists primary agencies that responded to this earthquake. Much of Nevada is comprised of rural or frontier settings. Thus, documenting the emergency response following this remote earthquake may provide insight to other counties and similar settings within the state. In the course of this review, the responding agencies were contacted and several interviews were conducted via telephone calls or email exchanges.

Table 1. Primary Agencies that responded to the 2020 Monte Cristo Range earthquake

Esmeralda County Sheriff's Office
Nye County Sheriff's Office
Nye County Emergency Management
Mineral County Emergency Management
Mineral County Sheriff's Office
Nevada Highway Patrol
Nevada Department of Transportation (NDOT)
Nevada Division of Emergency Management (NDEM)

Figure 1. Location of the 2020 Monte Cristo Range earthquake (epicenter shown as red dot), nearby communities of Mina (M), Luning (L), Tonopah (T), and road damage (RD) on Highway 95. Blue lines are county boundaries.

RESPONSE TO DAMAGE ON U.S. HIGHWAY 95

U.S. Highway 95 is a major north-south transportation artery in Nevada. Thus, the 2020 Monte Cristo Range earthquake damaged one of the most important highways in the state, and emergency and permanent repairs to the highway were of the highest importance. The most prominent damage to Highway 95 occurred over a 5-km stretch of the road and was caused by lateral spreading related to liquefaction, settlement, and possibly lurching of the roadway. The highway damage is discussed further in dePolo and De Masi (this volume).

A timeline of the emergency response to the Highway 95 damage was constructed from the event logs and interviews with the responding agencies (table 2). Remarkably rapid communication and coordination occurred between these different agencies on the morning of the event. Many of the responders had distinctly felt the earthquake so there was a sense of anticipation and urgency to the response.

The earthquake occurred in the early morning hours on a Friday. Even though it was early, there commonly would be light traffic on Highway 95. It is likely that several vehicles, including semi-trucks, drove over the road damage before it was controlled. The most significant road damage occurred over a 5-km stretch of highway (figs. 2, 3, and 4). The largest vertical offset in the road (~13 cm) was north facing, creating a greater obstacle for vehicles traveling southbound than northbound (figs. 2 and 4). Vehicles traveling northbound would launch off the small scarp versus vehicles traveling south that would hit and bump over it. A sedan heading south hit the scarp and blew out two tires, stalled the engine of the car, and had to be towed away. This incident was called into Esmeralda County Sheriff's Office at 4:37 a.m., which dispatched an officer to control the area of the hazard and contacted the Tonopah District office of NDOT. The officer arrived at the damage at 5:20 a.m. and traffic was detoured around the damage on the west shoulder of the road (fig. 5) until 7:30 a.m., when U.S. Highway 6 and Nevada State Route 360 were used as detours around the damaged part of Highway 95 (fig. 6). NDOT equipment was brought in, temporary emergency repairs were completed by 14:05 in the afternoon, and Highway 95 was reopened (figs. 7 and 8). Roadblocks at the detours were manned by a number of agencies on May 15th, including the Nevada Highway Patrol, Esmeralda, Mineral, and Nye County sheriff's deputies, and NDOT. There appeared to be excellent coordination and cooperation between agencies, which made responding to this damage and controlling the situation effective.

The highway damage from the 2020 Monte Cristo Range earthquake offers a caution for emergency responders traveling to investigate and/or respond to earthquake effects. Unknown road damage can disable a vehicle and potentially cause fatalities when traveling at highway speeds. Emergency responders have lost their lives when encountering earthquake road damage (e.g., an officer died from driving off a collapsed bridge section of a freeway after the 1994 Northridge, California earthquake). Thus, although it is important for the response to address the emergency, additional caution is required in the earthquake area, especially around higher risk structures such as bridges.

Table 2. Timeline of emergency response to remote road damage – May 15, 2020

04:03	M6.5 Earthquake occurs producing strong shaking for about 10–15 seconds
04:??	Southbound sedan hits 13-cm-high scarp at highway speeds, blows out two tires, and stalls
04:37	Traffic Hazard Report to Esmeralda County Sheriff's Office
04:40	Esmeralda Co. Sheriff notifies Tonopah NDOT
05:20	Esmeralda Co. Sheriff's Deputy arrives and controls traffic around damaged area
05:36	NDOT Maintenance from Mina arrives and begins damage assessment
06:00	NDOT Maintenance Supervisor from Tonopah arrives
07:30	Highway 95 closed through damaged area and a detour route was established
08:00	NDOT equipment arrives and begins emergency repairs to road
14:00	NDOT temporary repairs completed
14:05	Highway reopened to traffic

Figure 2. (above left) Esmeralda County sheriff's deputy blocks the road damage and establishes a temporary detour for traffic. View to the south. Photograph by Tom Sawyer.

Figure 3. (above right) Vertical offset measurement of the east side of the scarplet in Highway 95. Maximum offset was approximately 13 cm. Photograph by Kenneth Siri, NDOT.

Figure 4. (left) View to the east of buckling and laterally offset road damage. Although less dramatic than the scarplet in the highway, this kind of damage occurred over a 5-km stretch of the highway. Photograph by Tom Sawyer.

Figure 5. (left) Semi-trucks driving around the road damage on the western shoulder of the road. Severe fracturing of the eastern shoulder of the road can be seen in the foreground. View to the south. The scarp in the road is the same scarp as shown in figures 2 and 3. Photograph by Tom Sawyer.

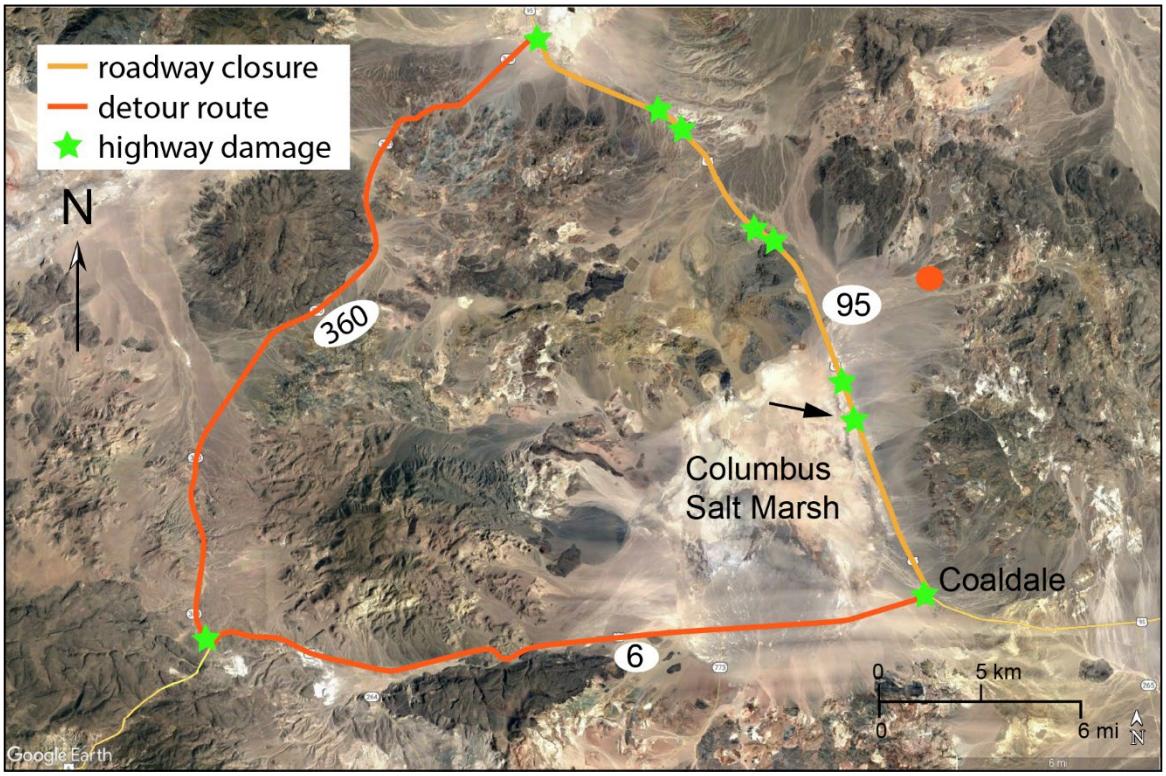

Figure 6. Detour route used to bypass the Highway 95 damage and the 2020 Monte Cristo Range earthquake epicenter (red dot). Road scarplet is located at the black arrow. The detour was about 19 km longer than traveling directly along Highway 95 and with lower speed limits resulting in several delivery and travel delays while it was in place. Figure modified from NDOT (2020).

Figure 7. NDOT work crew evaluating the ongoing temporary emergency repairs to Highway 95 at the largest vertical offset in the road. View to the southeast. Photograph by Craig dePolo.

Figure 8. Temporary repairs to Highway 95. The upper photograph (by Kenneth Siri, NDOT) shows the final grading of the repair (view to the southeast). The lower image is a drone photograph collected by Conni De Masi that shows the wedge of pavement fill to repair the vertical offset in the road (southeast is to the right and northeast is up).

GOVERNOR'S DECLARATION OF EMERGENCY FOR ROADWAY DAMAGE

On May 21, 2020, Governor Sisolak of Nevada declared a state of emergency due to the damage to the highway system from the Monte Cristo Range earthquake (fig. 9). The earthquake qualified as a "natural disaster of major proportions". An emergency declaration is one of the requirements to receive financial assistance for the road damage from the Federal Highway Administration. On August 17, 2020, the Nevada Department of Transportation completed its "Damage Survey Summary Report" and estimated the total for emergency and permanent repairs to the highways to be approximately $6 million, approximately split evenly between the two repairs (NDOT, 2020). For these emergency repairs, federal aid for the highway damage was almost 98% of the cost. Supporting the case that these are emergency repairs in the Damage Survey Summary Report, NDOT states:

> "NDOT considers all repair work on US95 to be emergency repairs because they were made right after the disaster to restore essential traffic, to minimize the extent of damage and to protect the remaining facilities."

Coordination of the emergency highway funding was managed by NDOT. Funding from the Federal Highway Administration was granted and the repairs to the highways were completed.

Figure 9. Governor's Declaration of Emergency for the earthquake damage to Nevada highways (stamp and signatures omitted).

DECLARATION OF EMERGENCY AFTER 6.5 MAGNITUDE EARTHQUAKE

WHEREAS, *Nevada Revised Statute 414.070 authorizes the Governor to issue a proclamation declaring a state of emergency when a natural disaster of major proportions has occurred within this state, and the assistance of state agencies is needed to supplement the efforts and capabilities of political subdivisions to save lives, protect property, and protect the health and safety of persons in this state; and*

WHEREAS, *on May 15, 2020, the State of Nevada experienced a magnitude 6.5 earthquake, the largest earthquake in the State of Nevada in over six decades; and*

WHEREAS, *the earthquake caused extensive damage to transportation routes, including Federal aid highways, throughout the counties of Esmeralda, Mineral, and Nye; and*

WHEREAS, *United States Highway 95 (US 95) sustained approximately three (3) miles of road damage between Esmeralda County (ES) mileposts 88 to 90, at milepost ES 95, and at Mineral County (MI) milepost 2, resulting in the closure of US 95; United States Route 6 sustained road damage within approximately twenty-two (22) miles between mileposts ES Oto 18 and MI 12 to 16; and Nevada State Route 360 sustained road damage within approximately twenty-three (23) miles between mileposts MI 0 to 23; and*

WHEREAS, *United States Highway 95, United States Route 6, and Nevada State Route 360 all suffered damages with repair estimates expected to exceed $700,000; and*

WHEREAS, *the condition of damaged transportation routes constitutes an emergency, as is contemplated by the terms of Sections 125 and 120(e) of Title 23, U.S.C.; and*

WHEREAS, *the counties of Esmeralda, Mineral, and Nye, require the assistance of the Nevada Department of Transportation to repair and reconstruct transportation routes damaged by the earthquake; and*

NOW, THEREFORE, I, *Steve Sisolak, Governor of the State of Nevada, pursuant to the authority vested in me by the Constitution and laws of the State of Nevada, hereby declare a state of emergency due to the May 15, 2020, earthquake, and the consequent damage to transportation routes within the State of Nevada. The immediate repair and reconstruction of the damaged highways is vital to the security, well-being, and safety of the citizens of the State of Nevada.*

COUNTY RECONNAISSANCE FOR INJURIES, DAMAGE, AND EFFECTS

There was a uniform response of the affected counties to initiate reconnaissance of potentially impacted areas, and to contact and apprise county officials of the earthquake. For example, Nye County Emergency Management assigned Tonopah Emergency Medical Services to investigate for any injuries in Tonopah. Likewise, Nye County Department of Public Works was contacted to conduct a physical inspection for damage. Nye County sheriff's deputies also performed a windshield survey in Tonopah looking for serious damage. The Nye County School District contracted a private engineering firm to inspect Tonopah schools. School buildings were cleared with no structural damage and only minor cosmetic damage. Similar to Nye County, Mineral County Emergency Management contacted the utilities and public works departments to check for any impacts to the towns of Mina and Luning, which were closest to the event. Most effects were found in Tonopah, and these were relatively minor. As far as we know, no injuries or deaths were reported as a result of the 2020 Monte Cristo Range earthquake, and all damage, except for that to Highway 95, was minor. The only emergency call received was for the Highway 95 damage.

A concern posed by Nye County Emergency Management was whether any of the various mining tunnels that exist under Tonopah could collapse from earthquake shaking. No effects to tunnels were reported from the Monte Cristo Range earthquake, but it highlights what could be a local seismic hazard for a mining town.

COORDINATION OF STATE RESPONSE

The Nevada Division of Emergency Management reached out to county emergency managers for updates of any damage or injuries and to offer any needed assistance. No additional assistance was requested. The majority of emergency response was led by the county personnel. NDOT and Nevada Highway Patrol responded by mitigating the road damage and assisted in traffic control. In addition to the emergency response, scientific teams led by the Nevada Bureau of Mines and Geology, the Nevada Geodetic Laboratory, and the Nevada Seismological Laboratory were deployed to the area and maintained close contact with emergency personnel.

CONCLUSIONS

The 2020 Monte Cristo Range earthquake occurred in a remote area of Nevada. County officials and sheriff's deputies immediately initiated reconnaissance for any damage or injuries in the communities closest to the earthquake. The only call for an emergency response was road damage to U.S. Highway 95, which damaged two tires on at least one car. The Esmeralda County Sheriff's Office received the call and immediately dispatched to control the hazard and contacted NDOT. Traffic control at the damage site occurred 1.3 hours after the earthquake, a detour was established 3.45 hours after, and temporary emergency road repairs were completed 10 hours after the event and the road was reopened. Overall, the emergency response to the earthquake was thoughtful and effective.

REFERENCE

Nevada Department of Transportation (NDOT), 2020, Damage Survey Summary Report–August 17, 2020, 55 p. (unpublished)

NEVADA BUREAU OF MINES AND GEOLOGY SPECIAL PUBLICATION 39

Photo-Documentation of the Damage and Effects Caused by the May 15, 2020 Monte Cristo Range, Nevada Earthquake

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ABSTRACT

The May 15, 2020 Monte Cristo Range, Nevada earthquake caused localized damage to U.S. Highway 95, a major north-south transportation route in Nevada, a few buildings, and several nonstructural features. Damage was limited because of the remote nature of the earthquake. The cause of the highway damage was not definitively determined but could have been related to collapsible soils, liquefaction, surface fracturing, lurching of the roadway, or a combination of these features. The primary factors that led to this highway damage were the proximity of the earthquake and the location of the road along the edge of a playa. At least one of the larger fractures in the highway damage area increased in size by as much as 64% over two days following the earthquake. Damage to buildings was due to intense shaking in the near field and probable longer period shaking in Tonopah. In Tonopah, two adjacent buildings appeared to vibrate out-of-phase damaging the contact between the buildings. Nonstructural damage consisted of cracked windows and masonry walls, a broken water line, and contents falling from shelves as far away as 57 km from the epicenter. A radio tower in the near field of the earthquake had sloughing damage on the perimeter of its foundation pad, and although the small building and antennas did not appear damaged, the tower was closed after the earthquake. The total cost of the Monte Cristo Range earthquake was >$6,048,600, over 99% of which was related to the highway damage. There were no injuries nor deaths reported from the event. Evidence of strong shaking in the earthquake area indicates there would have been more damage if the area was not sparsely settled.

INTRODUCTION

The 2020 Monte Cristo Range earthquake (M6.5) occurred on May 15th at 4:03 a.m. (PDT) in a relatively remote area of Nevada, which limited the damaging effects of the event. The epicenter was located approximately 20 km north of the junction of U.S. Highway 6 and U.S. Highway 95 in Esmeralda County. The nearest communities were Mina (31 km northwest from the epicenter), northern Fish Lake Valley (44 km), Luning (45 km northwest), Tonopah (57 km southeast), Dyer (59 km southwest), and in California, Benton (67 km southwest); the locations of these communities are shown in figure 1. The nearest buildings were on the north side of Columbus Salt Marsh (12 km southwest of the epicenter). A major north-south highway, U.S. Highway 95, passes west of the epicenter and crosses the aftershock zone. This highway sustained damage from localized ground failure but did not demonstrate significant direct offset from the surface rupture (the earthquake rupture is thought to have diminished in offset as it approached the surface; Hammond et al., 2021).

Following the earthquake, a National Science Foundation-sponsored Geotechnical Extreme Event Reconnaissance (GEER) Association study was commissioned and led by Dr. Ramin Motamed from the University of Nevada, Reno's Engineering Department. This GEER study (Motamed et al., 2021) documented several of the effects of the earthquake in a timely and detailed manner and is referenced heavily in this review.

The effects from the Monte Cristo Range earthquake were widespread. In the earthquake area, observations included surface fractures and offsets (Koehler et al., 2021; Dee et al., 2021), rockfalls, small landslides, shattered ground, ground failure, liquefaction and possible lateral spreading, and damage to roadways from the shaking. Surface fractures were mapped in an east-west zone of

fractures 28 km long, with small amounts (≤20 cm) of left-lateral displacement (Koehler et al., 2021; Dee et al., 2021). One building, about 12 km west of the epicenter but just south of the aftershock zone, showed classic shaking cracks emanating from the corners of window and door openings (Motamed et al., 2021). Several open-pit mines in the region had small rockfalls and cracks in decommissioned tailings and leach piles that were caused by the shaking (Price et al., this volume). The nearest towns of Mina and Luning appear to have been largely spared from damage, with even tall brick chimneys having survived. In the region, only a few buildings or other structures had minor or cosmetic damage.

This report describes the felt reports of the 2020 Monte Cristo Range earthquake, damage to highways, damage to buildings, nonstructural effects, and damage to a radio tower pad. Given that damage is typically removed by repairs, the goal is to document these effects to help guide future potential studies. Due to the rarity of damage photographs from this event, particularly road damage that was immediately repaired, this paper uses many photographs to document and record these effects. Specific earthquake information is commonly lost with time if it is not well documented, encouraging this effort.

Figure 1. Google Earth image of the earthquake region. Epicenter of the 2020 Monte Cristo Range earthquake shown as a red dot. Location of damage to U.S. Highway 95 shown as a blue dot. Also shown are the locations of Columbus Salt Marsh (CM), Tonopah (T), Mina (M), Luning (L), Northern Fish Lake Valley (F), Dyer (D), and Benton, California (B).

EARTHQUAKE FELT AREA

The 2020 Monte Cristo Range earthquake occurred at 4:03 a.m (PDT), well before sunrise while most people in the region were sleeping. This places a limit to the felt area for the event at epicentral distances of about 300 or more kilometers; people who noticed the shaking tended to already be awake during the earthquake. However, with a highly populated western U.S., enough people were awake to define the felt area relatively well. The earthquake was felt from San Diego and Needles, California and Tucson, Arizona in the south to Portland, Oregon and Boise, Idaho in the north and from San Francisco, California in the west to at least Salt Lake City, Utah in the east. The U.S. Geological Survey's "Did You Feel It" map for this earthquake that is primarily focused on Nevada and central California is shown in figure 2 and the entire area of response is shown in figure 3; 12,540 responses were submitted for these maps. The highest Modified Mercalli Intensity to a community was Intensity VI to possibly VII in places in Tonopah, where there was limited minor damage, and in northern Columbus Salt Marsh, where there were shaking cracks in at least one building (Motamed, et al., 2021). Figure 2 indicates there were also several other scattered intensity VI reports in the region as well. Intensities IV and V were common throughout much of Nevada, and intensities III and IV were common in Las Vegas Valley and in the San Joaquin Valley in California (fig. 2). Overall, the Monte Cristo Range earthquake was felt over an area of approximately 1,105,000 km^2.

Descriptions of the effects of the Monte Cristo Range earthquake were also reported to the Volcano Discovery website. These responses indicate that the most common range of shaking duration reported was 10 to 15 seconds. Reports of longer shaking durations may include basin effects; for example, there was a report of a house swaying for 30 seconds in Las Vegas Valley. Contents fell off shelves in northern Columbus Salt Marsh, Mina, northern Fish Lake Valley, Tonopah, and Benton, California. Rumbling accompanied the earthquake out to an epicentral distance of approximately 60 km. Within about 200 km, entire households were awakened in some cases, and beyond this distance it tended to be individuals awakened out to about 300 km. Hanging items were reported to be swinging out to about 200 km, whereas beyond that houses and fences tended to sway, and the water in pools and fish tanks sloshed back and forth.

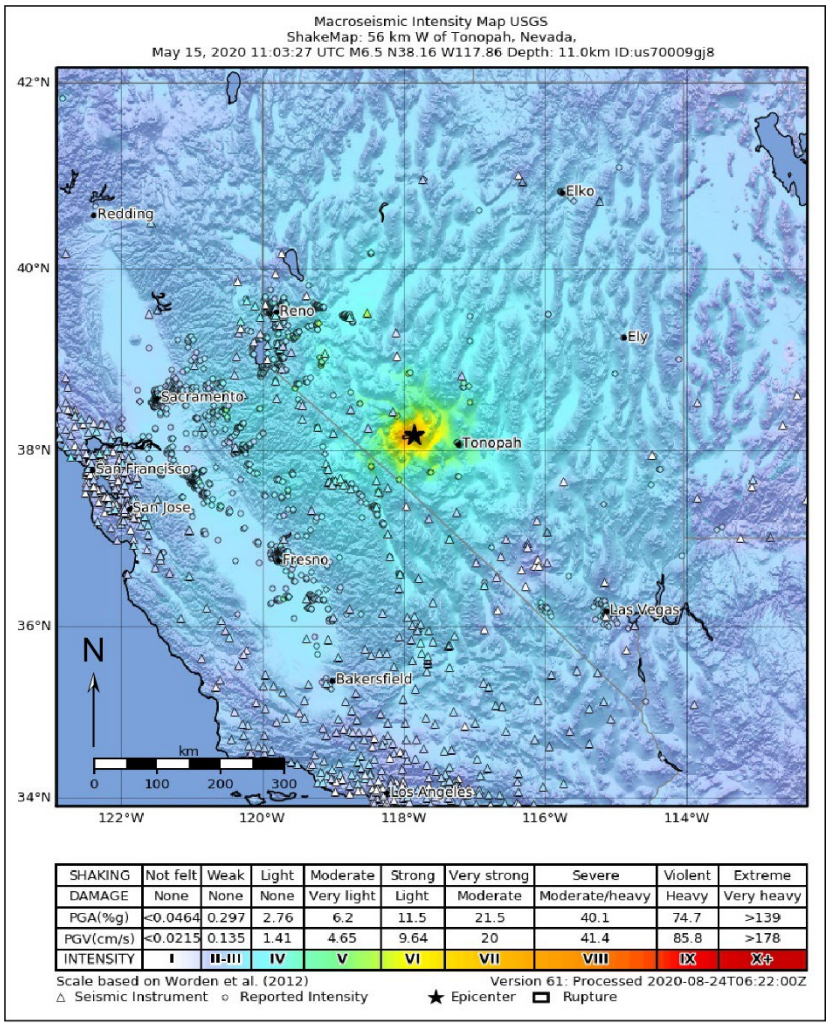


Figure 2. Shaking Intensity Map produced by the U.S. Geological Survey for the 2020 Monte Cristo Range earthquake (https://earthquake.usgs.gov/earthquakes/eventpage/nn00725272/executive). The primary focus of this figure is on Nevada and central California. The star is the epicenter of the Monte Cristo Range earthquake and state lines are shown. The colors indicate estimated Modified Mercalli Intensities based on responses to the "Did You Feel It" earthquake website.

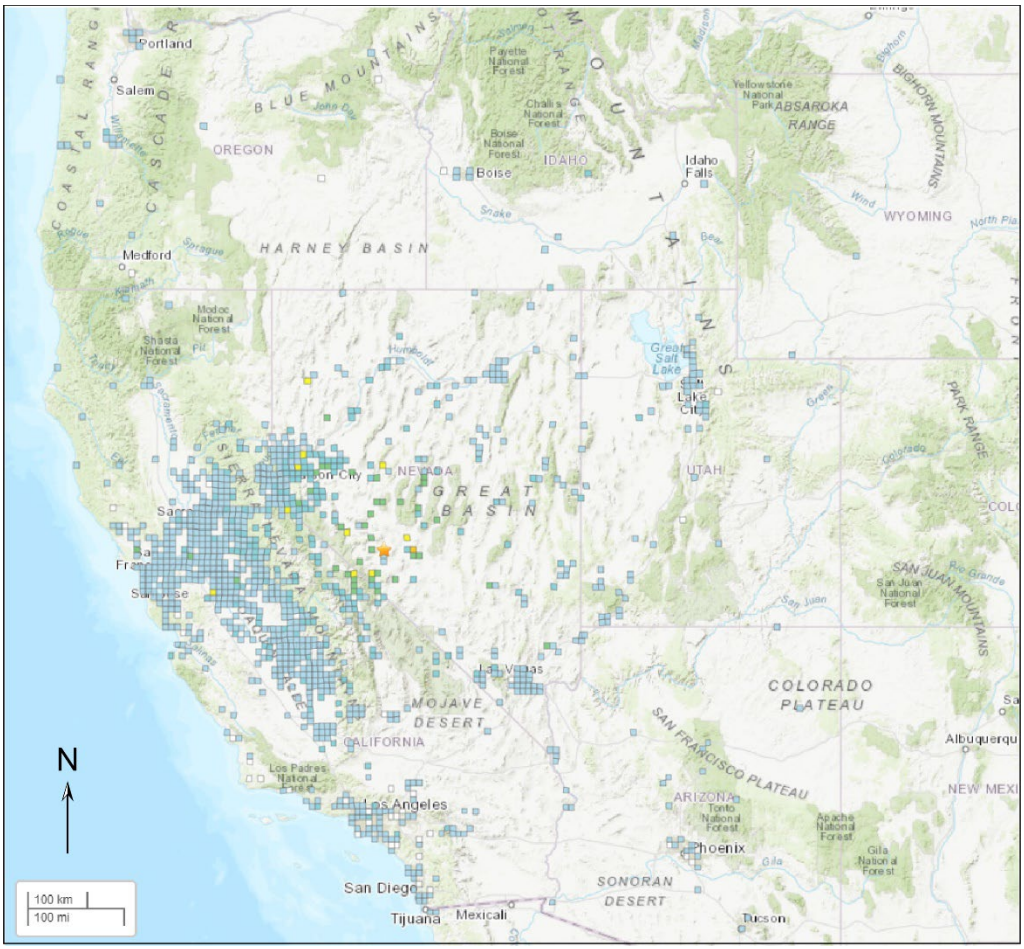


Figure 3. Distribution of felt reports (indicated as squares) to the U.S. Geological Survey "Did You Feel It" web site. Orange star indicates epicenter of the Monte Cristo Range earthquake. From interactive map at https://earthquake.usgs.gov/earthquakes/eventpage/nn00725272/executive.

HIGHWAY DAMAGE

Three highways in Nevada sustained damage from the Monte Cristo Range earthquake: U.S. Highway 95, U.S. Highway 6, and Nevada State Route 360. The most serious and costly damage from the earthquake was to Highway 95. The other two highways, which are farther from the event, had several transverse cracks that formed in the roadways that were further damaged when they were used as a detour around the U.S. Highway 95 damage.

DAMAGE TO HIGHWAY 95

U.S. Highway 95 obtained damage in at least three locations, with the most serious damage occurring over a 5-km stretch of the road in the earthquake area, along the eastern margin of a playa named Columbus Salt Marsh (figs. 1 and 4). In this area, damage was caused by ground settlement and liquefaction. Surface ruptures approached the highway but did not significantly damage it (Dee et al., 2021).

The earthquake occurred at 4:03 a.m. (PDT) while it was still dark. One southbound car was damaged after it hit a 5- to 13-cm-high north-facing offset in the roadway at highway speeds. The subsequent emergency call to 911 alerted authorities about the road damage, and the Esmeralda County Sheriff's Office immediately dispatched a deputy to control the road hazard and also immediately contacted the Nevada Department of Transportation (NDOT). NDOT personnel and equipment dispatched to the area and began temporary emergency repairs as quickly as they could get equipment in. Consequently, there are a limited number of photographs of the roadway damage before the repairs.

Most photographs are of the largest road offset at the south end of the damaged reach of highway, an area that was studied by Motamed, et al. (2021). Photographs of this area were captured at sunrise by Kenneth Siri (NDOT), another NDOT employee, and Thomas Sawyer (Piedmont Geosciences), before the road was repaired. Additional photographs of this area and the northernmost road damage area were captured by Craig dePolo shortly after road repairs were underway, but before repair of the northern end of the damaged section. Drone imagery was flown over this area by Thomas Sawyer and Conni de Masi.

The NDOT (2020) summary of the damage to Highway 95 is:

> *"US95 sustained surface pavement and shoulder damage along approximately three miles of the highway between MP 88.70 and MP 90.00 and near MP 95.00 in Esmeralda County, and in Mineral County near MP 2.00. Surface pavement and shoulder damage included cracks up to 2 inches wide and 15 inches deep and settling of 2 to 5 inches due to ground shaking and settling caused by the earthquake"*

The summary includes information from NDOT's "Damage Survey Summary Report". The main focus in the report are the two areas of the highway where we have information, labeled as location 1 and location 2 in figure 4.

ROAD DAMAGE AND GROUND FAILURE AT LOCATION 1

At location 1, there was a pronounced area of settlement and vertical offset of Highway 95 that included a 5-to 13-cm northwest-facing scarplet in the road, and fracturing in the area around the highway (fig. 5). The highway is oriented northwest-southeast in this area and is about 9 m wide. There is an approximate 4-m-wide flood dike about 22 m east of and parallel to the highway (fig. 6). The area of deformation is defined by fractures, small normal offsets and micro-grabens, and consists of a zone of northeast-trending fractures on the eastern side of the highway and a simpler, small, discontinuous fracture zone on the western side (fig. 7). The northern and southern boundaries are defined by fractures that crossed and paralleled the highway. The area of deformation is roughly rectangular in shape and is about 12,800 m^2 in size. The areas surrounding the fractures and the interior of the fractured area were undisturbed. The study area is shown in figure 6, a drone image collected by Conni De Masi two days after the temporary road repairs were completed.

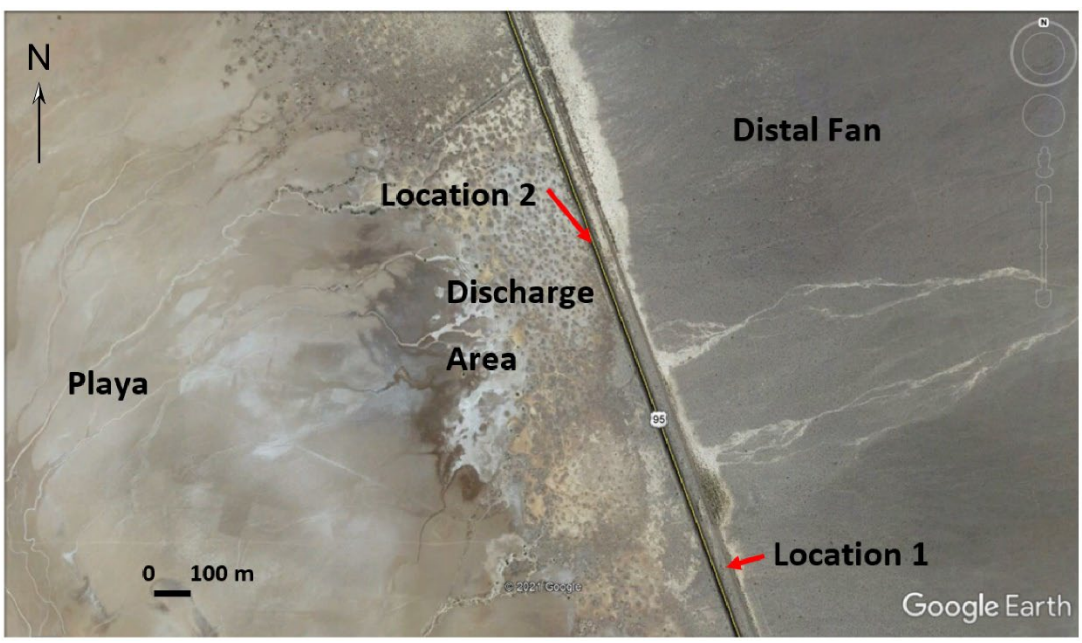


Figure 4. General geographic setting in the area of damage to U.S. Highway 95 (crossing diagonally in the central part of the image). The highway was built on the distal margin of the fans along the edge of the playa. A dike was built on the east side of the highway to control floods and it has created a ponding and water infiltration area along the eastern margin of the highway.

Figure 5. (Top) Esmeralda County sheriff's deputy blocks road hazard on U.S. Highway 95 at the largest vertical offset. Vehicles were temporarily asked to drive around on the western shoulder until a detour was established. Note the fracture in the road ends abruptly near the edge of the pavement on the west side (lower part of the photograph). View is looking to the east. Photograph by Esmeralda County Sheriff's Office.

Figure 6. (Left) Drone aerial photograph of location 1. North is towards the upper right-hand corner. The main damage to the roadway is at the bottom, where fresh pavement can be seen. Right of the road (~east) of the road is a flood dike with light-colored ponded sediments behind it. Image by Conni De Masi in 2020.

Figure 7. Image from figure 6 with fractures represented as red lines (thick – largest fractures, thin – smaller fractures). Yellow lines are fractures that were added from ground and drone photographs and are approximately located. The largest offset is indicated.

The southern part of the deformed area sits at U.S. Highway 95 and obtained north-northeast-striking fractures and road-parallel fractures (figs. 8–16). A 5- to 13-cm-high scarplet crossed the highway in this area (figs. 9, 10, and 12), and some subsidence of the road occurred adjacent to the scarplet (fig. 16). There was also a slight amount of right-lateral offset visible in the center and lane lines across the scarplet in the road (figs. 12 and 14). Several fractures in this area were parallel to the road or along the edge of the pavement and appeared to be strongly influenced by the highway (figs. 7, 8, and 17). Deformation of the highway in this area appeared to be localized near the scarplet; figures 13 and 14 show the roadway away from the scarp with lane lines for reference. Although a slight amount of right-lateral movement was noted, most of the deformation was caused by extension that was parallel to the highway.

Figure 8. Early morning (pre-repair) photo of the main damage in U.S. Highway 95. North is towards the upper right corner. This image and ground photographs were used to map the fractures with yellow lines in figure 7. Drone image by Tom Sawyer on May 15, 2020.

Figure 9. (Left) View to the west of the largest vertical offset in U.S. Highway 95. The break is mostly made up of a north-facing scarplet, except the area around the centerline, where there is a small down-dropped area (fig. 10). There is a small step in the break at the centerline as well. Photograph by Tom Sawyer.

Figure 10. (Right) View to the east of the main break. Small down-dropped area near the centerline is seen in the lower part of the photograph. The continuation of the road breakage into the eastern shoulder, a parallel fracture just left of this, and the curvature of the eastern side of the fractures to a road parallel orientation can be seen in the upper part of the photograph. Photograph by Kenneth Siri (NDOT).

Figure 11. Detail of the small down-dropped area near the center line. The down-dropped area is about 50 cm wide at the centerline. North is to the right side of the photograph and west is towards the top. Photograph by Kenneth Siri (NDOT).

Figure 12. Centerline of road across main break in U.S. Highway 95 and road block by Esmeralda County Sheriff's Office. A slight amount of right-lateral offset is seen across the main break. Photograph by Tom Sawyer.

Figure 13. Small area of down-dropped roadway near the center line of the highway. View to the northwest along U.S. Highway 95. Photograph by Tom Sawyer.

Figure 14. View to the southeast along the eastern white lane line across the scarp in U.S. Highway 95. A slight amount of right-lateral offset can be seen in the line across the main break, which had mostly normal displacement. This break continues into the eastern (right side) shoulder of the road. Photograph by Tom Sawyer.

Figure 15. (Top left) Detail of the eastern lane line at the scarp across the road. View to the southeast. The maximum reported offset in U.S. Highway 95 was 13 cm. This photograph shows almost 11 cm of offset (scale is in inches). Photograph by Kenneth Siri (NDOT).

Figure 16. (Top right) View to the west-southwest of the large offset in the U.S. Highway 95. The main break crosses the highway at a high angle, and fracturing is visible in the eastern shoulder of the road. Two sets of cross-cutting fractures are visible: those sub-parallel to the main break and fractures sub-parallel to the roadway. The road-parallel fracture propagated south of the main break. Note that on the western side of the road the lane line appears to warp slightly downwards adjacent to the rupture. Photograph by Tom Sawyer.

Figure 17. (Bottom right) Road damage near the largest vertical offset in U.S. Highway 95. View is to the south. This large crack was parallel to the road. In this area, deformation was concentrated around the roadway. Immediately north of this (behind), deformation is distributed eastward out into an adjacent field. Photograph by Tom Sawyer.

The eastern fracture zone was about 154 m in length, 8 to 27 m wide, and consisted of a little over 100 fractures (figs. 6 and 7). The zone included and trended northeastward from the road offset (figs. 17–22), and the highest scarplets were within this eastern zone. There was a widening of the zone where it crossed the flood dike (fig. 23). The largest normal offset was 36 cm (measured on May 17th, 2020) and occurred on a fracture near the north end of the zone. The location of the largest offset is indicated on figure 7. At the north end of the zone, fractures curve westward in a relatively abrupt fashion. Fractures within the eastern zone had small generally west-side-down, 2- to 3-cm-high normal dip-slip offsets (e.g., fig. 21) or lacked vertical offsets (fig. 22), and there were a few micro-grabens.

North of the eastern zone, several short, discontinuous fractures are located between the highway and the flood dike.

Figure 18. (Top left) Cracking in area adjacent to U.S. Highway 95, where the fracture zone leaves the roadway. View to the south. For reference, bush 1 is on left side (lower bush) and bush 2 is above it; both are shown in figure 19. Photograph by Tom Sawyer.

Figure 19. (Top right) View to the southwest of the fractures adjacent to and east of U.S. Highway 95. Fractures in this area form a wide zone with approximately 0.5 m spacing. Bush 1 from figure 18 is in the uppermost right and bush 2 is left of that with its top cut off by the edge of image. Photograph by Craig dePolo.

Figure 20. (Middle right) View to the southwest shows fractures leaving the roadway on the east. Bush 1 from figure 18 is in the upper center and bush 2 is to the left of bush 1. Bush 3 in figure 22 is in the lower left corner of the photograph. Photograph by Craig dePolo.

Figure 21. (Bottom right) Fractures trending northeast into the area away from U.S. Highway 95, immediately northeast of figure 20. View to the east-northeast. Photograph by Craig dePolo.

Figure 22. Fractures east of U.S. Highway 95 and approaching the flood dike. View to the southwest. Bush 3 is in the upper central part of the picture and Bush 4 on Figure 23 is just to the left of Bush 3 Photograph taken by Craig dePolo.

Figure 23. Fracturing east of U.S. Highway 95 and immediately west of the flood dike (seen in the upper left part of the photograph); Bush 4 is in the upper right. The large fracture has a 19-cm-high notebook on it. This fracture is part of a northeast zone of fractures trending from the roadway. Fractures south of these (seen in the upper part of the photograph) are more east-northeast striking. This shows a widening of the fracture zone in the area of the dike. Photograph taken by Craig dePolo.

Figure 24. View to the northwest of the flood dike with sheriff deputies and a state trooper investigating the cracks. This view is from the southern part of the fractured area and a fracture to the east of the dike is visible. The southern half of the straight, dike parallel crack is in the lower left center of the image. Photograph taken by Craig dePolo.

Figure 25. View to the west of the eastern side of a transverse fracture in the flood dike; this fracture is from the southern portion where the zone crosses the flood dike. Yellow notebook is for scale (19 cm) and is in the same position as in Figure 26. Photograph taken by Craig dePolo.

Fractures were present within the flood dike, where the eastern fracture zone crossed it, and to a lesser extent at the northern end of the zone, where fractures curved back to the west (figs. 7, 24–26). With one notable exception, the fractures through the dike were in the same northeast-to-east orientation as their associated fractures to the west. The exception is a single, remarkably straight fracture that is parallel to the dike (fig. 6). This straight fracture was intersected with a large fracture from west of the dike at its southern end. The widest part of the fracture zone, ~27 m wide, was where it crossed the dike.

Figure 26. View down and slightly south of the notebook shown in figure 25. Corrugations in this fracture indicate the opening/movement was transverse to the fracture and approximately parallel to the flood dike. Photograph by Craig dePolo.

Figure 27. Fractures at the base of the flood dike (lower left) and continuing east into the ponded sediment behind the flood dike. In the middle and upper left, the fractures are changing orientation to be parallel to the dike. Image is from the southern part of the fractures where they cross the dike. Photograph by Craig dePolo.

Figure 28. Fractures east of and parallel to the flood dike (the dike is on the left side of photograph). Photograph taken by Craig dePolo.

Figure 29. Fractures east of the flood dike. The fracture in the middle of the photograph is 10 to 12 cm high. Gravelly material shed from the dike is in the lower half of the image. Photograph by Craig dePolo

Fractures to the east of the flood dike were generally confined to a 9- to 11-m-wide brush zone along the dike and within fine-grained sediments ponded against the dike (figs. 6 and 7). The brush zone is likely present because of an ephemeral water table perched against the dike. The coincidence may indicate that the fractures within the brush zone could have been related to near-surface groundwater. Fractures east of the flood dike are shown in figures 7, and 27–33. Several of these fractures were sub-parallel to the dike, and overall, the zone did not extend very far to the east of the dike.

The largest scarp height occurred to the east of the flood dike along a northerly striking fracture (fig. 7). This offset was measured on May 15th and May 17th, 2020, with an increase in height between these two measurements. On May 15th the scarp height was about 22 cm (figs. 30 and 31), whereas on the 17th it was 36 cm high (fig. 32). Thus, settlement or progressive offset of 14 cm (or 64%), occurred along this fracture over the first two days following the earthquake. This fracture bounded a small, ~3.7-m-wide graben, which had an eastward tilted floor and an antithetic scarp with approximately 10 cm of east-side-down displacement on the 17th (fig. 33).

Figure 30. (Top left) Largest offset east of the flood dike and largest single trace vertical offset at location 1 (indicated on fig. 7). A 19-cm-long yellow notebook is just visible in the shadowed area of the scarp (red arrow shown in fig. 31). The total scarp height was approximately 22 cm on May 15, 2020. Photograph by Craig dePolo.

Figure 31. (Bottom left) Enhanced portion of figure 30 showing the scarp in the area of the notebook. The scarp was estimated to be about 22 cm on May 15, 2020.

Figure 32. (Top right) Photograph of the same location of the notebook on the scarp that is in figures 30 and 31. This photograph was captured by Conni de Masi on May 17, 2020, two days after the photograph in figure 30. This photograph shows a scarp height of 36 cm, which is an increase in scarp height of 14 cm (or 64%) in two days.

Figure 33. (Top left) Slight contraction in the western side of U.S. Highway 95 near the northern part of location 1. A small right-lateral strike-slip offset can be seen in the edge of the pavement. Photograph by Tom Sawyer.

Figure 34. (Right) View to the north of the break shown in figure 33, showing a right-lateral offset of approximately 3 cm of the western lane stripe. Photograph by NDOT.

Figure 35. Drone image of the fracture on the west side of U.S. Highway 95. South is toward the upper part of the image. This fracture was a singular feature and was commonly 2 to 10 mm wide and lacked discernable vertical offset. Drone image by Conni de Masi.

There were two small transverse breaks across U.S. Highway 95 in the north half of the disturbed area (fig. 7). In figure 6, the northernmost break appears to have experienced contraction, however, the break in the pavement was removed during the emergency highway repairs. The western side of this break is shown in figures 33 and 34. A second transverse break in the road occurred about 30 m to the southeast of the northern break. This fracture appears to have a slight amount of right-lateral offset of the center dividing line (fig. 6). There were also road-parallel cracks along the edge of the pavement and within the shoulder of the highway proximal to the second break.

The western fracture zone is a relatively simple alignment of discontinuous fractures that were about 150 m in length and extended southwest of the disturbed area (figs. 7 and 35). The southern half of this fracture was mapped by Motamed, et al. (2021) and is a relatively continuous single fracture that was 67 m long and was made up of small fractures and small, narrow grabens (Motamed, et al., 2021). The northern part of this zone includes several small fractures just west of the highway (fig. 7).

POTENTIAL CAUSES OF THE FRACTURES AT LOCATION 1

Motamed et al., (2021) proposed that the features at location 1 were possibly formed from a lateral spread related to liquefaction. Their study identified the basin margin setting of interfingering distal fan and playa deposits, recognized evidence for small sand boils 200 m to the west of location 1, and geotechnical testing was performed on sediments west of location 1. Motamed et al. (2021) note on the results of their laboratory tests:

> "most of the near surface materials sampled are potentially liquefiable based on the state-of-the art liquefaction prediction methods based on plasticity. Shallow soils were not sufficiently saturated to liquefy, but the stabilization of water content at 24% to 25% at 1.1 to 1.5 m depth suggests soils were nearly fully-saturated at and below that depth."

Their sampling area was not at location 1 but was nearby and similar conditions could reasonably be extrapolated to location 1. With regard to assessing the liquefaction origin at location 1, Motamed et al. (2021) state:

> "The identification of a lateral spread associated with liquefaction would be suggested by a) the arcuate and wider-spaced zones of deformation, b) the likely shallowing of the groundwater table approaching the playa margin, c) reduction in the fan gradient in this region, resulting in lower-energy deposition, hence more uniform fine sands and lower relative density, and d) possible interfingering with silt layers marginal to the playa which would tend to confine and maintain elevated pore pressures (R. Koehler pers. comm.)."

Motamed et al. (2021) noted that no compression features were found at location 1 that would indicate the toe of a lateral spread.

We suggest there are three hypotheses and possibly a combination of these that might have formed the ground deformation features at location 1 along U.S. Highway 95: 1) subsurface soil collapse (e.g., salt crystal consolidation), 2) liquefaction, and 3) enhanced northeast-striking surface cracking. The main body of deformation at location 1 was the eastern fracture zone. This was a pervasively fractured zone with an overall northeast orientation. There are two arcuate features within this zone: one where the zone widens as it crosses the flood dike and at the northern end (fig. 7). At the dike, the fractures curve just east of the dike and become sub-parallel with the dike. The widened fracture pattern in this area was likely related to the intersection of the fracture zone with the dike. The dike may have acted mechanically to influence the fractures or may have modulated local shaking that influenced their orientation. The northern arcuate area is the terminus of the eastern fracture zone and encloses a small area that includes the flood dike. These fractures end near a likely material change to coarser distal fan sediments.

The highway through the deformation at location 1 is an important datum. The highway only shows significant deformation where the eastern fracture zone intersects it. Two transverse fractures across the road in the northern part had a small amount of offset and one had slight contraction, but other than these three road breaks, there is no discernible bowing or lateral offset of the highway. Thus, the movement of the surface that might be related to lateral spreading appears to be limited.

The orientation of the eastern fracture zone is similar to other fractures mapped in the fans from this earthquake, but the amount of fracturing is much more pronounced at the road than elsewhere. Thus, it is possible that the eastern fracture zone was initiated by a surface fracture, but other processes, such as liquefaction or sediment consolidation, enhanced the deformation. Strong shaking oscillations would have likely been necessary for additional processes to occur and propagate to the surface. The western fracture was also a possible surface fracture but would have lacked the additional deformation mechanisms.

GROUND FAILURE AND ROAD DAMAGE AT LOCATION 2

Location 2 was the northernmost location of visible damage in U.S. Highway 95 (fig. 4) and was untouched by road repairs when visited mid-morning on May 15, 2020. The damage to the road was relatively minor. There were extension fractures to the east of the roadway, small right-lateral offsets in the road on the northern side of the deformation, and small thrusts on the western side. The northernmost part of the deformation at location 2 was most pronounced and deformation diminished to the south.

On the east side of the roadway were a set of extension fractures that were open as much as 2 cm. In this area, there were several fractures in a zone as much as 10 m wide and with cross-strike distances between them of 0.5 to 2 m (fig. 36). These fractures extended into the roadway on the north and south ends and were overall semi-parallel to the road (fig. 37). Thus, the fractures appeared to be related to the roadway.

Figure 36. Extension fractures east of U.S. Highway 95 occurring in fine-grained sediments ponded against the road at location 2. Road base is visible in the lower left. View is to the north. Fractures open as much as 2 cm, occur over a width of about 10 m adjacent to the road and are semi-parallel to road in their central part. Photograph by Craig dePolo.

Figure 37. Fractures extending into road shoulder on the east side of U.S. Highway 95, near the southern part of the deformation at location 2. View to the north. The fractures are semi-parallel to the roadway. The road was not offset in this area. Photograph by Craig dePolo.

Figure 38. (Far left) View to northwest on the east side of U.S. Highway 95 at the northern part of location 2. The right-lateral offset of the lane line indicates the road has shifted to the west approximately 2.5 cm. Photograph by Craig dePolo.

Figure 39. (Left) View to the north from the northern edge of the deformation at location 2 (U.S. Highway 95). Slight westward movement of the road is indicated by right-lateral offset of the centerline, which was transferred around what appears to be a panel in the road. Photograph by Craig dePolo.

U.S. Highway 95 obtained a small lateral offset at the northern end of the deformation but was not offset near the southern end. At the northern end, the offset of the lines on the road were distinct, relatively clean offsets of 1.6 to 2.4 cm right-lateral displacement (figs. 38–40). Some of this deformation appeared to also transfer around relatively more rigid panels in the highway (fig. 39).

Figure 40. View to the north of the offset west lane line in U.S. Highway 95 at location 2. Offset is about 2.5 cm. The lack of ground up material along the fracture indicates the movement was likely one movement of breakage (not oscillating back-and-forth), and the irregular shape indicates that extension also occurred during the offset. Photograph by Craig dePolo.

Figure 41. Overview of the contracted area west of the highway; view to the southwest. Similar to the area of extension fractures on the east side, the micro-thrusts were within 10 meters of the road and were semi-parallel to the roadway. Multiple toes are present. The area is flat, which opens the possibility that directed waves might have caused liquefied or weak ground beneath the roadway to shift with oscillations of the road. Photograph taken by Craig dePolo.

Figure 42. View to the south of small thrust faults in the playa floor adjacent to the west side of U.S. Highway 95 at location 2. This is the toe of the deformation with undisturbed ground on the right (west) side. These small thrusts appear to be shallow. This view gives the impression that the moving sediments were riding on a wave. Photograph was taken by Craig dePolo.

Figure 43. View east of one of toes of the micro-thrusts on the west side of U.S. Highway 95. An 8.5-cm-wide black lens cap for scale is in the left central part of the picture. The micro-thrust toes were as much as 10 to 15 cm high. Note the relatively undisturbed hanging wall (upper part) and undisturbed footwall (lower part). Photograph taken by Craig dePolo.

On the west side of U.S. Highway 95 were a series of micro-thrusts in the playa floor adjacent to the highway (figs. 41–43). These thrusts did not enter the base of the roadway and were confined to the playa sediments. The micro-thrusts had toes a few to 15 cm high (fig. 43). The footwall (west side) was undisturbed, and the hanging wall (between the toes and roadway) was relatively undisturbed in several places (fig. 43).

Each side of the roadway had distinct deformational styles, with extensional fractures on the east and contraction represented by the micro-thrusts on the west. Their position and style, coupled with the offsets in the road, indicate movement to the west. The deformation on the sides of the roadway seemed to be larger in magnitude than the offsets measured in the roadway. There were no ejecta features nor evidence for water seen at the surface, and the area is flat. The extension fractures and micro-thrusts could be classic features of a small lateral spread related to liquefaction

under U.S. Highway 95. A potential alternative hypothesis would be that focused waves caused strong westward oscillations of the roadway that resulted in the observed deformation.

EMERGENCY REPAIRS TO HIGHWAY 95

The emergency repairs consisted of two parts, the immediate temporary repairs to reopen the highway the day of the earthquake and longer-term repairs (which took 6 weeks to complete). NDOT (2020) states:

"The emergency repairs began the same day the earthquake occurred and were completed within 6 weeks of the earthquake. The earthquake damage along US95 included cracked pavement, pavement settling and shoulder settling, and drainage facility damage which required emergency repairs to minimize the extent of damage, protect the highway from weather- related damage, protect the public safety and restore essential traffic. Adverse weather can occur at any time along the US95 corridor and severe rainfall or freeze/thaw events would have caused significant additional damage to the highway. Immediate emergency repairs were required to prevent this, protect the public and to restore essential traffic."

During the repairs, the detour route shown in figure 44 along Highway 6 and State Route 360 was used.

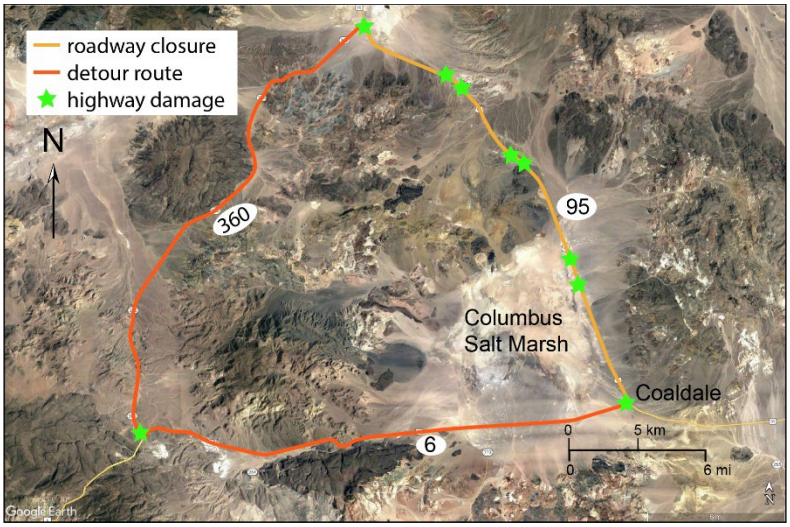
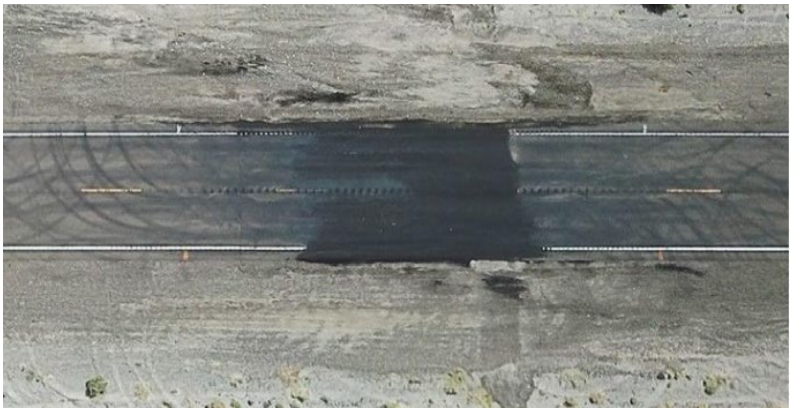


Figure 44. Detour around the area of damage on U.S. Highway 95 using U.S. Highway 6 and State Route 360. This route was used while emergency and permanent repairs were ongoing along Highway 95. Also shown are the locations of road damage noted by the NDOT.

Figure 45. Temporary repairs to U.S. Highway 95. The photograph to the right (by Kenneth Siri, NDOT) shows the final grading of the emergency repair. View to southeast. The photograph below is a drone image collected by Conni De Masi that shows the wedge of pavement fill to repair the vertical offset in the road. Southeast is to the right and northeast is up.



DAMAGE TO U.S. HIGHWAY 6 AND STATE ROUTE 360

There were two other highways affected by the shaking: U.S. Highway 6 and Nevada State Route 360. Most of this damage included cracks of 5- to 10-centimeters deep (figs. 46, and 47) and severe pavement fatigue (fig. 48; NDOT, 2020). The damage was due to ground shaking and settlement caused by the Monte Cristo Range earthquake and increased traffic from the use of these highways as detours during repairs to U.S. Highway 95 (NDOT, 2020). The cracks needed "single chip sealing" and the fatigued pavement needed "double chip sealing" for permanent repairs (NDOT, 2020).

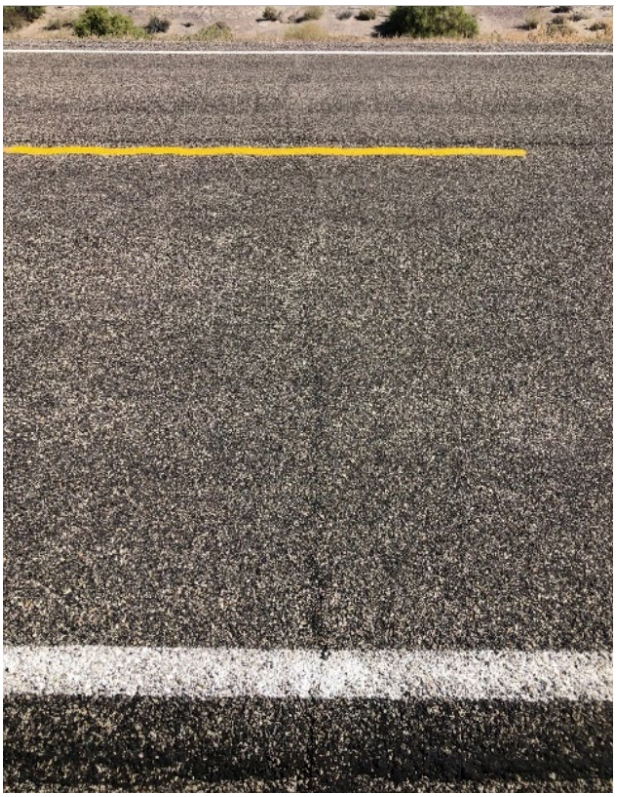


Figure 46. (Top right) Damage to U.S. Highway 6. A subtle crack can be seen in the central part of the image. Photograph from NDOT (2020).

Figure 47. (Bottom left) Minor damage to Nevada State Route 360. Photograph from NDOT (2020).

Figure 48. (Bottom right) Damage to State Route 360. A transverse crack is present in the central part of the figure and severe pavement fatigue is present in the lower central part of the photograph. Photograph from NDOT (2020).

BUILDING DAMAGE

Given the remote nature of the location of the Monte Cristo Range earthquake, only two stone-construction buildings are known to have experienced minor damage, a building at the northwest side of Columbus Salt Marsh (12 km southwest of the epicenter) and a building in Tonopah (57 km away from the epicenter). There were reports of a few other masonry buildings in Tonopah with small cracks in the mortar around some of the bricks, but all were minor and were essentially cosmetic in nature (and there was disagreement on some cracks as to whether they were pre-existing).

The nearest building to the epicenter was a two-story combination masonry and metal building on the north side of Columbus Salt Marsh (Motamed et al., 2021). This building was 12 km southwest of the epicenter, about 2 km south of the aftershock zone, and built near the distal fan – playa margin on the northern edge of the basin. The building was visited by the research team that produced the GEER report (Motamed et al., 2021). Motamed et al. (2021) report small cracks radiating out from the top corners of the doors of the building. An employee encountered in the building described the earthquake as "strong" and lasting 10 seconds, said that items fell from shelves and cupboards, and noted that the water line from a water tank was damaged by the earthquake (Motamed et al., 2021).

Figure 49. (Top) Damaged rear corner of a stone building in Tonopah. Note that the damage appears to be localized to the area where the top corner of the wood building comes in contact with the adjoining stone building and that the crowning bond beam on the stone building is intact. A small amount of damage exists to the right in the upper wall as well. Photograph by Tim Dahl.

Figure 50. (Right) Detail of damaged corner of the building shown in figure 49. Stone building construction is unreinforced masonry. Photograph by Tim Dahl.

One stone-construction building in Tonopah had damage to a rear upper corner of the building (figs. 49–51) and some settlement in the front of the building (fig. 52). In the photographs, the concrete crowning bond beam is intact around the corner of the stone building and the stone walls appear relatively intact beyond this corner. In addition, one piece of siding on the adjoining wood building appears to have come off. Thus, much of this damage was likely due to a pounding failure caused by out-of-phase shaking between the wood building and the stone building. Note that there was another small area of wall damage to the right of the corner in figure 49. The damaged stone building is comprised of unreinforced masonry construction as evidenced by the lack of rebar or other reinforcement in the area exposed by the damage. There was subsequent damage to the interior of this building due to a rainstorm that occurred shortly after the earthquake and caused flooding within the building. The total estimated cost for the damage at this building, including the water damage, was $37,000.

Other probable cracking damage occurred to several abandoned buildings in Tonopah, but it was impossible to distinguish these cracks from damage that existed before the earthquake (Naomi Wilde, 2021, personal communication).

Figure 51. Rear view of the stone damage shown in figures 49 and 50. Note the upper part of the wall is a façade. Photograph by Vikki Newell.

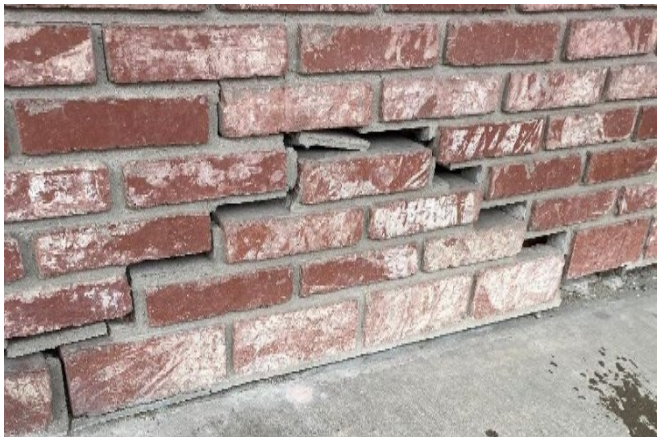


Figure 52. Localized area of subsidence in Tonopah along a sidewalk and below a brick wall, dropping down a portion of the wall. Photograph by Vikki Newell.

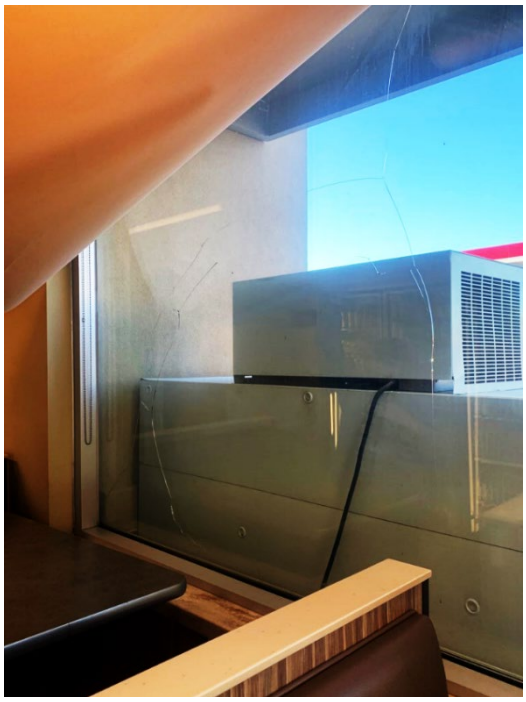


Figure 53. (Left) Cracked window in Tonopah. Photograph by Naomi Wilde.

Figure 54. (Right) Cracked window in Tonopah. Photograph by Naomi Wilde.

NONSTRUCTURAL DAMAGE

In addition to the broken pipeline mentioned earlier at the building on the north side of Columbus Salt Marsh, nonstructural damage was also reported in Tonopah. Damage in Tonopah included broken plate-glass windows at a coffee shop (figs. 53 and 54) and other broken windows, minor cracking in some brick buildings (fig. 55), a damaged 18-m (60-ft) high gas station sign, and many new cracks in roadways, mostly at road intersections (fig. 56). A door that became jammed at the elementary school in Tonopah was deemed to be the result of cosmetic damage upon inspection; this could have also been caused by one of the many aftershocks felt in Tonopah as the jammed door was noticed in the days following the main shock.

Figure 55. (Left) Crack that formed in a brick wall in Tonopah due to shaking from the Monte Cristo Range earthquake. Photograph by Naomi Wilde.

Figure 56. (Right) The crack on the left side of this area of cracked road in Tonopah was freshly opened (or reopened) from the shaking. Photograph by Naomi Wilde.

RADIO TOWER FOUNDATION PAD DAMAGE

A radio tower exists on a hill within the aftershock zone and adjacent to the zone of surface fracturing (39°09'38"; -118°00'12"; fig. 57). A pad was constructed for the tower that smoothed the rock in the center and added rocks and fill to the area surrounding the bedrock. This pad experienced ground failure from the shaking. Slumping of the fill occurred on the west-northwest and east-southeast sides of the radio tower. The failure on the east-southeast side of the tower is shown in figures 57 through 59, and the failure on the west-northwest side of the tower is shown in figures 60 through 64. These were likely areas where the fill was the thickest on the north-northeast to south-southwest oriented bedrock ridge. Only one small outbuilding was affected by the slumping area, and it was unclear if it was operational (figs 62–64). The slumping extended to the foundation of the main building and appeared to fail along the northern margin of the foundation for a short distance, but it does not appear to have propagated into the foundation or have caused any distortion to the building (figs. 63 and 64). A meter box that was separated from the main building, which was built on top of pipe extending from the ground, was slightly tilted by the ground failure (fig. 64). It is unknown whether there were effects to the functionality of the radio tower; a notice on the tower said "site closed" when visited in early June, 2020. The main building, masts, and antennas all appeared to be undamaged.

Figure 57. Damage to the eastern side of the dirt pad around a radio tower. View to the northeast. Note the leaning fence on the right. Photograph by Craig dePolo.

Figure 58. View to the southwest of the area in figure 55. Photograph by Craig dePolo.

Figure 59. (Top left) Closer view to the east of the sloughed area in figures 55 and 56. Photograph by Craig dePolo.

Figure 60. (Bottom left) Multiple fractures present in the failure on the western side of the tower. The main building is in the upper left of photograph and an outbuilding is in the upper right. Photograph by Craig dePolo.

Figure 61. Ground failure on the western side of the radio tower. The ground pulled away and down from the fence footing in the foreground. Photograph by Craig dePolo.

Figure 62. View to the northwest of the western ground failure and the outbuilding, which is within the sloughing area. Photograph by Craig dePolo.

Figure 63. View to the northeast showing a crack that extends from the rear of the outbuilding to the northern corner of the main building. Photograph by Craig dePolo.

Figure 64. (Left) View to the southwest of the ground failure on the western side of the tower. The failure reaches the northwestern side of the main building but does not appear to propagate beyond into the foundation or under this building. A meter box on the outside of the building (upper central part of the photograph) is tilted away from the building due to the ground failure. Photograph by Craig dePolo.

OTHER EARTHQUAKE EFFECTS

At least one vehicle was damaged when it impacted the scarp across U.S. Highway 95. It was reported by one of the first NDOT employees to arrive on scene that there was a southbound sedan that blew out two tires and was stalled on the side of the highway.

Cloudy water in wells was reported in northern Fish Lake Valley. Some items were knocked from shelves in the valley.

Shaking from the Monte Cristo earthquake reportedly added cracks to the walls and caused structural damage to a closed community swimming pool in Lovelock, Nevada (KKFT News, April 16, 2021). The pool, which had some issues prior to the earthquake, was considered beyond repair and Lovelock initiated a funding drive to replace the pool.

Businesses were largely uninterrupted by the earthquake, with the exception of delivery delays caused by the U.S. Highway 95 detour that lasted 6 hours and 35 minutes on May 15th, 2020. The detour was 19 km longer than the direct route and had lower speed limits. It is believed that the earthquake's impact on tourism was also likely minimal to non-existent, but it is impossible to gauge due to the COVID-19 pandemic having an overall impact on tourism at the time.

ESTIMATED COST OF THE 2020 MONTE CRISTO RANGE EARTHQUAKE

The cost of the earthquake is estimated, with many costs unreported or unknown adding difficulty to estimate overall cost. As such, the overall estimated cost is almost certainly low and the estimates provided in table 1 are intentionally minimum costs. In addition, minor shaking damage, such as cracking, is commonly not repaired, so no direct cost was incurred. Highway repairs account for about 99% of the total cost of this earthquake. The other costs were likely incurred as damaged windows, pipeline, vehicle, and the radio tower foundation damage were repaired. The estimated minimum cost of the 2020 Monte Cristo Range earthquake was $6,048,600.

Table 1. Compiled estimated costs of the 2020 Monte Cristo Range earthquake

Nevada highway damage (three roads):

Emergency repairs: ~$3M

Permanent repairs: ~$3M

Radio tower foundation damage: $5000+

Vehicle damage: $400+

Building damage: $37,000 *(Tonopah)*, $1000 *(Columbus Salt Marsh)*

Nonstructural damage/damage to building contents $5000 *(plate glass windows, sign)*

Broken water pipe: $200 *(Columbus Salt Marsh)*

Delivery delays due to Highway 95 detour: $???

Total: $6,048,600

DISCUSSION

Although there were significant local effects, the M6.5 Monte Cristo Range earthquake shows that a major earthquake can occur in rural or frontier Nevada with relatively minimal effects. The Monte Cristo Range earthquake did not significantly disrupt business, commerce, or lives beyond the novelty of having experienced a notable natural event and the response to that event. Few structures outside of several roads, a radio tower, and a few old buildings were within the near-field of this earthquake. Ground effects including surface faults and shaking fractures attest to the potential for local damage if more buildings were located in the earthquake area. The effects of strong shaking in the near field can be seen in figure 65 where a small excavated pile of dirt in the earthquake area was shattered by shaking.

Progressive surface displacement as high as 64% was observed at location 1. Such phenomenon endorses the wisdom of the NDOT's two-tiered approach to fixing the earthquake damage along Highway 95. The highway department performed temporary repairs on the day of the event to render the highway passable, and final emergency repairs were completed about six weeks later. Completing final repairs too early could have resulted in damage to those repairs if potential progressive deformation occurred. This also emphasizes that the temporary repairs should be monitored for possible damage after an earthquake event.

Figure 65. Small debris pile (about a meter and a half high) related to an exploration trench that was near an area of surface fractures related to the main shock. The debris pile has been shattered from earthquake shaking, likely related to the main shock. Other exploration piles in the area showed similar effects. Photograph by Craig dePolo.

CONCLUSIONS

The 2020 Monte Cristo Range earthquake caused local effects to three highways in Nevada and caused minor to moderate damage to two buildings, one in the earthquake area and one in Tonopah, 57 km away from the epicenter. Minor nonstructural damage also occurred to a few other buildings. The limited effects were due to the remote nature of the event.

Damage to the highways was greatest along the edge of the Columbus Salt Marsh and consisted of small (<13 cm) offsets in the road and adjacent areas of settlement of the road. Vertical offsets as large as 36 cm were measured away from the road. The potential causes of this damage were ground settlement, liquefaction, possible surface fracturing, and lurching of the road.

Although the earthquake was widely felt, it did not result in disruption of business, with exception of delivery delays caused by the detour in U.S. Highway 95. There were no reported injuries or deaths from this earthquake.

Nevertheless, the earthquake effects cost over $6,048,600 in repairs, with over 99% of this being related to emergency repair of the roadways.

ACKNOWLEDGMENTS

This review of damage could not have been made without the help of several people at NDOT from both their Carson City headquarters and the Tonopah Field Office including Kenneth Siri, Harold Dawson, and James Walker. Special thanks to James Walker (NDOT), who provided an excellent and rapid review of the manuscript. Documenting the damage in Tonopah was assisted by Naomi Wilde and Tim Dahl. Several of the USGS Did-You-Feel-It reports were supplied by Vince Quitoriano. Also, thanks to Tom Sawyer of Piedmont Geosciences, who was one of the first people to arrive in the highway damage area, for sharing his pre-repair photographs. Funding for this research and compilation was provided by the Nevada Division of Emergency Management and the Federal Emergency Management Agency.

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Earthquake Effects at Mines and Geological Sites near the 2020 Monte Cristo Range Earthquake Sequence

by

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ABSTRACT

Shaking from the magnitude 6.5 Monte Cristo Range earthquake and some of its aftershocks was strong enough to cause rockfalls from the highwalls of inactive open-pit mines 21 km west and 12 km east-northeast of the epicenter. Rockfalls also likely created a dust cloud in an area of poorly consolidated tuffaceous sedimentary rocks 33 km southwest of the epicenter. At other mining locations with comparable epicentral distances, earthquake ground motion did not cause notable effects. Shaking was not strong enough to cause rockfalls or topple semi-precarious erosional rock formations 13 km south-southeast of the epicenter. Shaking also was not strong enough to cause rockfalls at an inactive open-pit mine 21 km southeast of the epicenter or at an exploration project 21 km east-northeast of the epicenter. No damage was noted at the active lithium-brine operation 50 km south-southeast of the epicenter. The most common earthquake effects noted in this compilation were small and moderate rockfalls in open-pit mines.

INTRODUCTION

The 2020 Monte Cristo Range earthquake in western Nevada occurred in an area that has been mined and prospected for over 150 years. There are three inactive, modern-era precious-metal open-pit mines and several exploration projects in the mountains near the epicenter (Davis and Muntean, 2019, Price et al., 2018; fig. 1). The mines, which have highwalls that are susceptible to landslides and rockfalls from earthquake shaking, include the Candelaria Mine (with production from 1982 to 1999 of approximately 33 million troy ounces of silver and 104,000 troy ounces of gold), the Boss Mine (with production from 1987 to 1989 of 32,000 troy ounces of gold), and the McLean Mine (with approximately 20,000 troy ounces of gold produced in the late 1980s). Mineral exploration continues in the region.

At 4:03 a.m. (PDT) on May 15, 2020, a magnitude 6.5 earthquake occurred in the northern part of Columbus Salt Marsh and the Monte Cristo Range of west-central Nevada. The shaking from the event caused highway and building damage. The natural effects of the earthquake were widespread surface ruptures and ground cracks, rockfalls, small landslides, and liquefaction. The earthquake was the result of left-lateral slip on an unmapped strand of the Candelaria fault zone (Koehler et al., 2021).

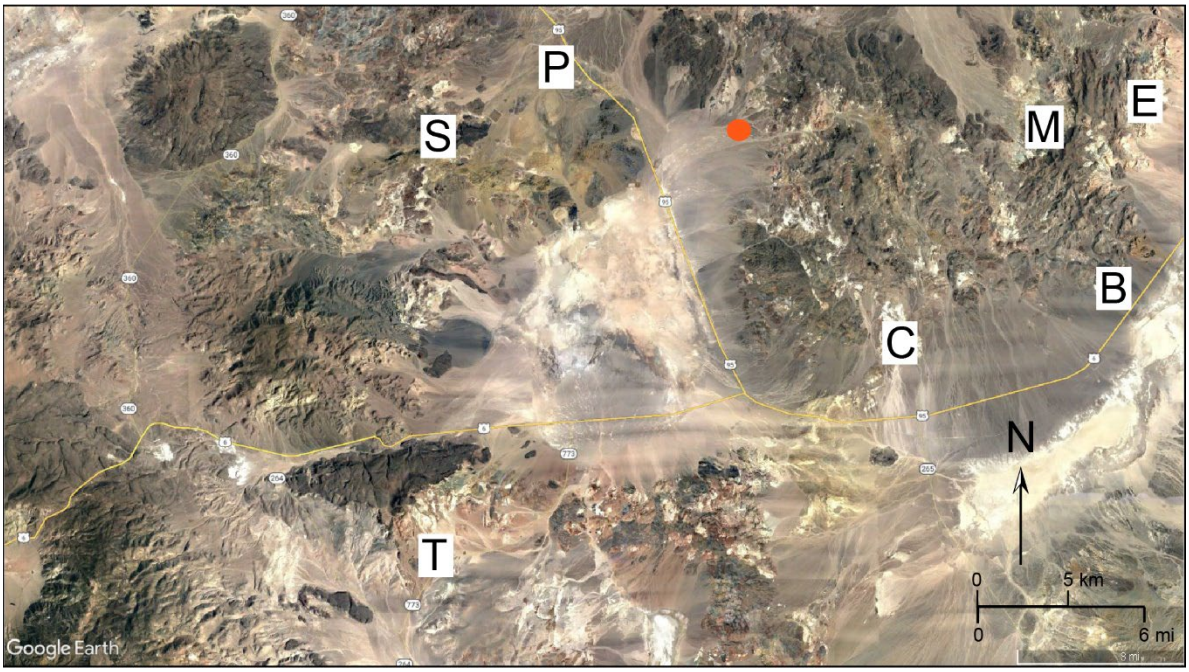

Figure 1. Locations of mines and geological sites near the epicenter (Google Earth image). Red dot = epicenter; B = Boss Mine; C = Monte Cristo Castle area; E = Eastside project; M = McLean pit; S = Candelaria silver mine; T = The Sump; P = exploration dirt pile.

EARTHQUAKE EFFECTS ON MINES

Rockfalls, rockslides, and the formation of extension cracks were the most common effects noted in mines from the Monte Cristo Range earthquake sequence. These features were not directly observed to have formed during shaking but appeared to be recent when observed and photographed. In two cases, rising dust clouds near the time of shaking indicate these rockfalls were likely formed from earthquake ground motion.

The Candelaria open-pit mine was 21 km from the epicenter of the 2020 Monte Cristo Range earthquake, but was within 5 km of the aftershock zone, which was mostly west of the epicenter. The Candelaria pit was observed on June 7th during reconnaissance of the area. Fresh rockfalls and slides were observed in the northwestern portion of the pit (fig. 2), where many rockfalls and rockslides had occurred previously and built up a small debris cone.

Figure 2. Photograph of the Candelaria open pit, showing small rockfalls that likely were caused by shaking from the Monte Cristo Range earthquake sequence. Photograph by Donna L. dePolo, June 7, 2020.

On May 22, 2020, Ruth Carraher received a call from an equipment operator who described "dust clouds pouring out" of the McLean pit (12 km east of the epicenter). The dust clouds presumably were caused by one of the largest aftershocks of the sequence (M5.1) that occurred that day. On March 26, 2020, while visiting the property to inspect and photograph effects, Carraher observed sporadic small rockslides occurring and dust in the pit while inspecting it. Carraher also noted that she has been in the area frequently for over 15 years and up until the earthquake, rockfalls were a rare occurrence. The photographs (figs. 3–7) document rockfalls and slumping in the pit and opening of cracks and slumping at the leach pad at the site. Although the rockfalls and slumping appear to have occurred recently before being photographed, without eyewitness accounts, we cannot say with certainty that they were caused by shaking from the earthquake sequence. The cracking in the tailings pile is clearly recent (fig. 7) and was photographed 11 days following the mainshock of the sequence; confidence is high that these were caused by earthquake shaking and the cracks confirm that shaking did occur in the McLean pit from the sequence.

Craig dePolo observed a small pile of dirt related to an exploration trench on June 6th (fig. 8) that was about 9 km to the west of the epicenter, 1 to 2 km north of the aftershock zone, and was within the zone of surface faulting. This dirt pile, which was at least several years old and somewhat consolidated, was shattered by earthquake shaking. This was likely shattered by the mainshock, and cracking has probably been enhanced by nearby aftershocks.

Figure 3. Photographs of the McLean pit in 2005 (above) and shortly after the earthquake in 2020 (left). There is much more debris in the outlined area, the bottom of the pit has much more material filling it, and more dust covers rocks (dulling the alteration colors) in 2020 than in 2005. Photographs by Ruth A. Carraher, May 26, 2020.

Figure 4. Photographs of the McLean pit in 2005. Areas outlined in yellow and blue are those in figure 5. Photograph by Ruth A. Carraher.

Figure 5. Photographs of the McLean pit in 2020, after the earthquake. Slumping occurred in both the yellow and blue areas. Photographs by Ruth A. Carraher, May 26, 2020.

Figure 6. Post-earthquake 2020 photographs of cracks (left and center) and slumping (right) at the decommissioned McLean leach pad. Photographs by Ruth A. Carraher, May 26, 2020.

Figure 7. Enlargement of a portion of the left photograph in figure 6. The cracks appear fresh and were likely caused by shaking from the Monte Cristo Range earthquake sequence.

Figure 8. Small debris pile (about a meter and a half high) related to an exploration trench, photographed by Craig M. dePolo on June 6, 2020. The pile is 1 to 2 km north of the aftershock area and within an area of surface fractures related to the main shock ("P" on figure 1). The dirt pile has been shattered from earthquake shaking, likely related to the main shock. Other exploration piles in the area showed similar effects.

John Reynolds (personal communication, June 15, 2020), a Reno-area geologist working on the Rhyolite Ridge lithium-boron project in the Silver Peak Range, noted that "Linda Williams of Dyer reported seeing a large dust cloud the morning of the main 6.5 event [The Sump, figs. 1 and 9]. She described it as positioned near "The Sump" and could not account for it since no wind was blowing." The Sump is a badlands feature in mostly poorly consolidated, tuffaceous, lacustrine sedimentary rocks and ash-fall tuffs 33 km southwest of the epicenter (fig. 9).

Figure 9. Photographs of "The Sump", from the Travel Nevada website, Exploring the Sump Near State Route 773 Off US 6 (travelnevada.com). Clouds of dust were seen rising from this area on the morning of the main shock.

MINES AND GEOLOGIC FEATURES THAT LACKED EARTHQUAKE EFFECTS

Andy Wallace (personal communication, 16 December 2020) reported no significant rockfalls at the Eastside gold exploration project (21 km east-northeast of the epicenter, "E" on fig. 1) or apparently at the Boss Mine (21 km southeast of the epicenter; "B" on fig. 1).

The "Monte Cristo Castle" area on the south side of the Monte Cristo Range (13 km south-southeast of the epicenter, "C" on fig. 1) has been proposed to be a state park because of its unusual erosional features in Tertiary rhyolite tuffs, andesite, and tuffaceous sedimentary rocks. The Nevada Bureau of Mines and Geology (Price and Price, 2006) established an EarthCache site in the area and photographed some of the unusual formations. JGP rephotographed some of these features shortly after the magnitude 6.5 earthquake (figs. 10–13). There appeared to be no damage to the precarious formations, and in the three-kilometer loop up and down canyons in the area, no clear evidence of rockfalls, such as track marks left by displaced rocks in soft tuffs, was observed.

Figure 10. Unusual erosional rock formation in the "Monte Cristo Castle" area photographed in 2006 (left) and June 6, 2020 (right). Location: 38°3′30″N, 117°47′24″W. Photos by Jonathan G. Price.

Figure 11. Unusual erosional rock formation in the "Monte Cristo Castle" area photographed in 2006 (left) and June 6, 2020 (right). Location: 38°3′41″N, 117°47′26″W. Photos by Jonathan G. Price.

Figure 12. Landscape in the "Monte Cristo Castle" area photographed in 2006 (left) and June 6, 2020 (right). Location: 38°3'37"N, 117°47'24"W, looking west toward Boundary Peak. Photos by Jonathan G. Price.

Figure 13. Unusual erosional rock formation in the "Monte Cristo Castle" area photographed in 2006 (left) and June 6, 2020 (right). Location: 38°3'34"N, 117°47'19"W. Photos by Jonathan G. Price.

John Reynolds reported there were not rockfalls or landslides near the Rhyolite Ridge project, 38 km south of the epicenter. We inquired whether there was damage or other effects of the earthquake at the active Silver Peak lithium operation in Clayton Valley, 50 km south of the epicenter. Scott Thibodeaux (personal communication, December 16, 2020) reported that the company inspected their facility directly after the earthquake and saw no damage, and that they observed no effects in the wellfield, where they pump lithium-bearing brines from subsurface aquifers to the evaporation ponds. Thibodeaux, who lives in Silver Peak, was awoken by the strong shaking from the earthquake.

SOME IMPLICATIONS OF EARTHQUAKE EFFECTS

Mining companies design their facilities (e.g., roads and highwalls in open pits, buildings, leach pads, waste piles, and tailings dams) to withstand expected local hazards, such as unusual rainfalls, high winds, and earthquakes. The major lesson to be learned from the Monte Cristo Range earthquake and from other historical earthquakes in Nevada is that the effects of earthquakes (including ground shaking, liquefaction, ground cracking, and fault rupture) should be anticipated anywhere within the state. Safety of the workforce is paramount; for earthquakes, this involves awareness of what to do during intense ground shaking and anticipating aftershocks. Many historical Nevada

earthquakes of magnitude 7 have been preceded within days to months by smaller earthquakes. It is also recommended that after a major earthquake, engineers inspect facilities to assess any damage that may have occurred and new hazards that may have developed.

CONCLUSIONS

Rockfalls that were likely related to the 2020 Monte Cristo Range earthquake and its aftershocks were noted at least 21 km away from the mainshock epicenter, and likely occurred 33 km away. The noted effects included rockfalls, cracking, slumping, and shattered dirt piles. On the other hand, semi-precarious rock formations within about 13 km away did not show any effects of the shaking. Although effects of this magnitude 6.5 earthquake were minimal at nearby mining operations, the abundance and distribution of Quaternary faults attest to earthquake hazards throughout Nevada.

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Earthquake Awareness and Preparedness in Esmeralda, Mineral, and Nye Counties

by

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ABSTRACT

This study reviewed the ShakeOut participation, CASPER—a public information survey, and county mitigation plans to gauge the awareness and preparedness of the citizens in the three counties, Esmeralda, Mineral, and Nye counties, affected by the 2020 Monte Cristo Range earthquake. An important factor when thinking about these counties is their settlement character. Within these three counties are large tracts of unpopulated and frontier areas, in addition to several rural areas and small towns, and one urban area. Residents in these frontier and rural areas are naturally quite resilient, and a significant percentage appear to be prepared for disasters and isolation. This was confirmed by the Mineral County Community Assessment for Public Health Emergency Response (CASPER) survey that showed that 38% of households surveyed felt they were prepared for an emergency, and 48.9% were somewhat prepared for an emergency. That is a remarkable 86.9% of households having some level of preparedness. In addition, 90.4% of surveyed households stored three days' worth of food per person, and 67.2% of surveyed households maintained emergency kits.

County ShakeOut participation numbers generally correlated to county populations, but otherwise showed no trends and were not in sync with other Nevada participation numbers. County participation levels have been between 0% and 15%. There are lots of paths to increasing these values, but in the frontier areas, earthquake risk reduction communicated directly to residents may have a more effective impact than encouraging them to visit the ShakeOut web site. For example, registering for an exercise and reading information on a web site is difficult for residents without internet. County mitigation plans indicate earthquake hazard within the top three hazards for Esmeralda, Mineral, and Nye counties. Action items towards earthquake risk reduction include continued use of the International Building Code and inventorying unreinforced masonry buildings. Beyond this, counties focused on aspects that were more important to each county, including attention to the earthquake risk of critical facilities, industrial facilities, utility infrastructure, and mobile homes.

Although perhaps not specifically for earthquakes, most citizens of the tri-county area are prepared for disasters. Formally signing up and participating in preparedness drills is not always practical for residents in rural and frontier areas, especially if they lack easy internet access. Perhaps what is more important to these residents is effective communication on earthquake resilience, tailored to what makes sense for them to integrate into their existing disaster plans and preparedness. Nevertheless, a county goal of reaching a larger ShakeOut participation percentage can be used as a vehicle for motivating and communicating to residents. The 2020 Monte Cristo Range earthquake occurred in a remote area, and residents were exposed to shaking but no injuries were reported.

INTRODUCTION

The 2020 Monte Cristo Range earthquake (M6.5) occurred in rural and frontier areas of Nevada, which comprise most of Nevada. The earthquake occurred near the boundary between Esmeralda and Mineral counties and was 34 km from Nye County (fig. 1). Thus, these three counties were significantly shaken by the earthquake and needed to check in on their citizens. Damage was pronounced on Highway 95 in the earthquake area but was more limited elsewhere. There were no known injuries and no deaths. With the exception of a temporary detour around the damage on Highway 95 for a while, business continued as usual across the three counties. Aside from traveling to and controlling traffic around the damaged highway, emergency

response consisted mostly of county emergency managers contacting public works, utilities, and emergency personnel to survey towns in the earthquake region for any damage and injuries.

This paper is a short synopsis of the earthquake risk reduction engagement in these three counties as evidenced by participation in the Great Nevada ShakeOut, review of a Mineral County study done on public awareness and perceptions of hazards, and examining attention to earthquakes in county mitigation plans. The settlement nature of these counties (frontier, rural, or urban) is an important consideration when making observations, such as ShakeOut participation.

This area of central Nevada is earthquake country (fig. 1), with major earthquakes shaking the region including twice in 1872 (Owens Valley [M7.8] and central Nevada [M6?]), 1910 Tonopah Junction earthquake (M6), 1932 Cedar Mountain earthquake (M7.1), and 1934 Excelsior Mountains earthquake (M6.4). Other earthquake sequences have shaken parts of the region, such as the 1954 Churchill County earthquakes (e.g., 1954 Fairview Peak and Dixie Valley earthquakes), although not in damaging ways. Earthquakes have also occurred regionally, such as the 1980 Mammoth Lakes, California earthquakes (M6–6.4), keeping the potential for earthquake awareness at a personal level relatively high. In addition to earthquakes, these are mining counties where the notions of faults, fault offsets, and general geologic understanding are commonplace.

Gauging preparedness in these counties is difficult without detailed surveys. However, it is noted that in frontier counties, personal disaster preparedness is usually high as situations such as isolation or loss of electricity due to severe storms and other events are not uncommon. It is natural for general preparedness to be higher in these areas than in urban areas.

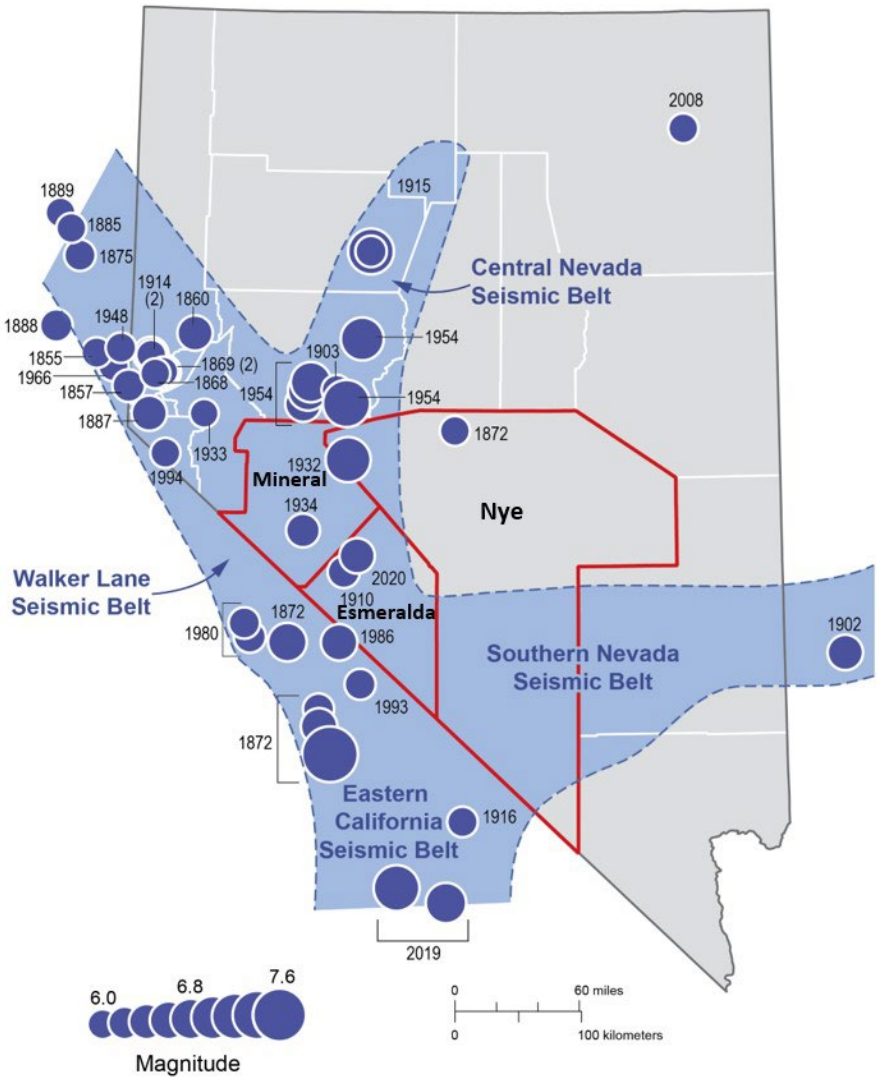

Figure 1. Major earthquakes and seismic belts in Nevada. Esmeralda, Mineral, and Nye counties are outlined in red and are labeled.

Table 1. Background information for Esmeralda, Mineral, and Nye counties (~2019)*

County	Esmeralda	Mineral	Nye
Population	969	4,456	46,523
Largest Community Pop.	298, Goldfield	2,686, Hawthorne	37,298, Pahrump
Area of County (km^2/mi^2)	9,300/3,589	9,880/3,813	47,140/18,199
Median Income	$33,203	$35,466	$41,181
Settlement Character	frontier w/rural	frontier and rural	Frontier, rural, urban

*Source: County web sites and Google summaries

SETTING

Table 1 provides background information on Esmeralda, Mineral, and Nye counties, specifically the population of the county and its largest community, the geographic size of the county, and the median income. As shown in table 1, there are significant differences between these counties in population, although all of them can be considered rural and frontier counties (with exception of Pahrump Valley in southern Nye County).

There are a few types of settlement characteristics in this tri-county area, but much of it is a frontier setting. Frontier areas are sparsely populated areas that are relatively isolated from population centers and services, such as health care, grocery stores, schools, and utilities. Rural areas have many definitions, but the notion is for people that are settled in non-metropolitan areas. Rural areas in these counties have a wide range of access to population centers and services (such as internet). In general, rural areas in the tri-county region are more connected than isolated. Only one location is characterized as an urban setting in this region, which is Pahrump in Nye County, although there are smaller communities of significance, such as Tonopah with a population of 2009. Characterizing a county's settlement can be challenging, but it basically considers the spatial distribution of population densities. Esmeralda County is sparsely populated with a few small rural communities and unpopulated areas. Mineral County consists of five small communities with large tracts of sparsely populated and unpopulated land. Mineral County also includes a significant Native American population (approximately 25% of its population). Nye County consists of several unpopulated areas (e.g., the military test ranges), and spans the gamut from frontier to rural, and one urban area (Pahrump).

Frontier areas have some important characteristics to consider when evaluating hazard awareness and preparedness. As mentioned, these areas are sparsely populated. Internet and other lines of communication, such as radio, may not be available or are limited. Residents are more self-reliant and prepared for emergencies because they are largely on their own for the first several hours after an event until help can arrive. Residents in frontier areas are commonly well prepared and stock supplies for isolation after severe storms. Frontier settlements also tend to have a lower ratio of trained responders to residents than more populated areas.

COUNTY PARTICIPATION IN THE GREAT NEVADA SHAKEOUT

An annual earthquake awareness activity in Nevada is the Great Nevada ShakeOut initiated by the Nevada Earthquake Safety Council and the Nevada Seismological Laboratory in 2010. Participation in the ShakeOut exercise needs to be renewed annually and is recorded; therefore, it provides an engagement measure for a county and the types of groups participating. This annual exercise is an opportunity to engage Nevadans in earthquake preparedness and mitigation measures as well as highlight earthquake hazards in the state. ShakeOut participation as a metric is imperfect. Registration in the ShakeOut does not additionally indicate that mitigation actions will be taken, and some residents could forget to participate. On the other hand, residents who are well aware of earthquake hazards and may have even taken steps to mitigate earthquake risks may not register and be counted. The web site for the Nevada ShakeOut can be found on the internet at: https://www.shakeout.org/nevada. Figure 2 shows the sign-up categories for the ShakeOut exercise.

Individuals/Families
Childcare and Pre-Schools
K-12 Schools and Districts
Colleges and Universities
Local Government
State Government
Federal/National Government (Including Military)
Tribes/Indigenous Peoples
Businesses
Hotels and Other Lodgings
Healthcare
Senior Facilities/Communities
Disability/AFN Organizations
Non-Profit Organizations
Neighborhood Groups
Preparedness Organizations
Faith-based Organizations
Museums, Libraries, Parks, etc.
Volunteer/Service Clubs
Youth Organizations
Animal Shelter/Service Providers
Agriculture/Livestock Sector
Volunteer Radio Groups
Science/Engineering Organizations
Media Organizations
Other

Figure 2. Sign-up categories for ShakeOut registration. Review of annual county participation for these categories provides insight on the groups participating in the ShakeOut and where opportunities exist to target new participants.

Nevada participation in the Great Nevada ShakeOut has increased between 2010 and 2020, from 112, 834 to 540,000 participants. Much of this increase was due to increased participation by school districts and universities, a result of targeted outreach to educate the next generations of Nevadans about earthquake risks.

Table 2 shows the ShakeOut participation values for the last six years for Esmeralda County, Mineral County, Nye County, and Nevada overall. The participation numbers for the different counties correlate on a first order with the county populations; more participation from more populated counties. There is otherwise no overall trend in the participation numbers as they have fluctuated during the six-year period and are not in sync with each other. The diversity of participation also increases with population between these three counties. Overall, participation by these counties also did not align with Nevada's overall participation in the ShakeOut, which is dominated by the large urban centers in the state. County participation percentages of their populations ranged from 0% to nearly 15%.

Table 2. Nevada and county participation numbers for the Great Nevada ShakeOut from 2015 through 2020.*

Year	2015	2016	2017	2018	2019	2020
Esmeralda Co.	26	3	29	30	59	0
Mineral Co.	655	5	65	600	265	72
Nye Co.	4,866	3,970	2,708	4,414	3,727	3,962
Nevada	634,519	593,016	598,435	600,969	592,550	540,000

*Source: Nevada ShakeOut web sites for the respective years.

Esmeralda County is mostly a frontier setting and internet connectivity in the area has been limited. Since the ShakeOut is internet based, it would require some residents to travel to a location with internet to register. Esmeralda County is also the lowest populated county in Nevada, with less than 1000 residents. Therefore, low participation numbers from Esmeralda County are not surprising. Participation in Esmeralda County has been mostly from the schools and a few individuals. In 2020, Esmeralda County was one of the two counties in the state with zero participation in the ShakeOut, a little surprising given a magnitude 6.5 earthquake occurred in the county that year. This lack of participation could have been caused by the COVID-19 pandemic, other distractions, or other factors, such as political reasons. Perhaps people felt no need for an exercise after experiencing a real event. There are likely only one to a few people actually registering for Esmeralda County; therefore, transitioning to a non-participant status would be easy and does not necessarily reflect a dramatic shift that would affect future participation.

Mineral County has only about 4.6x more residents than Esmeralda County (less than 5000), that mostly reside in five small towns. In 2015, nearly 15% of the county population participated in the Nevada ShakeOut. Categories that people registered for during the six-year period include schools, local government, healthcare, non-profit organizations, and individuals. The largest participation numbers result from school participation. One notable group that was missing from participation over the six-year period was Native American Tribes. Given that Native Americans comprise about 25% of the population in Mineral County, there is an important opportunity to engage these residents.

Nye County, with the largest population of the three counties, has experienced positive participation in the Nevada ShakeOut, both in numbers and in the groups represented. Over the last six years between 6% and 10% of the Nye County population participated. Groups that have been represented as registrants include schools, local government, state government, healthcare, tribes, senior facilities, and individuals.

We want Nevadans to be safe during earthquakes, so large ShakeOut participation is encouraged from all counties. The lower participation levels of these three counties is quite understandable, however, especially with the perspectives of their respective populations and frontier nature. Figure 3 shows the percentage of county population that participated in the Great Nevada ShakeOut in 2014. The higher population counties tend to have the highest percentage participation (20%–25%), whereas the more rural and frontier counties tend to have 5% to 20% participation.

To increase ShakeOut participation numbers in frontier areas, other methods to register for the ShakeOut could be explored that overcome the internet hurdle (e.g., register at county events or through a sponsorship, such as the county local emergency planning committee (LEPC) or the emergency management team that could upload registrations). Specific frontier-region outreach could also be considered that both advertises the ShakeOut and provides mitigation information to increase preparedness. We appreciate, however, that residents living in frontier areas are commonly at least somewhat prepared for a disaster.

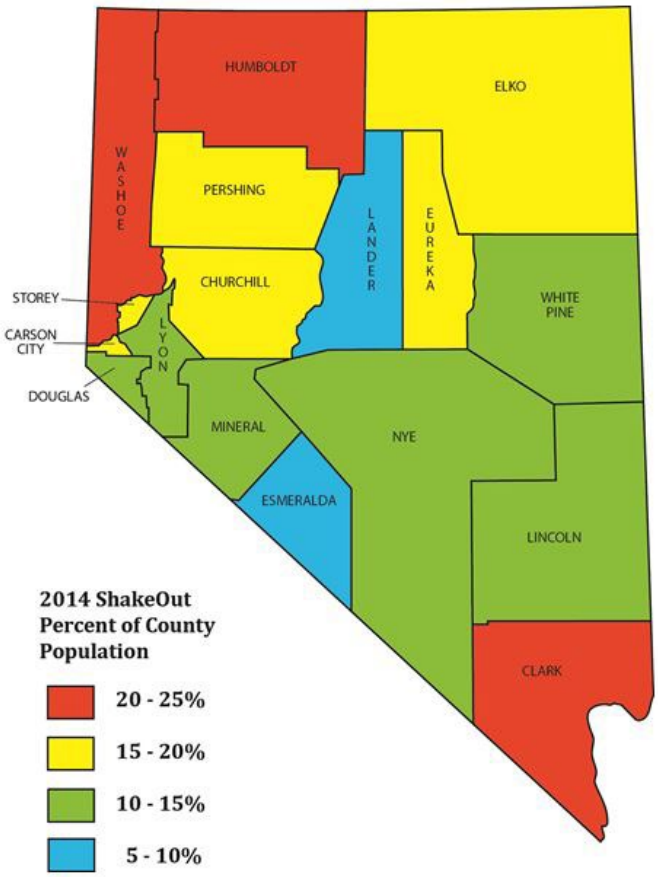

Figure 3. Percentage of county population that participated in the 2014 Great Nevada ShakeOut. Figure from dePolo (2015).

MINERAL COUNTY COMMUNITY ASSESSMENT FOR PUBLIC HEALTH EMERGENCY RESPONSE (CASPER)

In 2018, The Nevada Division of Public and Behavioral Health conducted a survey in Mineral County "to evaluate the emergency preparedness capabilities and public health needs of its communities." This involved 170 interviews within the county assessing a wide range of emergency and preparedness questions. The survey results provide some insight into these aspects in a frontier and rural Nevada setting, and several of the results are discussed here. First, the most prevalent hazard listed to affect their county was earthquakes, which were ranked number one by 60.6% of households surveyed. For preparedness, 38% of households surveyed felt they were prepared for an emergency, and 48.9% were somewhat prepared for an emergency. This supports the notion that residents in frontier and rural areas are generally prepared for emergencies, with 86.9% of households having some level of preparedness. In addition, 90.4% of surveyed households stored three days' worth of food per person, and 67.2% of surveyed households owned emergency kits. These are very encouraging statistics. Lastly, when asked where residents would acquire reliable emergency information, 46.3% of households surveyed would learn information from law enforcement, 24.2% would learn information from a family member or friend, and only 11.9% would obtain information from regional news outlets. The Mineral County survey reinforces a natural resilience that exists in frontier and rural environments and underscores that these Nevadans are aware of earthquake hazards. It also suggests that law enforcement could be a trusted messenger of mitigation information. As a last note, the emergency manager for Mineral County commented in an interview that one of the main inhibitions to mitigation in his county was financial—that many people didn't have the extra funds to mitigate for shaking. Communicating low- and no-cost seismic mitigation techniques could be helpful in this setting.

COUNTY MITIGATION PLANS AND EARTHQUAKE RESILIENCY

County mitigation plans expand beyond individual preparedness and attempt to address broader issues, such as reducing the risk of unreinforced masonry buildings. Counties are required to rank their hazards in the plans, and this ranking tends to be influenced by current or recent disasters, which is logical. This is not a critique of these plans, rather we are using them as another metric for this study. Overall, the three county plans are well developed.

The results of this review are that Mineral County ranked earthquakes as the highest countywide hazard, Nye County ranked earthquakes in a tie for second highest, and Esmeralda County ranked earthquakes as third highest (behind drought and flood). Additionally, Mineral County ranked the planning significance of an earthquake to be high and Esmeralda County ranked it as moderate (Nye County did not indicate this ranking). All three counties profiled earthquakes in their hazard section and gave fairly accurate portrayals of their respective earthquake hazards. All three counties recommended continuing to require building codes for new construction and addressing unreinforced masonry buildings, two of the most effective long-term earthquake risk reduction measures. Beyond this, the counties focused on aspects that were more important to each county, including attention to the earthquake risk of critical facilities, industrial facilities, utility infrastructure, and mobile homes.

The three counties ranked earthquakes as one of their top three hazards and articulated specific goals that will help them become earthquake resilient. It should also be noted that Nye County recently commissioned a study to

characterize the earthquake hazard in the county and recommended additional steps towards mitigation; this is a significant acknowledgement and investment by the county towards understanding its earthquake risks and how to become earthquake resilient.

THE COVID PANDEMIC AND MITIGATION

The Monte Cristo Range earthquake occurred during the COVID-19 pandemic of 2020–2021. This pandemic illustrated some aspects of mitigation that may not have been totally appreciated in our efforts to promote earthquake mitigation. Stated directly, individual belief systems and political beliefs can be a deciding factor in whether people will consider taking a mitigative action or not. In the case of the pandemic, a notable percentage of the population decided not to take mitigative steps for the virus in the first year. This is a complicated topic involving aspects such as social cueing from the internet and many personal beliefs that made suggestions to influence people to take mitigative actions difficult. Local champions appeared to have the best chance at influencing a reluctant public. The pandemic was ongoing during the earthquake and response, so we mention it as an insight into roadblocks to mitigation efforts that are sometimes encountered.

CONCLUSIONS

Overall, residents in this tri-county region possess a fairly strong baselevel of awareness about earthquakes that can be built upon. This awareness comes from historical earthquakes, felt earthquakes, and common mining and geologic concepts. A sampling of residents from Mineral County supports this by having the largest percentage ranking earthquakes as their number one hazard, and all three county mitigation plans included earthquakes in their top three hazards. Residents also possess a certain baselevel of understanding and familiarity with dealing with disasters, such being prepared to deal with weather isolation. Again, viewing the Mineral County survey, over a third were prepared for an emergency, almost half were at least somewhat prepared, and over 90% had food for each person for at least three days.

Factors that inhibit mitigation progress with individuals and families but that can potentially be worked around include financial thresholds, lack of internet access, lack of direct outreach, and high levels of competition with high-demand daily life activities.

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