**Geotechnical Extreme Events Reconnaissance Association**
**www.geerassociation.org**

# GEOTECHNICAL ENGINEERING RECONNAISSANCE OF THE 30 NOVEMBER 2018 M7.0 ANCHORAGE, ALASKA EARTHQUAKE

Version 1.0

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# Geotechnical Engineering Reconnaissance of the 30 November 2018 Mw 7.0 Anchorage, Alaska Earthquake

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We acknowledge the time and consideration of the numerous residents of Anchorage and the surrounding communities. Your first-hand experiences and observations greatly improved our understanding of this event and added valuable perspective.

# EXECUTIVE SUMMARY

A M7.0 earthquake occurred at 08:29 AM local time on November 30, 2018 approximately 11.3 kilometers north of downtown Anchorage, Alaska (61.346°N, 149.955°W). The instraslab event occurred due to normal faulting within the subducting Pacific plate at an approximate hypocentral depth of 40 kilometers beneath the ground surface. 25 functional ground motion instrument stations recorded the earthquake. Most of these stations showed recorded peak ground accelerations (PGA) between 0.2 g and 0.3 g, with the highest PGA value of 0.474g in the midtown section of Anchorage.

Between the dates of December 8 through 15, 2018, the Geotechnical Extreme Events Reconnaissance Association (GEER) deployed a multi-disciplinary Phase I team comprised of seven investigators to observe and document the significant geotechnical engineering impacts and lessons learned from this event. The GEER team collaborated closely with other engineering reconnaissance efforts including those led by the Earthquake Engineering Research Institute (EERI), the Structural Extreme Events Reconnaissance Association (StEER), the U.S. Geological Survey (USGS), and the Alaska Division of Geological & Geophysical surveys (DGGS). The GEER team also benefited greatly from coordination and partnerships with the local geotechnical engineering community and the Municipality of Anchorage (MOA) Geotechnical Advisory Commission (GAC), state department of transportation engineers, Anchorage building officials and engineering service managers, municipal public works officials, National Institute of Standards and Technology (NIST) and Federal Emergency Management Agency (FEMA) officials, and various municipal emergency response coordinators. Currently, GEER plans to deploy a Phase II team focused on remote sensing and geophysical data collection in spring 2019 - after the snowmelt.

No fatalities were reported following the November 30 Anchorage earthquake, and initial damage assessments suggest that most infrastructure damage was non-structural. Nearly all significant embankment slope failures along highways and major arterials were repaired by the State of Alaska Department of Transportation & Public Facilities (AKDOT) within one week of the event. In addition, deep intraslab earthquakes like those of the November 30 Anchorage event have historically produced smaller ground motion intensities and relatively insignificant infrastructure damage in developed regions of the world. However, despite these favorable observations and outcomes, the November 30 Anchorage earthquake should not be disregarded or classified as an insignificant event. The November 30 Anchorage earthquake is significant to the engineering community for the following reasons:

1. The November 30 Anchorage earthquake is the largest magnitude earthquake to strike near a major U.S. city since the 1994 Northridge earthquake.
2. A significant number of co-seismic landslides and liquefaction ground failures have already occurred in Anchorage in recent history, most notably during the 1964 M9.2 Good Friday earthquake.
3. The Anchorage area currently has a relatively dense network of ground motion recording stations, including instrumented structures and deep vertical arrays.

4. Numerous challenging soil conditions exist in the region including relatively sensitive clays, liquefiable soils, soft organic soils, and a seasonally frozen crust that is 15-50 cm thick.
5. The November 30 Anchorage earthquake provides the opportunity to assess the effectiveness of seismic provisions in modern building code; the Municipality of Anchorage currently adopts and enforces the 2012 International Building Code (IBC).
6. Various types of geotechnical site improvements (e.g., deep soil mixing, deep dynamic compaction, and excavation and replacement) have been implemented across Anchorage over the past 50 years, allowing us to observe and document the seismic performance of these types of ground improvements.

Based on the observations from the GEER Phase I team and its collaborators, many significant lessons learned can be taken from the November 30 Anchorage earthquake, including:

1. Only three instances of structural collapse were observed by the GEER Phase I team. This observation suggests that modern building code, when implemented properly, is generally effective in preventing structural collapse for ground motions equal to or less than the design ground motion.
2. It seems that the duration of strong shaking from the M7.0 event was not long enough to initiate substantial movements on the historic landslides from the 1964 M9.2 earthquake, including the slides at the Turnagain Heights and 4th Avenue. Investigators from the USGS were able to observe very small cracks forming at the head of the historic slides at the Turnagain Heights (no cracks were observed at the 4th Avenue slide) prior to the arrival of the GEER team and the substantial snowfall that occurred during the week of December 8. However, these cracks are believed to have developed in response to the ground oscillation from the November 30 event and are not believed to indicate a reactivation of the slides.
3. Although the Port of Alaska experienced some damage to its administration building, terminals, and experienced ground deformations in isolated areas, the damage was limited in impact and Port operations were delayed for only a short period of time. Efforts to counter significant corrosion of terminal-supporting piles and fenders appeared to provide significant benefit during the earthquake.
4. While the majority of the damage that was observed in Anchorage and in the surrounding communities appeared to be non-structural, the isolated cases of structural damage that were observed by the GEER team appeared to be caused by geotechnical issues, particularly settlement of the foundation and/or slope deformations. Such cases of structural damage were also more commonly observed in residential structures and small commercial structures. Larger commercial or industrial structures generally performed well in the November 30 event.
5. Structural damage and significant embankment deformations appeared to occur most frequently in areas where significant amounts of organic soils are located (e.g., swampy areas or peat bogs), or in areas of sloping ground.
6. While isolated instances of soil liquefaction were observed and confirmed by the GEER team within Anchorage, it was difficult to confirm liquefaction as the cause of observed

ground deformations at many sites because of the snow cap covering the ground surface. Bearing capacity issues in organic soils produced damage similar to that observed with soil liquefaction. Additional investigation, likely in the spring after the snowmelt, will be needed to confirm the mechanism of observed ground deformations at many sites.

7. While evidences of soil liquefaction including cracks, small sand boils, and significant settlements were observed within the footprint of several residential and small commercial structures, few if any of these evidences were observed in the free-field near these structures. Additionally, the majority of these observations occurred in swampy areas such as the Sand Lake or Jewel Lake neighborhoods of Anchorage. Given the common practice of over-excavation in organic soils and replacement with sand fill in these types of areas in Anchorage, it appears that soil liquefaction in improperly placed or insufficiently compacted granular fills may have contributed to the observed structural settlements.
8. Considering all of the structural settlements and slope deformations that were observed by the GEER team, the vast majority of these involved anthropogenic fills. In some cases (e.g., Vine Road embankment failure), it is clear that the deformations occurred due to loss of shear strength in the underlying bearing soils. In other cases, it is not yet clear whether the deformations occurred within the fills themselves or in the underlying bearing soils.
9. The GEER team visited several sites in Anchorage where soil ground improvement had been installed, and all were observed to have performed well during the November 30 earthquake. However, it is important to note that many more sites without soil ground improvement were visited and were observed to also perform well.
10. In terms of resiliency, the combined local, state, and federal engineering response to the November 30 Anchorage earthquake is commendable. The GEER team deployed to Anchorage within eight days of the event. However, within the eight-day span between the earthquake and our team’s arrival, all major highway embankment deformations had been repaired, utility services had been restored to nearly all customers, all highway and road bridges had been inspected, and structural repairs to many residences were already underway.

This Version 1.0 report is intended to provide an executive summary of the significant observations and findings from the GEER Phase I field deployment. A more detailed report documenting the observations and findings from the GEER Phase I team (Version 2.0) will be prepared and released in early 2019.

# INTRODUCTION

The moment magnitude 7.0 (M7.0) Anchorage earthquake occurred on 30 November 2018 at 08:29 AM local time and caused widespread power outages, structural and non-structural damage to buildings, damage to roadways and railways, and closure of schools and businesses. The earthquake initiated below the southern Susitna lowlands (61.346°N, 149.955°W) approximately 11.3 kilometers north of downtown Anchorage at a hypocentral depth of 40 kilometers (Figure 1).

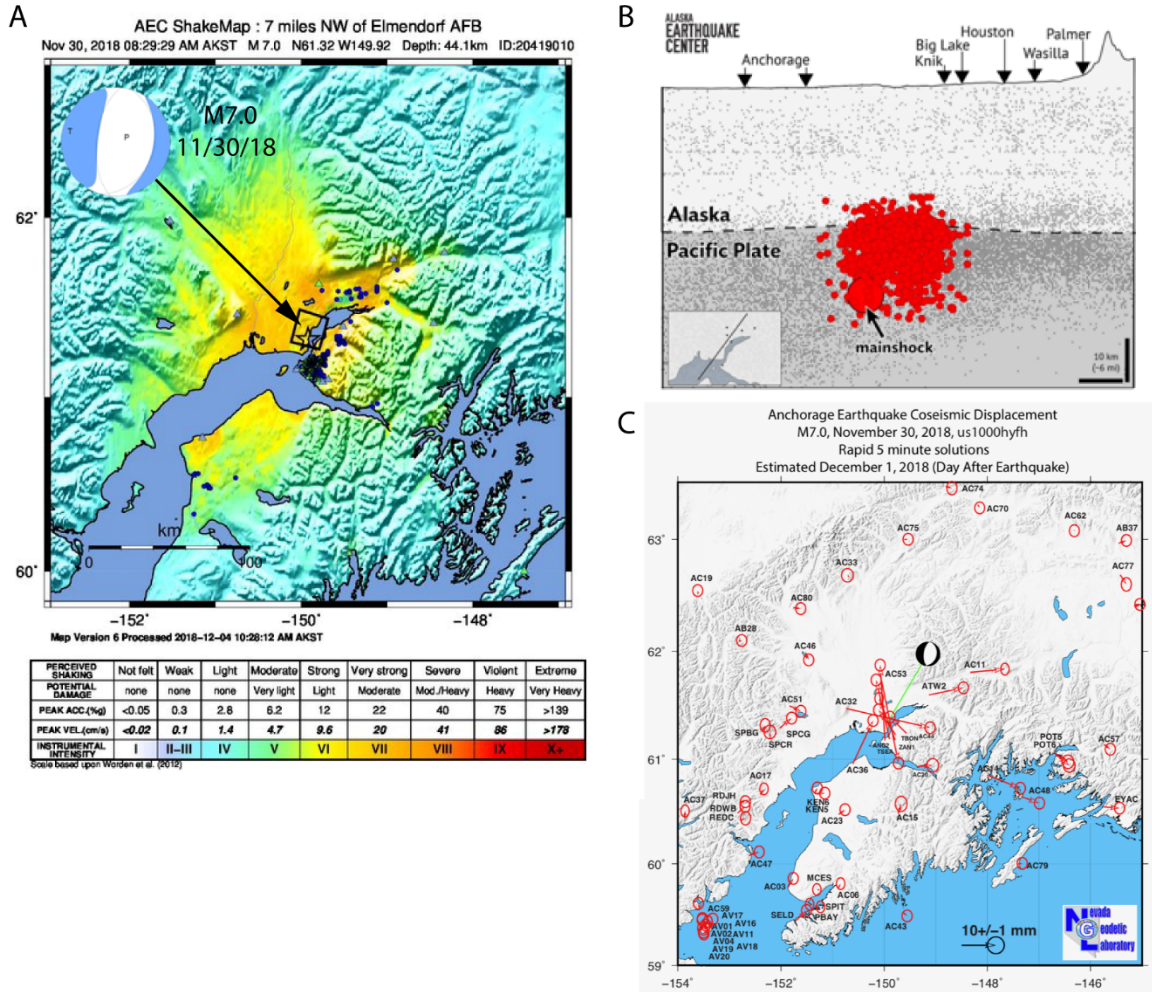
The earthquake was located within the subducting Pacific Plate and was the result of normal faulting along a north-south striking, moderately dipping, intraslab fault plane. This type of earthquake is common in the region and is similar to the M7.1 Iniskin earthquake that occurred in 2016. Although these types of deep, intraslab earthquakes are commonly associated with minor structural damage, the close proximity of the November 30 event to the Anchorage metropolitan area resulted in more severe damage that affected the City of Anchorage and the nearby communities of Wasilla, Houston, Palmer, and Eagle River. Despite significant impacts to infrastructure, loss of life did not occur.

The NSF-funded Geotechnical Extreme Events Reconnaissance (GEER) association mobilized a multidisciplinary team to the affected region from 8 to 15 December 2018. Our team was comprised of seven experts in the fields of liquefaction, slope stability, geotechnical engineering, ground improvement, ground motions, and earthquake geology. Our team included co-leaders Kevin Franke (Brigham Young University) and Rich Koehler (University of Nevada, Reno), as well as members Armin Stuedlein (Oregon State University), Ian Pierce (University of Nevada, Reno), Ashly Cabas (North Carolina University), Zhaohui (Joey) Yang (University of Alaska Anchorage), and Christine (Zee) Beyzaei (SAGE Engineers, Oakland). The team worked in close collaboration with local geotechnical engineering consultants, the Municipality of Anchorage Geotechnical Advisory Commission, students and researchers from the University of Alaska Anchorage, and the U.S. Geological Survey. The main objectives of the GEER team were to identify, observe, and document perishable data and assess general patterns of damage to better understand earthquake effects. This type of information is important for improving engineering design, informing future planning efforts, and reducing society's exposure to seismic risk. The 8 to 15 December GEER deployment has been classified as a Phase I deployment. A second GEER deployment (Phase 2) focusing on remote sensing and geophysical data collection will likely occur in late spring after the snowmelt.

Our approach was to inspect and document damage throughout the affected area using a combination of on-ground site mapping and aerial reconnaissance with state-of-science geomatics technology and photogrammetry. The combination of techniques results in a thorough characterization of damage and provides baseline data for innovative future research. This report (Version 1.0) provides an executive summary of our activities and preliminary findings and is intended to be an easily accessible resource for the technical community as well as city, borough, state, and federal personnel responding to the event. Following this executive summary report, a larger report presenting a more thorough description of the significant aspects, sites, and observations from the earthquake will be released in early 2019 (Version 2.0).

# SUMMARY OF EARTHQUAKE

The M7.0 November 30 earthquake began at a hypocentral depth of about 40 kilometers and was associated with a moment release of 4.71e+19 N-m. Very strong shaking intensities (MMI VII) were experienced in the greater Anchorage, Eagle River, Wasilla, and Palmer areas with moderate to strong shaking intensities (MMI V-VI) felt throughout the Susitna Basin and northwestern Kenai Peninsula (Figure 1A). A preliminary assessment of the aftershocks by the Alaska Earthquake Center (AEC) indicates that the rupture began in the subducting Pacific plate and ruptured upward and towards the north along a plane ~24-40 kilometers in length (Figure 1B). As of December 27, 2018, there have been over 6,100 aftershocks including over 40 M>4 and 5 M>5 aftershocks in the sequence (AEC). Preliminary analyses of the geodetic signal the day after the earthquake by the Nevada Geodetic Laboratory (NGL) indicate north-south contraction and coseismic ESE oriented horizontal displacements of about 2 cm in Anchorage (Figure 1C). The measured displacements extend farther towards the east, suggesting that the slip occurred on the shallower, down to the east nodal plane observed in the seismic data (William Hammond, NGL, pers. comm.). Thus, the available data suggests that the earthquake is best characterized as an intraplate normal faulting event.




| PERCEIVED SHAKING | Not felt | Weak | Light | Moderate | Strong | Very strong | Severe | Violent | Extreme |
|---|---|---|---|---|---|---|---|---|---|
| POTENTIAL DAMAGE | none | none | none | Very light | Light | Moderate | Mod./Heavy | Heavy | Very Heavy |
| PEAK ACC.(%g) | <0.05 | 0.3 | 2.8 | 6.2 | 12 | 22 | 40 | 75 | >139 |
| PEAK VEL.(cm/s) | <0.02 | 0.1 | 1.4 | 4.7 | 9.6 | 20 | 41 | 86 | >178 |
| INSTRUMENTAL INTENSITY | I | II–III | IV | V | VI | VII | VIII | IX | X+ |

**Figure 1.** (A) Location of the epicenter, focal mechanism, and shaking intensities in the affected area (source: USGS), (B) a cross section of the epicenter and distribution of aftershocks (source: Alaska Earthquake Center), and (C) Preliminary assessment of geodetic displacement vectors provided by William Hammond of the Nevada Geodetic Laboratory

# Immediate Response and Preliminary Reconnaissance Efforts

The earthquake occurred in the early morning hours of November 30th (8:29 AM AK Time) as most of the region was beginning their daily routine and resulted in the immediate closure of many businesses and schools. Widespread power outages, water line shut-offs, and traffic congestion were some of the immediate impacts across the region in the hours after the event as residents tried to contact family and friends and make their way home to assess damages. Information of more severe damage to roadways and buildings began rapidly circulating throughout the area on social media and news outlets, prompting the USGS and DGGS to mobilize helicopter and ground surveys to evaluate the extent and severity of landslides and evaluate geologic effects. These initial surveys proved invaluable to our team as snowfall began to cover evidence of ground deformation in the days following the event. Upon arrival, our team was briefed by the USGS and DGGS, and we utilized their GPS locations and photographs of observed landslides and liquefaction phenomena to inform our field reconnaissance. A map showing the locations visited by the GEER team is presented in Figure 2.

In addition to the USGS and DGGS, valuable preliminary information regarding post-earthquake structural and non-structural damage assessment and site locations was obtained through collaboration and coordination with several organizations and groups (Figure 3). For example, our team communicated regularly with reconnaissance teams from EERI and StEER, participating in regular information sharing and coordination meetings organized by EERI. Local geotechnical engineering groups including the MOA GAC also met with and briefed our team on information they had obtained following the earthquake. Engineers from AKDOT met with our team and educated us on the status of transportation infrastructure in the region. Our team was also referred to MOA building safety officials and public works officials/engineers, who subsequently collaborated with us and provided much valuable information regarding the distribution, type, and frequency of reported infrastructure damage. Based on the observations and recommendations from these local professionals, our team developed a list of priority sites to investigate during our deployment. This list of priority sites evolved during the week of our deployment as additional information was collected by us and our collaborators.

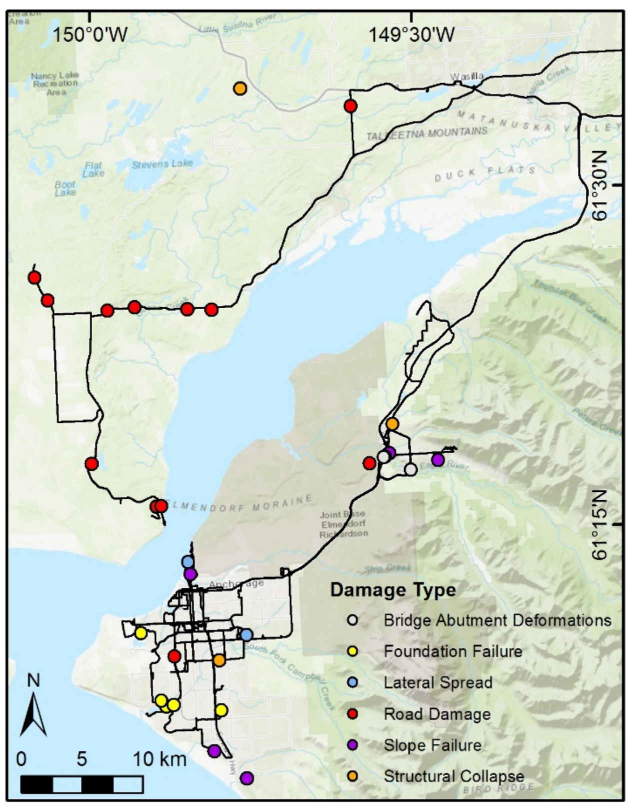



**Figure 2.** Map showing track lines (black) and locations of damage observed and documented by the GEER team (colored dots).

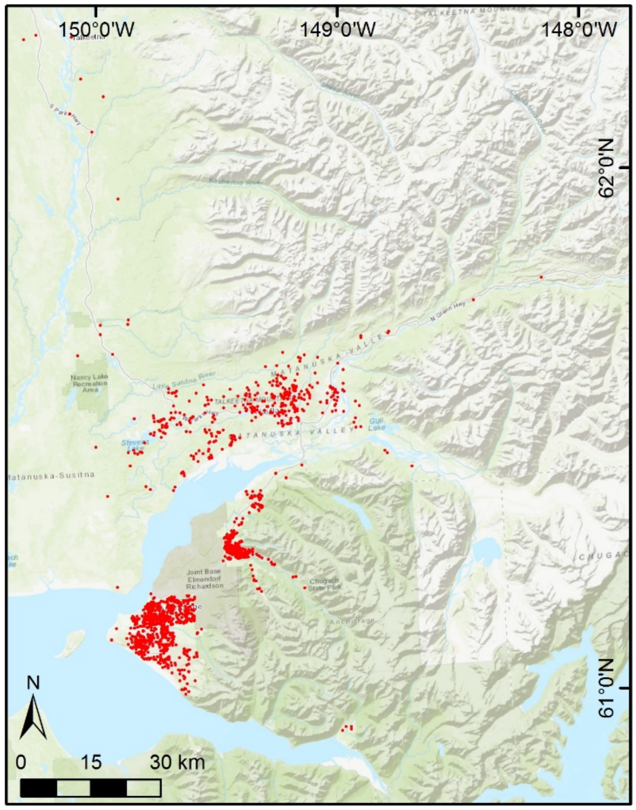



**Figure 3.** Map of the affected area showing locations of self-reported structural and non-structural damage (red dots). Damage distribution information provided by Casey Cook, Mat-Su Borough emergency manager and Ross Noffsinger, acting building official, Municipality of Anchorage.

# Regional Tectonics and Seismicity

Tectonic deformation in south-central Alaska is driven by subduction of the Pacific Plate beneath the North American plate along the Alaska-Aleutian subduction zone and has created the rugged Chugach Mountains and the Cook Inlet forearc basin. Seismicity includes events in the shallow crust, intermediate and deep interplate events along the shallowly dipping subduction interface, and intraplate events that represent internal deformation of the subducting Pacific Plate. Shallow crustal sources include fault-cored folds in upper Cook Inlet and the Castle Mountain fault which extends across the Susitna lowland north of Anchorage. Many earthquakes originating within the Pacific Plate are felt in Anchorage every year. Significant events include the 2016 (M7.1) Iniskin earthquake and the 2014 (M6.3), 1999 (M5.2), and 1991 (M6.3) events.

The Alaska-Aleutian subduction zone was the source of the 1964 M9.2 Great Alaska earthquake, which ruptured over 800 km of the plate interface and was associated with up to 25 m of horizontal displacement. The 1964 earthquake caused major ground shaking and landslide damage in Anchorage and generated a destructive tsunami that devastated coastal communities in Prince William Sound. Similar events are thought to have occurred nine times in the last 5,000 years with recurrence intervals ranging between 333 and 875 years (Carver and Plafker, 2008).

# REGIONAL GEOLOGY

## Bedrock and Quaternary geology, Upper Cook Inlet

Mesozoic crystalline igneous and metamorphic rocks comprise the basement bedrock in the region. These rocks are overlain by weakly consolidated clastic sedimentary rocks of Tertiary age that are up to 3,900 m thick (Figure 4). Late Quaternary deposits in the region include extensive glaciomarine deposits, glacial moraines, ice-stagnation deposits, and alluvium associated with proglacial fluvial systems, and extensive swamps and peat bogs (Reger and Updike, 1993). The Quaternary depositional package is up to 1,200 m thick in the lower Susitna River area (Reger and Updike, 1993). Surficial geologic units in Anchorage primarily consist of glaciomarine Bootlegger Cove formation and glacial deposits (described below). Surficial deposits are saturated across much of the region and are susceptible to liquefaction.

## Surficial Geology, Anchorage area

The Quaternary geology of the Anchorage vicinity is the result of several major glaciations. The stratigraphy and timing of their deposition is detailed in Miller and Dobrovolny (1959) and Reger et al. (1995). The oldest glacial deposits are associated with the Eklutna glacier and include till and outwash deposits that are exposed north of the Eagle River Flats along the Knik Arm bluff. Deposits associated with the Knik glaciation are variably exposed throughout the Anchorage area and include lateral and ground moraines, pitted outwash, glaciofluvial and ice-contact deposits, and glaciomarine clay known as the Bootlegger Cove formation. The Bootlegger Cove formation is one of the more extensive deposits in the area and underlies the Susitna Basin, Anchorage, and the region to the south of the city. The Bootlegger Cove formation consists of glaciomarine clay, silty clay, and silty fine sand with variable amounts of medium grained sand and gravel (Updike, 1984). Major destructive landslides originated in the Bootlegger Cove formation during the 1964 earthquake. The youngest glacial deposits are associated with the latest Pleistocene Naptowne glaciation, overly deposits of the Knik glaciation, and include sorted and unsorted glacial drift, well preserved moraines, kame fields and kame terraces, and outwash.

Inspection of the surficial geologic map in Figure 4 indicates that Holocene alluvial fans bury glacial deposits over much of northwest Anchorage including downtown. Glaciomarine deposits are the dominant surficial unit in the midtown area. Undifferentiated late Pleistocene glacial deposits are exposed along the eastern part of the Anchorage Bowl along the base of the Chugach Mountains and in the vicinity of the airport. The Bootlegger Cove formation is exposed along the coastal bluffs from the vicinity of the Port of Anchorage to the airport and within the lower Campbell Creek drainage. A narrow northeast trending band of glaciodeltaic deposits is exposed southeast of Campbell Creek in south Anchorage.

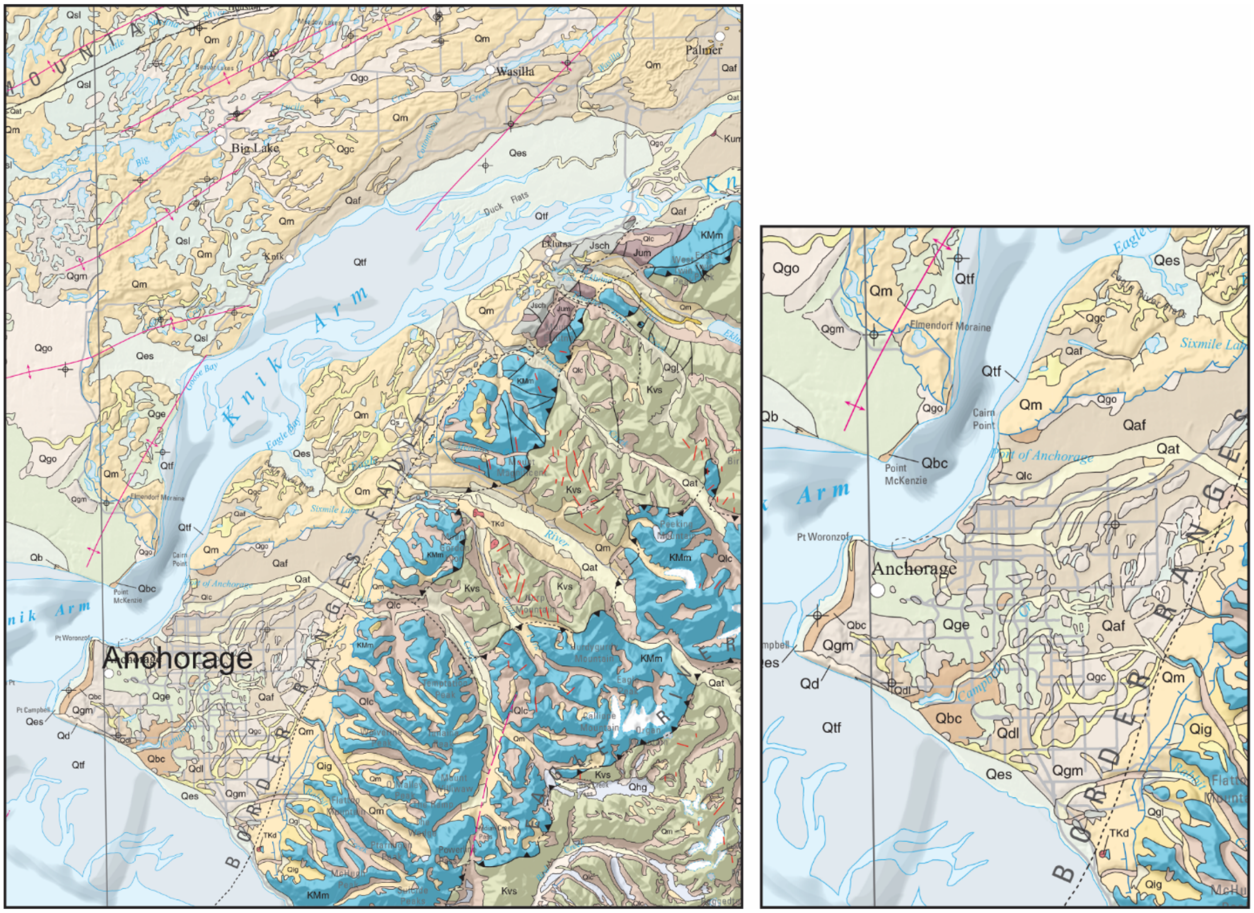



**Figure 4.** Part of the geologic map of the Cook Inlet region (after Wilson et al., 2012). Main area affected by the earthquake (left) and close up view of Anchorage (right).

# Ground Motions

## Seismic Network in Anchorage

The seismic network in the metropolitan area of Anchorage is operated and maintained by the USGS (through their National Strong Motion Project, NSMP), and by the Alaska Earthquake Center (AEC). The latter operates seismic monitoring stations across the state of Alaska, and their data center is located at the Geophysical Institute on the University of Alaska Fairbanks campus (UAGI). Data from these networks are disseminated at (https://strongmotioncenter.org/cgi-bin/CESMD/iqr_dist_DM2.pl?iqrid=us1000hyfh, and https://earthquake.alaska.edu/network). There are 20 free field strong motion recording stations operated by UAGI, and 24 NSMP recording stations. In addition, there are various instrumented high-rise buildings (i.e., structural arrays) located in different parts of Anchorage, including the Atwood building (Lat/Long: 61.2150, -149.8930; close to the Delaney Park downhole array with seven sensors down to a depth of 61 m), the BP building (Lat/Long: 61.1920, -149.8640), the Frontier Building (Lat/Long: 61.1880, -149.8840), and the Hilton Hotel (Lat/Long: 61.2190, -149.8920). Figure 5 depicts the density and coverage of the seismic network available in the region impacted by the recent M7.0 earthquake, which creates a unique opportunity to further investigate the impacts of this event. We learned that some of the recorded motions from the Center for Engineering Strong Motion Data, CESMD, and the AEC were still being processed. Our team also learned that some instruments did not record data during the November 30 Anchorage earthquake due to technical issues. Considering these factors, we decided to focus the reconnaissance efforts on the stations where reliable data were recorded and/or knowledge of significant damage nearby was available.

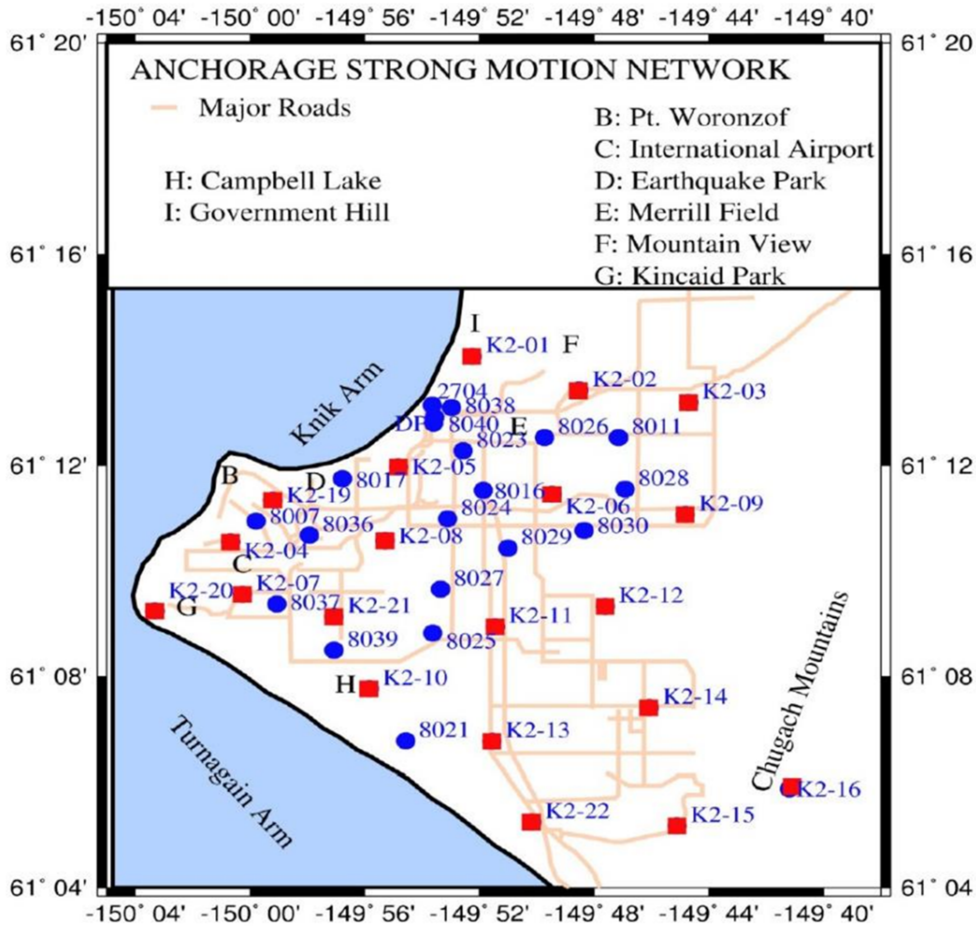



**Figure 5.** Anchorage Strong Motion Network. The red squares are the free-field recording stations operated by the University of Alaska, and blue circles are USGS stations (after Dutta and Yang, 2010).

A list of ground motion recording stations (and the corresponding recorded ground motions) was downloaded from the CESMD website, and their locations were cross-matched with identified infrastructure with significant level of damage. The latter information resulted from a preliminary list of relevant sites made during our first meeting with the local geotechnical engineering and engineering seismology community, and additional lists of damaged buildings (i.e., yellow- and red-tagged) shared by the Municipality of Anchorage. We identified 40 stations with reliable data (from the CESMD website, the AEC website, and the USGS ShakeMap). Out of those 40, 14 had available records on the CESMD website by the time of completion of this Version 1.0 report.

During our reconnaissance efforts, we visited more than 30 sites in the vicinity of those 14 stations. It is important to note that as more records become available, our team will continue to investigate the characteristics of those ground motions to identify candidate sites where additional subsurface characterization (including geophysical testing) can become relevant. Table 1 presents the peak ground accelerations (PGA) at selected stations from the CESMD. Only free field motions have been processed for version 1 of this report. Values of PGA corresponding to the recorded data at the basement of the four instrumented buildings are reported directly from the CESMD website (i.e., stations 2716 (Lat/Long: 61.2190, -149.8920); 8040 (Lat/Long: 61.2150, -149.8930); 8016 (Lat/Long: 61.1920, -149.8640); and 8042 (Lat/Long: 61.1880, -149.8840)). Our Version 2 report will provide analyses of the remaining data and any new recordings processed and uploaded to the CESMD and/or AEC websites. It is also important to note, that the corresponding records from station NSMP 8047 (Lat/Long: 61.1890, -149.8020) were no longer available at the CESMD website by the time of completion of this report.

**Table 1.** Peak ground accelerations at selected stations operated by the USGS, and the AEC.

| Station ID | Station Name | Latitude | Longitude | Epicentral Distance (Km) | PGA HNN (g) | PGA HNE (g) | Visited by GEER team |
|---|---|---|---|---|---|---|---|
| K223 | AK:Anchorage;Gvt Hill Elem Sch | 61.2338 | -149.8675 | 12.4 | 0.180 | 0.269 | Y |
| 2716 | AK:Anchorage;Hilton Hotel | 61.2190 | -149.8920 | 13.7 | 0.214 | 0.208 | Y |
| 8038 | AK:Anchorage;FS 01 (Central) | 61.2184 | -149.8829 | 13.9 | 0.254 | 0.293 | Y |
| 8040 | Anchorage - R B Atwood Bldg | 61.2150 | -149.8930 | 14.3 | 0.208 | 0.208 | Y |
| 8016 | AK:Anchorage;BP Bld | 61.1920 | -149.8640 | 16.9 | 0.283 | 0.283 | Y |
| 8042 | AK:Anchorage;Frontier Bld | 61.1880 | -149.8840 | 17.2 | 0.193 | 0.193 | N |
| 8036 | AK:Anchorage;DOI OAS | 61.1779 | -149.9657 | 18.1 | 0.392 | 0.276 | Y |
| 8047 | AK:Anchorage;USGS ESC | 61.1890 | -149.8020 | 18.3 | - | - | Y |
| 8030 | Anchorage - Police HQ | 61.1795 | -149.8058 | 19.3 | 0.290 | 0.227 | Y |
| 8027 | AK:Anchorage;St Fish&Game | 61.1609 | -149.8894 | 20.1 | 0.193 | 0.472 | Y |
| 8037 | Anchorage - NOAA Weather Fac | 61.1563 | -149.9850 | 20.7 | 0.361 | 0.277 | Y |
| 8021 | AK:Anchorage;Klatt Elem Sch | 61.1129 | -149.9095 | 25.4 | 0.113 | 0.123 | Y |
| 2738 | AK:Cantwell;ADOT Maint Sta | 63.3890 | -148.8850 | 234.8 | 0.125 | 0.125 | N |
| 2767 | AK:Fairbanks;Moose Creek Dam | 64.7930 | -147.1810 | 410.8 | - - | - - | N |

# Recorded Ground Motions

The ShakeMap from the USGS corresponding to the November 30 Anchorage earthquake is shown in Figure 1. The maximum peak ground acceleration recorded from this event was 0.472g at the NSMP station #8027, which is located adjacent to the Alaska Department of Fish and Game building (Lat/Long: 61.1609, -149.8894). Figure 6 shows the location of this station relative to the epicenter of the November 30 Anchorage earthquake, as well as other selected stations from seismic network in the region, and Shakemap PGA and Modified Mercalli Intensity (MMI) contours.

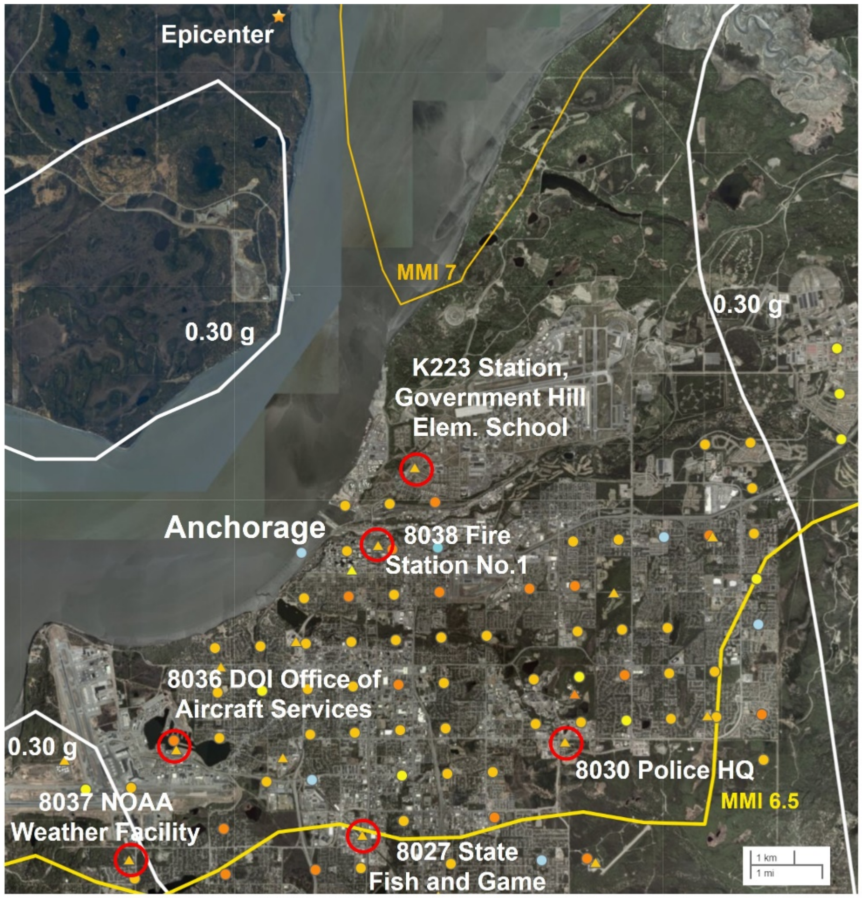



**Figure 6.** Location of selected stations (triangles) in the network, and Did you Feel It (DYFI) ShakeMap stations (circles). Modified after ShakeMap produced for this event by the USGS (https://earthquake.usgs.gov).

Response and Fourier spectra corresponding to the two horizontal components from the mainshock recorded at station #8027 (Lat/Long: 61.1609, -149.8894) are provided in Figure 7. The polarization in the ground motion is evident as the HNE component is stronger over a wide range of spectral periods. Our team visited the site of this station, which is actually inside a locked warehouse located immediately to the north of the Fish and Game building (Lat/Long: 61.1609, -149.8894). The latter settled nearly 30 cm in one of the corners of the building. This settlement occurred within 50 m of the instrument. Damage observed at the Fish and Game building (Lat/Long: 61.1609, -149.8894) was thoroughly documented and is described in detail in later sections.

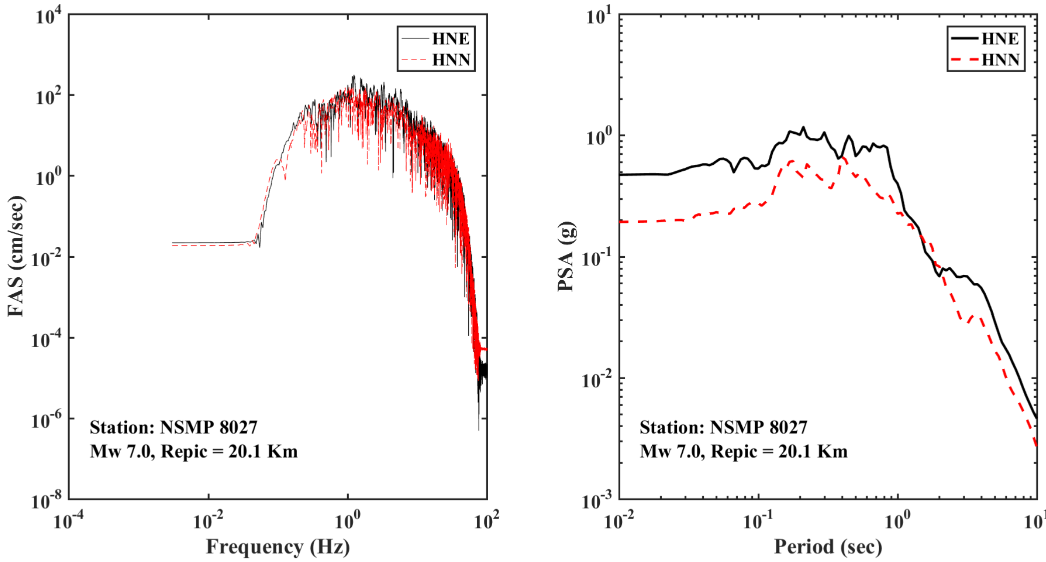



**Figure 7.** (left) Mainshock acceleration Fourier amplitude spectrum, and (right) pseudo acceleration response spectra (5% damping) for two horizontal components recorded at NSMP 8027 (Lat/Long: 61.1609, -149.8894).

Station K223 (Lat/Long: 61.2338, -149.8675) was the closest operating station (with available recorded data by the time of completion of this Version 1.0 report) to the mainshock epicenter. Figure 8 presents the Fourier amplitude spectra (FAS) and pseudo-acceleration response spectra (5% damping) corresponding to the two horizontal components recorded at station K223 (Lat/Long: 61.2338, -149.8675). The K223 ground motion also shows evidence of polarization in the HNE direction at oscillator periods lower than 1 sec. At longer oscillator periods (i.e., T> 1.0 sec), the HNN component is stronger. It is important to note that some of these recorded motions were filtered below frequencies of 0.1 Hz and above 40 Hz.

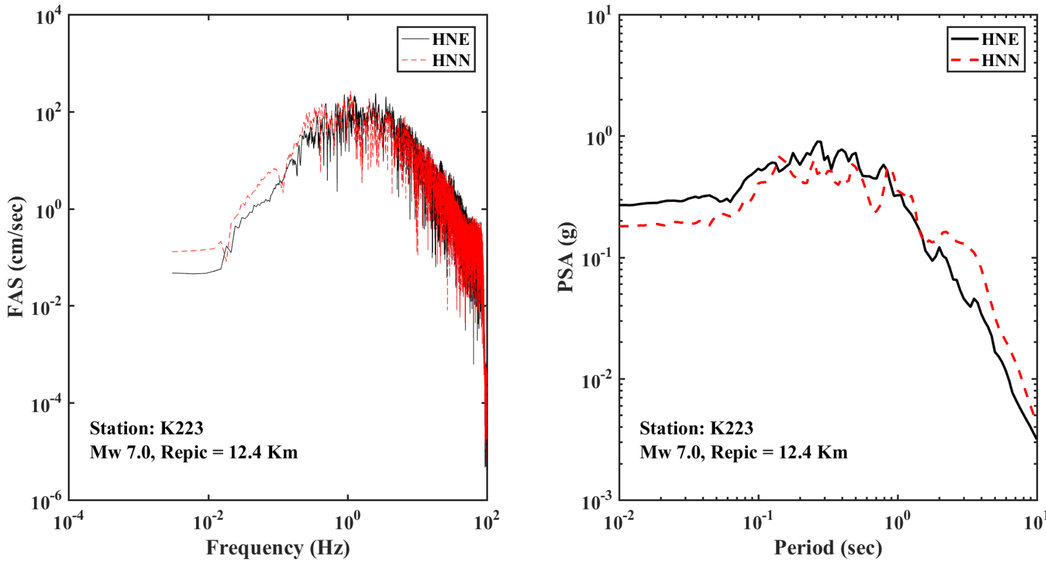



**Figure 8.** (left) Acceleration Fourier amplitude spectrum, and (right) Pseudo-acceleration response spectra (5% damping) for two horizontal components recorded at station K223 (Lat/Long: 61.2338, -149.8675).

Recorded ground motions at stations NSMP 8036 (Lat/Long: 61.1779, -149.9657), and NSMP 8038 (Lat/Long: 61.2184, -149.8829) were also considered relevant by our team due to its closeness to damaged infrastructure and observed ground failures. Station NSMP 8036 at the Department of Interior, Office of Aviation Services is located less than 1 km away from the Coast International Inn (Lat/Long: 61.1752, -149.9475), where structural damage to its first floor caused the building to be deemed not safe to be occupied. At the time of inspection by our team members, a whole area of this two-story building, where walls had shifted and separated from the foundation, was closed. Information regarding the foundation design was not available. Figure 9 provides photos of the damaged walls as well as the pseudo-spectral accelerations obtained from the recorded motions nearby at station 8036. Largest values of PSA correspond to an oscillator period of approximately 0.2 sec.

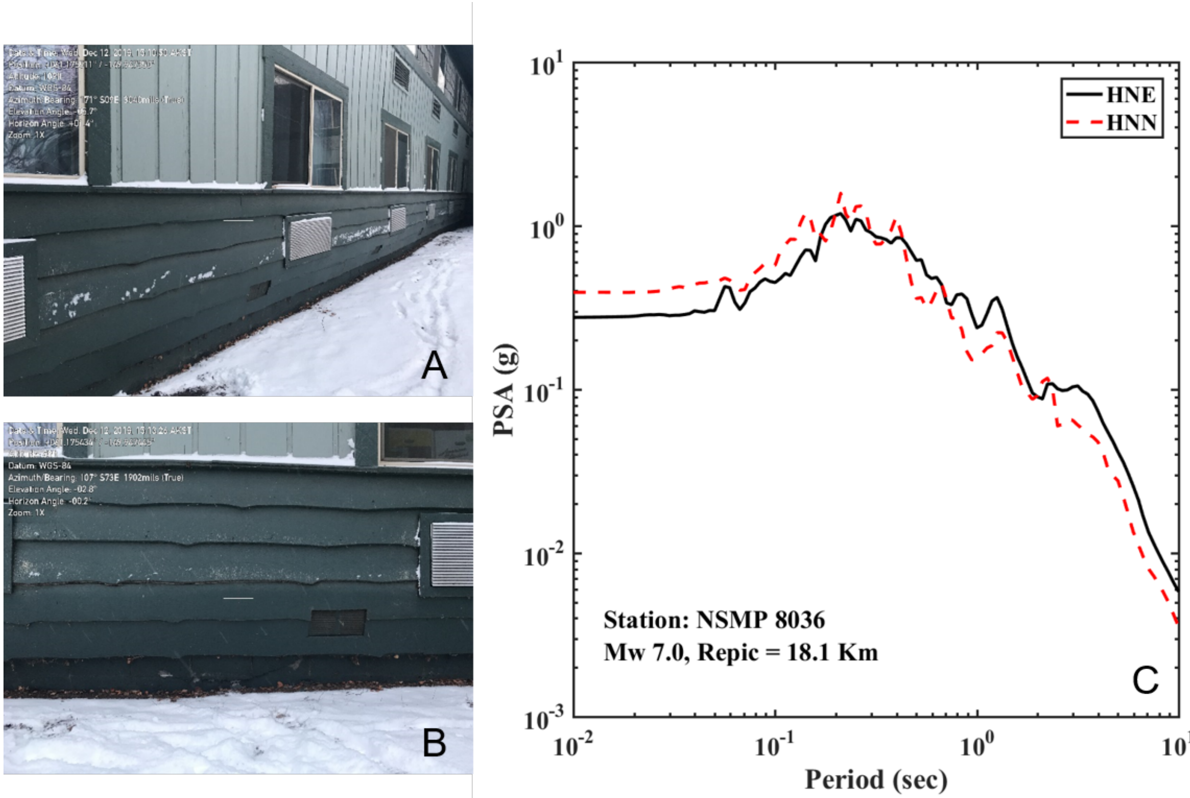



**Figure 9.** Damage observed at the Coast International Inn (Lat/Long: 61.1752, -149.9475), A) Shifted walls on the first floor, B) details of the deformation, and C) Pseudo-acceleration response spectra (5% damping) for two horizontal components recorded at station 8036 (Lat/Long: 61.1779, -149.9657).

Station 8038 (Lat/Long: 61.2184, -149.8829) is close to the Port of Alaska (Lat/Long: 61.2304, -149.8846), which makes the corresponding recorded ground motions key information to assess the performance of this critical facility during a large magnitude seismic event. Members of our team identified a slope failure adjacent to the port during their inspection of the port facilities. Due to difficulties accessing this area from the port, other members of our team documented the slope failure from the top in a public park. Photos depicting key features of the slope failure are shown in Figure 10, including a scarp of about 50 cm. It is possible that other significant cracks had been covered by the snow by the time of our inspection.

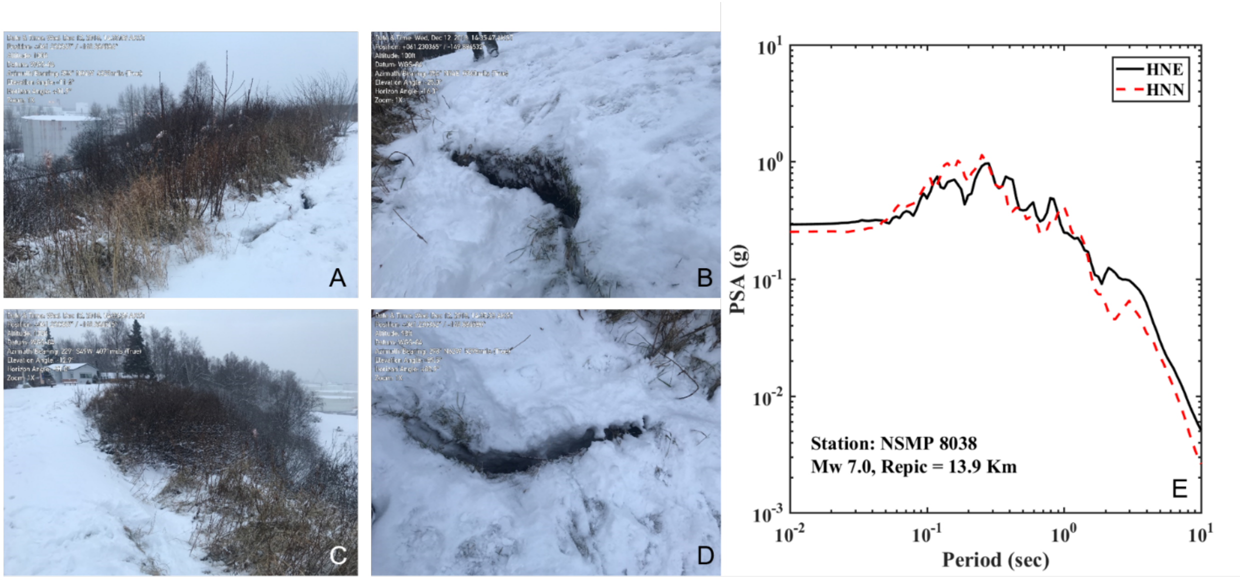



**Figure 10.** Slope failure adjacent to the Port of Alaska (Lat/Long: 61.2304, -149.8846). (A) and (C) provide an overall view of the slope and some of the port facilities, (B) depicts the approximately 50-cm scarp and, (D) shows a specific crack at this site with a width of approximately 20 cm. (E) provides the pseudo-acceleration response spectra (5% damping) for two horizontal components recorded at a nearby station (i.e., NSMP 8038, Lat/Long: 61.2184, -149.8829)

Our team also visited strong motion recording stations located near sites that performed well during this event, for example six buildings in the Alaska Native Tribal Health Consortium (ANTHC) campus. Multiple buildings with different foundation types and ground improvement techniques implemented are all located within the ANTHC, and their performance during the mainshock of the 30 November Anchorage earthquake is described in later sections of this report. Figure 11 shows response and Fourier spectra corresponding to the two horizontal components from the mainshock recorded at station NSMP 8030 (Lat/Long: 61.1795, -149.8058).

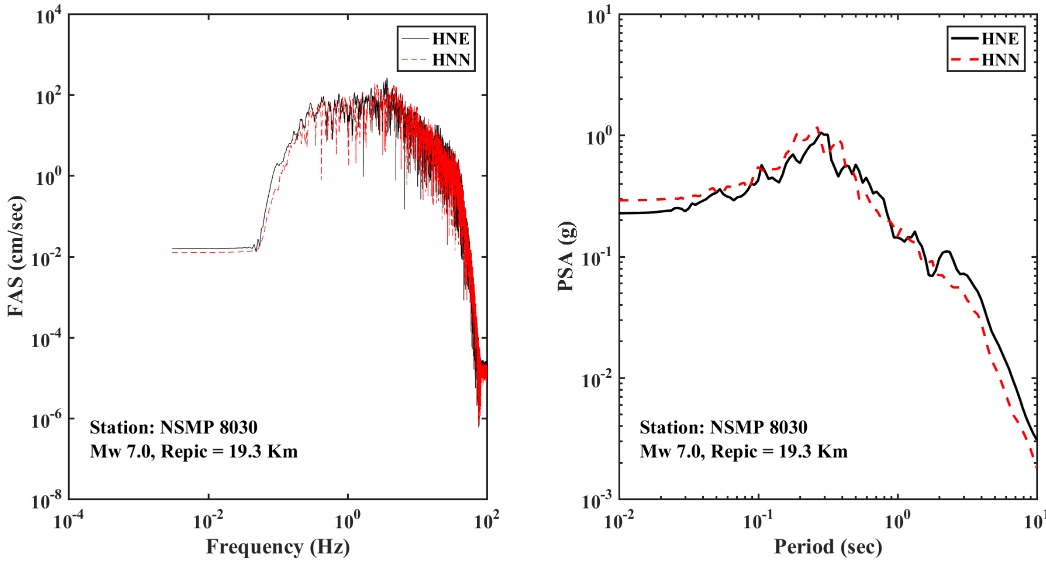



**Figure 11.** (left) Acceleration Fourier amplitude spectrum, and (right) Pseudo-acceleration response spectra (5% damping) for two horizontal components recorded at station NSMP 8030 (Lat/Long: 61.1795, -149.8058).

Minimal damage was observed in the vicinities of station NSMP 8037 (located at the NOAA Weather Facility, Lat/Long: 61.1563, -149.9850). Our team visited a residential complex on the gravel pit by the Sand Lake area and not much damage was observed in terms of settlement. Figure 12 shows response and Fourier spectra corresponding to the two horizontal components from the mainshock recorded at station NSMP 8037 (Lat/Long: 61.1563, -149.9850).

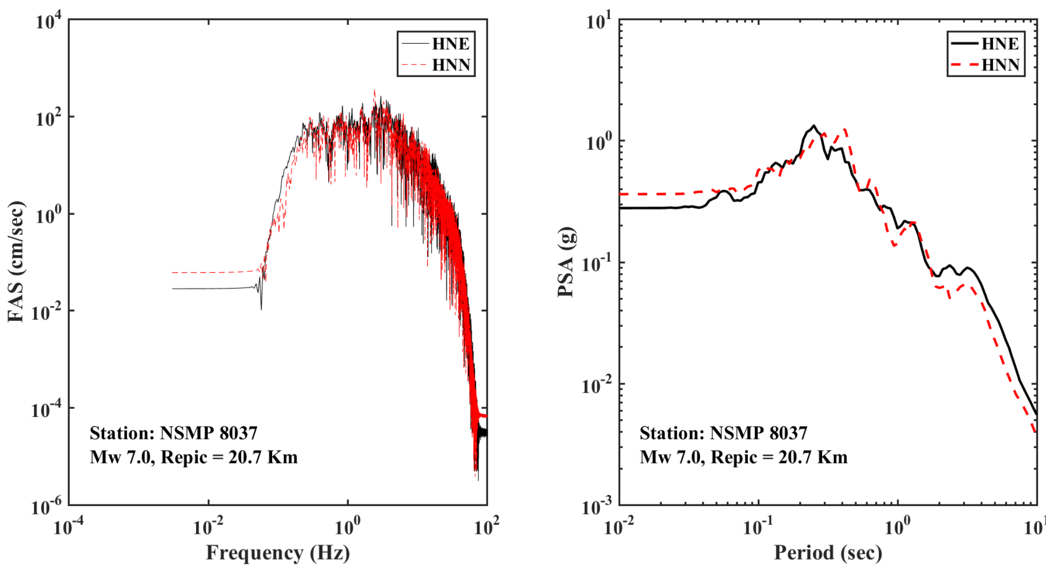



**Figure 12.** (left) Acceleration Fourier amplitude spectrum, and (right) Pseudo-acceleration response spectra (5% damping) for two horizontal components recorded at station 8037 (Lat/Long: 61.1563, -149.9850).

Additional site visits to accelerographs are likely in subsequent phases of work as well as the collection of site parameters for stations lacking prior subsurface characterization, including shear wave velocity profiles. Version 2.0 of the GEER report will provide insights resulting from the analysis of these additional data.

# SUMMARY OF GEER PHASE I TEAM OBSERVATIONS

Coordination with local officials resulted in more than 500 sites of reported damage (see Figure 3). In an attempt to learn from this earthquake, our team categorized the damage types that were reported and assigned particular emphasis to the following categories (in no particular order): highway embankment slopes and bridges, ground improvement sites, sites with various foundation types adjacent to one another, ground motion recording station sites (particularly sites with potential evidence of liquefaction nearby), historic landslide sites, sites of critical infrastructure (e.g., railroad embankments, ports), sites with potential landslide impacts to infrastructure, and sites with potential liquefaction impacts to infrastructure. Our team coordinated our daily activities based on these emphasized categories of damage, but also documented other types of significant damage that was encountered along the way.

It is important to clarify the challenging field conditions that existed during our Phase I deployment. Shortened arctic daylight hours limited our effective field time to the hours of 9:00am to 4:30pm each day. Two significant snow storms during our deployment covered the ground with more than 20 cm of snow, making the observation of surficial evidence of liquefaction and small ground deformations very challenging. Our team therefore needed to rely heavily on pre-snow observations made by other reconnaissance teams prior to our team's arrival (see Acknowledgements).

## Buildings

Overall, buildings in Anchorage and surrounding communities performed well during this earthquake event. Observed damage in commercial buildings was relatively minor. More significant damage was observed primarily in residential and small commercial structures. Much of the observed damage appeared to occur due to localized liquefaction and settlement in the granular fills placed directly beneath these types of structures. Observed residential/small commercial building damage in Anchorage was not extensive but seemed to occur in pockets throughout the swampy/marshy parts of the city. Damage to residences in the Eagle River community appeared to occur primarily from seismic slope deformations.

This section provides brief descriptions of selected building sites that were investigated. Not all building sites that were visited are summarized and reported here. However, a more thorough and complete report on observed building performance and damage will be presented in the forthcoming Version 2.0 report.

## Alaska Native Tribal Health Consortium (ANTHC) Campus, Anchorage

The Alaska Native Tribal Health Consortium (ANTHC, Lat/Long: 61.1827, -149.8034) was visited by our team on Monday December 10, 2018. Paul Morrison of ANTHC escorted GEER members through the interior of buildings at 3900 Ambassador Drive and 4000 Ambassador Drive that suffered damage as described below. ANTHC also gave permission for our team to observe and document exterior conditions at these two locations and several other buildings on campus (4115 Ambassador Drive, 4141 Ambassador Drive, 4001-4043 Tudor Centre Drive, and 4315 Diplomacy Drive) which did not have any reported damage, except for minor nonstructural damage.

Facility operations at ANTHC were relatively uninterrupted. Electrical power system redundancies allowed power to continue throughout and after the event without the use of the backup generator. Surgeries and procedures were paused during the event but were resumed and completed after the event.

### 3900 and 4000 Ambassador Drive, Anchorage

3900 and 4000 Ambassador Drive (Lat/Long: 61.1821, -149.8066 and 61.1828, -149.8061) are founded on steel pipe piles ranging in length from 12 to 15 m with diameters of 325 or 610 mm and installed with one, two, or three piles per building column. Damage to the interior of 3900 Ambassador Drive appeared limited to the entryway (sliding glass doors and access doors in the front vestibule were damaged, and settlements on the order of 10-22 mm were observed). Walls and door entryways resting on the slab-on-grade placed in between pile caps and providing access to offices along the exterior of the northeast corner also experienced settlement and tilt ranging from 5-10 mm and 1.2-3.1 degrees, respectively. Settlement of sloped fill immediately outside the building at these locations reached magnitudes of up to 100 mm, indicating that the ground loss of soil supporting the interior slabs resulted in movement relative to the pile caps. Damage to the interior of the adjacent (and internally-connected) 4000 Ambassador Drive building manifested in terms of loss of serviceability of some doorways and cracking of drywall along the eastern margin of the building. Along the eastern exterior of the building, an unconnected brick deck structure that had previously experienced settlement and lateral movement exhibited further movement downward and outward toward the pond to the east as a result of the earthquake (Figure 13). This outward lateral movement manifested over the length of the building exterior and joined at the concrete walkway and stairs separating this building and 3900 Ambassador Drive.

**Figure 13.** 4000 Ambassador Drive - brick deck structure exhibiting settlement and lateral movement (Lat/Long: 61.1826, -149.8061).

### 4115 Ambassador Drive, Anchorage

4115 Ambassador Drive (Lat/Long: 61.1841, -149.8043) is founded on shallow foundations overlying ground improved by deep dynamic compaction. An inspection of the building exterior by our team revealed little signs of damage. A short portion of the exterior concrete walkway adjacent to the northeast corner of the building exterior and approximately 6 m in length appeared to have settled 5 to 15 mm relative to the wall. A portion of this walkway supported HVAC or similar type of equipment.

Inspections of the building exteriors at the following locations also revealed little signs of damage:

- 4141 Ambassador Drive (piles)
- 4001 Tudor Centre Drive - Patient Housing at ANMC (excavate+replace, shallow foundations)
- 4043 Tudor Centre Drive - North Parking Structure (trash fill, shallow foundations)
- 4315 Diplomacy Drive - Hospital (shallow foundations, staging area for old asphalt plant)

The details of subsurface conditions, ground improvement, and foundations at the ANTHC Campus buildings are being sought presently to inform the Version 2.0 report.

## Department of Fish and Game Building, Anchorage

The Alaska Department of Fish and Game Building (333 Raspberry Rd, Anchorage; lat/long: 61.1593, -149.8879) showed signs of significant stress from settlement beneath the south wing of the building. The two-story wood frame structure is shaped as an “L.” Ground cracking was observed within about three meters of the structure, and the ground had visibly settled up to 16 cm directly along its east side. Employees in the building reported interior settlements “of about 1 foot (25 cm),” though those claims could not be substantiated by our team because that portion of the building had been evacuated and was closed to all non-essential personnel. Figure 14 shows the type of damage that was externally visible at the Department of Fish and Game building. No surface evidence of liquefaction was visible beyond about three meters from the building, suggesting that these observed effects may have been limited to beneath the building footprint.

The observed liquefaction-induced damages at the Department of Fish and Game Building is particularly significant because a ground motion recording station (NP 8027) is housed in a small warehouse next to the building, within about 30 meters of the observed damage.


**Figure 14.** Observed liquefaction evidence at the south wing of the Alaska Department of Fish and Game Building (Lat/Long: 61.1592, -149.8879).

## Jamestown Drive, Anchorage

A series of condominium units (Lat/Long: 61.1295, -149.8459) were associated with significant settlement of up to 30 cm (Figure 15). Cracks extending across the front driveways of the units were about 7 cm wide and up to 23 cm deep. Fine sand was ejected onto the surface along deformation cracks. During the GEER team inspection, construction crews were vacuuming foundation materials from below the garage of one unit, presumably to backfill with more stable materials.

A B

**Figure 15.** Settlement of condominium units along Jamestown Drive, Anchorage (Lat/Long: 61.1295, -149.8459). (A) Settlement cracks along the front driveways (black arrows). (B) Repair crews removing backfill materials.

## Houston Middle School, Houston

Initial inspection of the red-tagged Houston middle school (Lat/Long: 61.5863, -149.7719) indicated that there was limited evidence of damage to the exterior of the building, generally limited to minor cracking and dislodgement of several facade bricks from walls and the tops of columns (Figure 16). However, after discussions with the Mat-Su Borough emergency manager it was learned that the school had suffered extensive structural damage to the ceiling and the interior of the building and was not expected to reopen. Large chunks of concrete were reported to have fallen through the interior ceilings, and critical structural supporting elements inside the building were reported to have failed. Our team was not allowed inside the building due to safety concerns.

A B

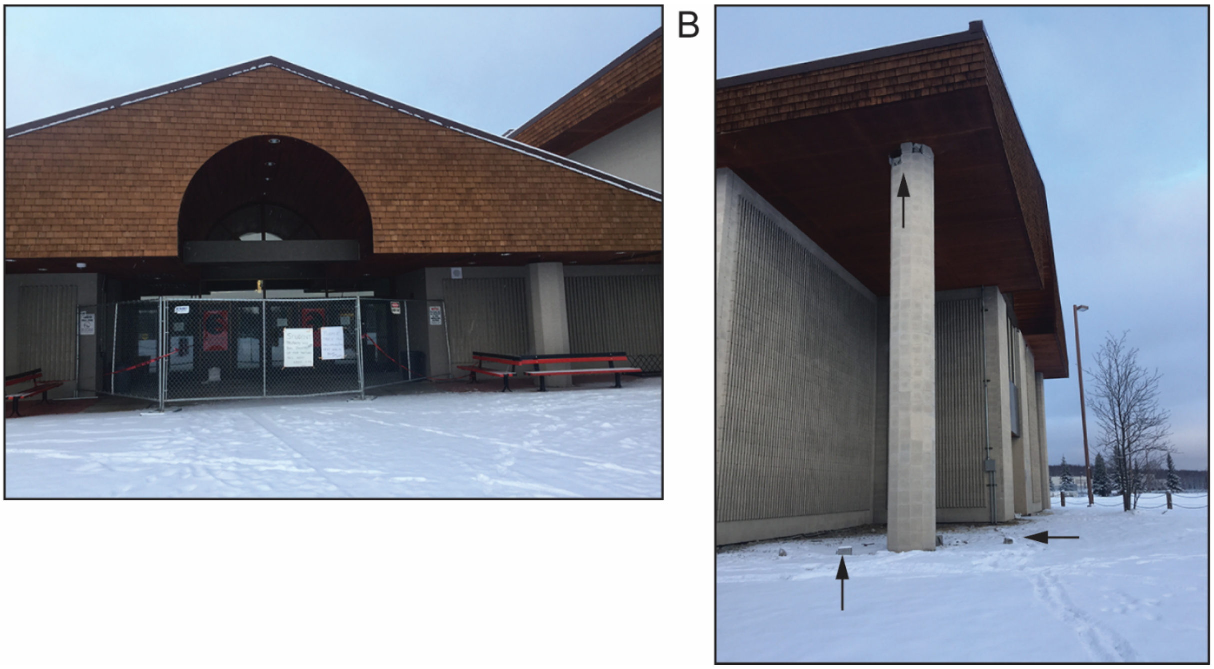


**Figure 16.** Red-tagged Houston Middle School in Houston (Lat/Long: 61.5863, -149.7719). (A) Fenced off entrance to the school. (B) Support column along southwest side of school showing displaced facade bricks (Black arrows).

## Downtown Eagle River

Extensive non-structural damage was observed throughout the main business district of Eagle River (Figure 17). Many businesses had broken windows and extensive water damage from broken water pipes. One building, including Garcias Cantina (Lat/Long: 61.3277, -149.5728), was associated with separation of support columns from the ground. Most of the support columns were cracked at their bases. Structural damage was also observed at an Eagle River pawn shop (Lat/Long: 61.3340, -149.5637) where the tilt-up cinder block wall panels had rotated out and the interior ceiling was partially collapsed inward. The walls had been braced and repairs were underway when our team was onsite.


**Figure 17.** Building damage in downtown Eagle River. (A) bowing and tilting of the cinder block walls of the Eagle River pawn shop (Lat/Long: 61.3340, -149.5637), (B) partial collapse of the ceiling in the Eagle River pawn shop (Lat/Long: 61.3340, -149.5637), (C) sheared and cracked columns in the Garcias Cantina building (Lat/Long: 61.3277, -149.5728), and (D) water damage and ceiling tile failure in the Garcias Cantina building (Lat/Long: 61.3277, -149.5728).

## Residential Damages in General

The majority structural damages observed during the Phase I GEER reconnaissance occurred in residential and small commercial buildings. The observed damage appeared to occur due to liquefaction-induced effects, particularly settlement (Figure 18). Interestingly, these effects seemed to occur only beneath the structures themselves and not in the free field. Also interesting was the pattern of observed damage. For example, we would observe that one or more adjacent structures within a particular cul-de-sac would show similar evidences of liquefaction-induced damage (e.g., settlements of 1-20 cm, tilting, occasional sand boils in the crawl space, and cracking). However, the remaining structures in the cul-de-sac, often within meters of the damaged structures, would show no evidences of structural damage.

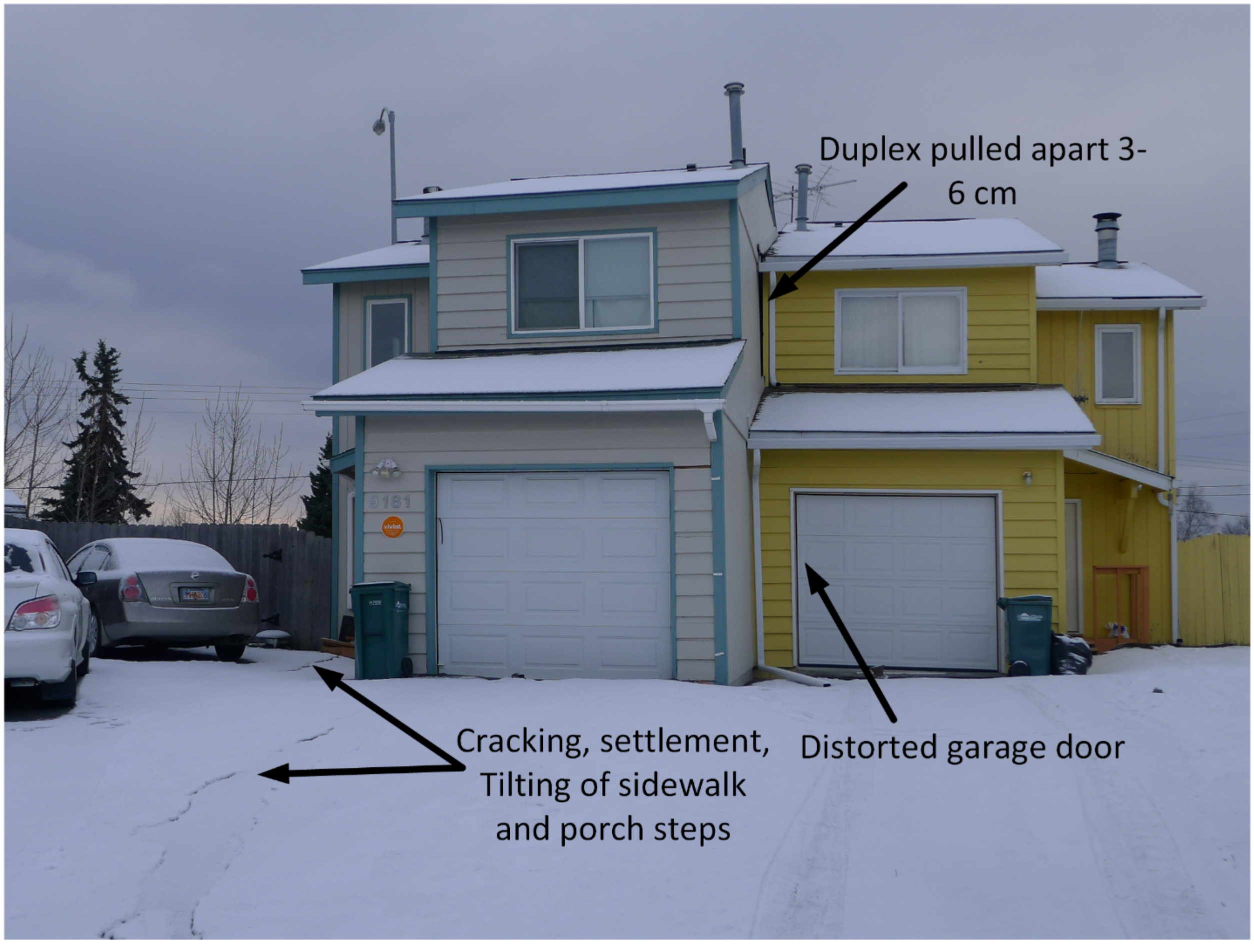



**Figure 18.** Example of the type of localized liquefaction-induced damage observed at many residences in Anchorage (Lat/Long: 61.1378, -149.9382).

## Bridges

In general, our Phase 1 reconnaissance team observed relatively little problems with bridges. By the time of our deployment, all AKDOT bridges in the region had already been inspected by AKDOT personnel, and areas of potential problems had been identified. Nearly all documented bridge problems involved settlements and lateral movements in the approach fill at one or both of the abutments, resulting in compression of the bridge deck and slight rotation at the affected abutments.

Our team inspected and confirmed all of the bridge problem sites communicated to us by AKDOT. All of these bridges were operational at the time of our Phase 1 deployment. This section summarizes our observations from a few of these bridge sites. The Version 2.0 report will contain additional information from all of the bridge sites that were inspected by our team.

## West Dowling Road Bridge, Anchorage

Members of our team visited the W. Dowling Rd. Bridge (AKDOT Bridge No. 2273, Lat/Long: 61.1655, -149.8977) on 10 and 12 December 2018 to evaluate its performance. Observations made by the team were supplemented by AKDOT inspection photos shared with the team by David Hemstreet, State Foundation Engineer of AKDOT. This three-year old bridge is a single span, 61 m long and 30 m wide steel box girder bridge and serves as an overpass of Arctic Boulevard and tracks owned by Alaska Railroad. The bridge arcs to a heading southwest from the northeastern approach of W. Dowling St. with an approximate radius of 300 m. A large (approximately 10 to 12 m) culvert/tunnel (AKDOT Culvert No. 4100) retained by the MSE wall and accommodating two lanes of traffic on the western on-grade spur of W. Dowling Road lies immediately southwest of the overpass and under the southern approach fill. General subsurface conditions for the site consist of 2 m of fill overlying 2 m of peat, then 5 m of soft, low plasticity silt, transitioning to medium stiff to very stiff silt and clay to 33 m depth, underlain in turn by very dense, glacially overridden gravel identified as glacial till (Yamasaki et al., 2015). Design concerns ranged from static global stability and consolidation during construction of the 12 m tall, MSE wall-type abutments and approaches to seismic stability and settlement performance. Following consideration of a range of foundation alternatives at the site, wet soil mixing was selected for ground improvement of the soft peat and soft, liquefiable silt deposit with bridge abutments supported on shallow foundations. Deep soil mixing consisted of 2.44 m diameter, 6 m long columns with 90% area replacement ratio under the spread footings supporting the skewed bridge abutments and 50% area replacement ratio in front of and behind the abutments.

Post-earthquake inspections revealed a range of light damage; however, overall, the bridge and approaches performed well. Guardrails spanning expansion joints appeared slightly buckled at the extreme fiber of the strong direction, and light I-Sections supporting guard rails appeared to have buckled flanges and webbing. Expansion joints appeared to have exhibited pounding with shear cracks observed along the northeast abutments and a relative permanent displacement parallel to the join of approximately 25 mm. Spalling and/or delamination of concrete for several shear keys along both abutments indicated transverse interaction of the bridge deck and superstructure with the abutment substructure (Escamilla, 2018). Expansion bearings visible to the AKDOT inspection team appeared fully extended with little capacity for future relative movements: this indicates that the abutments may have moved closer to one another. Measurements of abutment tilt by our team showed that the southwestern abutment wall tilted away from the approach a maximum of 1.1 degrees on its eastern edge reducing to 0.4 degrees on its western edge. The northeastern abutment exhibited less tilt, with zero tilt along its western edge to 0.4 degrees away from the approach (and towards the span) along its eastern edge. These observations were consistent with the loss of expansion of the superstructure noted by AKDOT. Minor spalling was observed at the abutments and MSE wall panels. MSE wall panels retaining fill over and adjacent to the large culvert rotated towards the culvert on both sides of the culvert and approach fill and exhibited movements characterized by panel gap closure and extension of up to 75 mm, and tilt of up to 4.2 degrees (Figure 19).

No ground failure or signs of large differential soil movements were observed at the bridge approaches and abutments. A minor slope failure on the southern face of the eastern approach was noted, exhibited spreading-type cracks 100 mm wide and characterized by vertical scarp faces 300 mm tall. Planted saplings exhibited significant rotation commensurate with the slope failure.


**Figure 19.** West Dowling Road Bridge – overview and close-ups of wall panel movements (Lat/Long: 61.1651, -149.8991).

## Glenn Highway Northbound Bridges, Eagle River

The Glenn Highway is the primary land transportation route between Anchorage and the communities/cities located to the north. This highway includes two parallel bridges over the Eagle River (Lat/Long: 61.3107, -149.5780).

### Northbound Bridge

The northbound Glenn Highway Bridge is a relatively new multi-span reinforced concrete bridge supported by multi-column reinforced concrete bents. The north abutment of the bridge has a 1:1 reinforced soil spill slope, and the abutments of the bridge are skewed. Additional details regarding the dimensions and design of the bridge will be provided in the Version 2.0 report.

Abutment movements at the southern abutment of the northbound bridge (Lat/Long: 61.3102, -149.5771) were observed and documented. These movements included settlement of 15-30 cm in spill slope (Figure 20) and 20-30 cm lateral movements that appeared to mobilize passive earth pressure behind the skewed abutment face. These earth pressures initiated minor rotation of the abutment (1-3 cm). Large (44 cm H-Piles) were exposed in the settlement-induced gap below the abutment stem wall. Inspection of the columnar bents supporting the bridge revealed minor to no damage. One 2cm-wide crack was observed around a large bent foundation indicating mobilization during the earthquake, but no concrete spalling.

No damage was observed at the northern abutment of the northbound bridge.


**Figure 20.** Settlements and lateral deformations in the spill slope at the south abutment of the northbound Glenn Highway Bridge over Eagle River (Lat/long: 61.3117, -149.5760).

## Southbound Bridge

The southbound Glenn Highway Bridge is an older multi-span reinforced concrete bridge. Reinforced concrete girders rest on flexible bearing pads and are visible for inspection, which revealed evidences of soil deformation at the abutment. No gap existed between the ends of the girders and abutment wall. As shown in Figure 21, settlements of up to 3 cm were measured in the spill slope in front of the abutment. The bearing pads supporting the girders showed straining and deformations of up to 3 cm. Minor cracking and downslope movement was visible in the spill slope soils, but it was unclear if those cracks developed from the earthquake or prior movements due to static loads.

No damage was observed at the northern abutment of the southbound bridge.

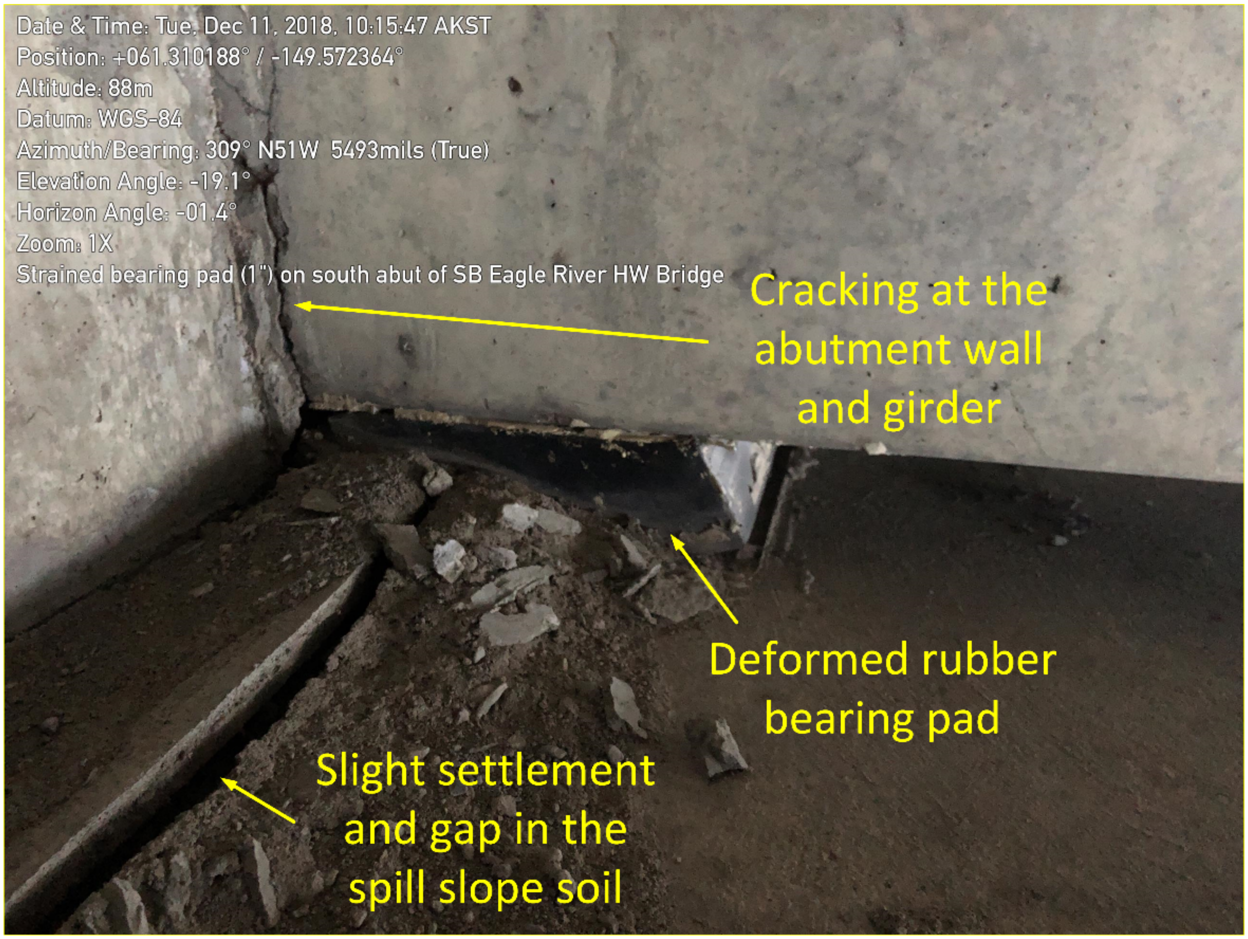



**Figure 21**. Observed girders and abutment seat at the southern abutment of the southbound Glenn Highway Bridge over Eagle River (Lat/Long: 61.1310, -149.5724).

## Briggs Bridge, Eagle River

Members of our team visited the three-span, 186.3 m long Briggs Bridge (lat/long: 61.2985, -149.5397) spanning the Eagle River south of the town bearing the same name on 11 December 2018 to inspect the approaches, abutments, and wingwalls. This bridge is a steel girder and truss diaphram-type structure and appears to have been constructed in 1990. The wearing surface of this bridge lies approximately 23 m above Eagle River at mid-span. The two bridge pier footings appear to be supported on a combination of vertical (21 total, 3 x 7) and battered (74 total, two sets of 2 x 16 along longitudinal axes and two sets of 3 x 7 along transverse axes), steel HP12 and HP14 pile sections, whereas the 35 m wide bridge abutments (stepped to match superelevation of wearing surface) consists of typical stem wall-abutment footing structures on two rows of HP12 sections (inner piles battered to resist overturning, outer piles vertical).

While the details of this case history will be significantly updated in Version 2.0 of the report, the following was noted along the north abutment: minor slope failure of the north approach (on the east side, mobilization and widening of existing cracks in the wingwalls, settlement of the abutment stemwall footing as indicated by bearing pad bolts 1-5 cm above the pads, movement of girder flanges relative to the bearing pads, and soil movements (lateral and vertical) relative to the western wingwalls (see Figure 22). At the south abutment, surrounding soil conditions were obscured by ice and snow. Evidence of soil movement or cracking was not observed beneath the bridge when moving from the east to west side. The bolt on the west side was in a vertical position while the bolt on the east side was observed to have tilted inward toward the abutment. Looking north from the south abutment, minor slope failures were observed at the north abutment and extending west in slopes along the river.

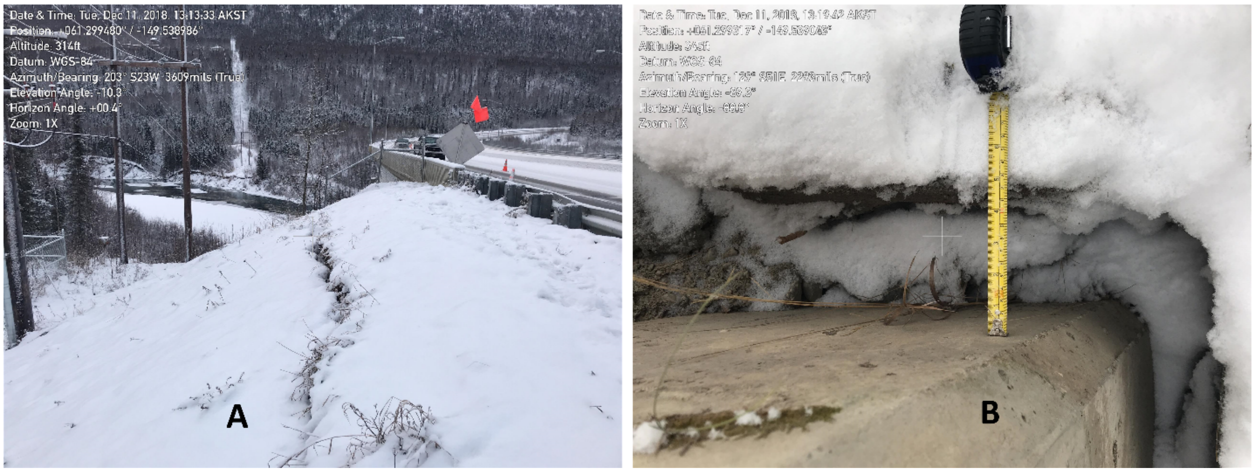



**Figure 22.** Evidence of slope deformation at the north abutment of the Briggs Bridge over Eagle River (Lat/Long: 61.2995, -149.5390). (A) Cracking apparent in the slope through the snow visible at both sides of the abutment. (B) Separation of approximately 12 cm between the abutment face and the spill slope soil.

## Utilities

A meeting between members of our team and Stephen Nuss, Engineering Director with Anchorage Water and Wastewater Utility, occurred on 13 December 2018. At the time of that meeting, 171 AWWU assets had been inspected. Of all those assets that were inspected, only three were assigned yellow tags to identify need for repair. At the time of our meeting, 50 breaks in water and sewer lines had been identified. 28 of those breaks were identified by the end of November 30, the day of the earthquake. Failures in water pipes were limited to locations where pre-existing weaknesses existed. For example, locations of unrestrained pipes, shackled points that were heavily corroded, valves with corroded gray iron bolts on the bonnets, or older cast iron pipes. Two of the problem areas occurred due to “geotechnical failure” in the slopes west of the Briggs bridge in Eagle River and at Turnagain Heights. Detailed locations of these reported geotechnical failures were not provided to our team at the time of our meeting. Failures in sewer pipes continue to be more difficult to locate. AWWU must rely on reports of backed up sewage lines in residents’ homes to identify areas of potential breaks or damage. Between 1977 and 1999, AWWU extensively used ductile iron for its piping. More recently, AWWU uses AWW-C900 PVC for its piping due to its corrosion and chemical resistance, its combination of rigidity and flexibility, its cost, and its size compatibility with ductile iron.

A meeting between members of our team and Archie Giddings, director of Wasilla Department of Public Works occurred on 11 December 2018. It was communicated to our team that only two water line breaks had occurred in the system, and they had already been identified and repaired.

Wasilla incorporates a pressurized sewer system, which makes it easier to identify leaks in the system. As of December 11, no known leaks were identified in the pressurized sewer system.

Wasilla incorporates high density polyethylene (HDPE) for all of its water and sewer piping. The two identified breaks in the water line occurred at fused joints in the piping.

No gas line breaks were identified in Anchorage or surrounding communities. However, our team continues to collect additional information regarding the performance of all utilities. Our findings will be updated in the Version 2.0 report.

## Ports

The Port of Alaska (PoA, previously known as the Port of Anchorage) represents the State of Alaska's primary inbound cargo handling facility and is responsible for transferring 85% of all goods entering the state. Situated approximately 2 km north of Downtown Anchorage (lat/long: 61.2393, -149.8883), the PoA opened in 1961 and evolved over the years to presently consist of three terminals, a fuel tank farm, and a cement handling facility. Despite the MOA's long history as the State's air hub and population center, prior to the 1964 Good Friday Earthquake, the Port of Seward served as the State's cargo and freight hub. Owing to the destruction of Seward due to the M9.2 subduction zone earthquake and more critically the tsunami that followed, the PoA became the critical cargo handling facility in the state. Studies by the Port of Alaska and its consultants have shown that while at risk of earthquake damage (as noted in this reconnaissance and briefly summarized below), its position along the Knik Arm of the Cook Inlet largely prevents it from catastrophic tsunamis often associated with subduction zone earthquakes. This is a critical aspect for the State of Alaska, as it serves significant roles in commerce, national defense, and disaster recovery. Members of our Phase I team visited the PoA on 12 December; the following summary is derived from interviews with Port personnel, our site visit, and photos provided by Port personnel).

Damage to the PoA arising from the 30 November earthquake was observed within its terminals, administration building, slopes (coastal bluffs) along the eastern margin of the property, and along the waterfront. The administration building suffered permanent relative movements, damage to the elevator, and dislocation of non-structural components. Observable damage to the terminals (i.e., pile-supported docks running parallel to the shoreline) was largely limited to spalling along the expansion joints separating Terminal 1 and Terminal 2 indicating the development of pounding during the earthquake. The piles supporting the docks (approximately 1,420) are largely 610 mm (24") pipe piles with 11 mm (7/16") original wall thickness, with 760 mm diameter pipe piles used for support of dolphin berthing structures and other pile types serving as protective fenders along the outer row of dock bents. A significant number of the piles have experienced corrosion to levels consistent with loss of service (commensurate with the PoA's 10-year goal of replacing every terminal); for example, in recent years, a fender decoupled from a terminal and was lost in the berth, presenting challenges to visiting ships and yearly dredging operations. As a result, the Port had chained the remaining fenders to the dock, and this likely contributed to the zero-loss of fenders during the earthquake. An immediate, although partial, water-born inspection did not reveal above-water damage to piles or pile-dock connections. A pile jacketing program to shore up the dock-supporting, corroded piles appears to have largely prevented damage during the earthquake. The three gantry cranes were not in use during the earthquake and were tied to the crane rails following typical good port practices, which may have contributed to reduced damage levels to the dock and cranes.

No damage was observed along the ring-shaped grade beam-supported cement storage dome structure lying south of the port terminals and immediately east of the waterfront. The cement storage dome was placed on ground treated with a 3 m tall surcharge, is of 40,000 tons capacity, and was 80% full during the earthquake. The lack of damage may have been due to the new deep soil mixing (DSM) ground improvement placed between the waterfront and the cement storage dome during the summer of 2018 in anticipation of construction of the new petroleum and cement terminal planned to resume in 2019. No visible ground failure in the vicinity of the DSM treatment could be documented at the time of our Phase I team visit. However, photographs taken the morning of the earthquake and provided to our team showed lateral spreading type failures of limited extent in the tidal flats lying in front of the DSM-treated area. The failed soil mass was reworked by tidal action in the days immediately following the earthquake, and evidence of the lateral spread was no longer visible by the time our team visited the site on December 12.

Several vegetated bluffs running north-south and lying immediately to the east of the Port property experienced failure. It appears that significant movements (on the orders of meters) were restricted to colluvium that commonly mantles the coastal bluffs in the Anchorage region. A large crack running the length of the crest of a bluff was investigated by other members of our Phase I team after the initial Port visit and is described in the Slopes and Embankments Section. Several pinnacled bluffs (triangular bluffs produced by closely-spaced drainage features) along the east margin of the northern expansion area experienced surficial and planar slope failure consistent with “infinite slope” failure mechanisms that appeared to originate from the top of the slope and slough along previously exposed native, non-colluvial soils.

The greatest extent of damage appeared to occur due to lateral spreading in features that largely were expressed parallel to open faces running along the north-south Port alignment. Port personnel reported crack widths ranging from 10 to 30 cm and vertical offsets of block failures of up to 1 m in height. Within the main port property, a near-continuous crack was observed to run along three-quarters of the 670 m long, rip-rap covered, partially-submerged slopes separating the Port uplands from the three terminal docks. Although the setback of the crack from the crest of the rip-rap lined sloped varied, it was frequently observed at a setback of about 3.6 m. At the time of our Phase I team visit, crack widths of 15 to 50 mm were noted, however Port personnel and photographs provided to the team taken on the day of the earthquake suggest that the crack widths were originally larger. Locally along this area, slumping of failed soil blocks within the partially-submerged slopes occurred, and these blocks had exhibited vertical offsets of up to 1 m in height. These ground failures had been temporarily repaired by the Port with more permanent repairs planned for the spring.

The north expansion area of the PoA represents port development that had initiated in 2009 but was terminated following the observation of loss of fill behind sheet pile bulkhead structures. The site presently consists of rip-rap lined and partially submerged slopes and vertical grade separations behind open sheet pile cells designed to act as a membrane structure. No significant differential movements or connection interlock failures were observed within the sheet pile structure. Lateral spreading-type ground failure with multiple blocks of failed soil were observed by Port personnel in the north expansion area in close proximity to the rip-rap lined slope immediately following the earthquake with crack widths of up to 300 mm in width and up to and possibly exceeding 3 m depth. Photos taken by the Port personnel show widespread water on the ground surface but unaccompanied by ejecta. These cracks had closed somewhat by the time our team visited but were readily identifiable despite new snow and ice mantling the asphalt surface. However, a new or previously undetected crack approximately 200 mm wide and approximately 1 m deep had opened and was observed by our team (Figure 23).

**Figure 23.** Port of Alaska – segments of lateral crack system (Lat/Long: 61.2531, -149.8804).

# Slopes and Embankments

Numerous slope and embankment issues were observed by our Phase I reconnaissance team. Most of these instances seemed to occur in fill slopes, areas with organic underlying soil, or areas with potential liquefied soil. In the Eagle River area, many of the slope failures appeared to occur on hillslopes vegetated with mature trees. This section will briefly describe observations at a select number of landslide sites. All landslide and slope instability observations will be described in greater detail in the Version 2.0 report.

## Rabbit Creek Landslide Complex, Anchorage

Collaborators from the USGS indicated that they had observed significant sliding in the vicinity of Rabbit Creek, located in southeast Anchorage next to the Cook Sound. Our team visited and confirmed the landsliding (Lat/Long: 61.0912, -149.8470). These slides along the coastal bluffs in the vicinity of Rabbit Creek are associated with bluff cracking, multiple individual small slide blocks, and appear to extend for kilometers in both directions along the bluffs. The larger landslide complex was associated with southwest directed translational failure of weak glaciodeltaic deposits. The head scarp along the landslide was observed to range from 2-3 meters high, and it encroached within 50 meters of the coastal railroad line. Landsliding in this area also occurred during the 1964 earthquake (Potter Hill landslide), indicating that the bluffs in this area are particularly susceptible to slope failures. Figure 24 presents an image of the head scarp of the landslide, which was measured to be 2.3 m high in this location.


**Figure 24.** Head scarp of the Rabbit Creek Landslide Complex (Lat/Long: 61.0912, -149.8470).

## Bluff Failure, Port of Alaska, Anchorage

A small slope failure (Figure 25) occurred above the port of Alaska in a public park (Lat/Long: 61.2303, -149.8849). Here a crack along the top of the bluff extended for ~50 m set back ~1-3 m from the edge of the bluff. The crack was generally arcuate and up to ~20 cm wide, 50 cm deep, and had limited vertical separation. There was sufficient motion in some locations to rotate a few signs and trees. On the day of our visit, there was considerable snow that may have covered more extensive cracking. This slide could pose a hazard to the port immediately below the slope, and monitoring is recommended.


**Figure 25.** Bluff landslide located above the Port of Alaska (Lat/Long: 61.2303, -149.8849).

## Minnesota Boulevard embankment failure, Anchorage

A large embankment failure occurred along the northwest side of the northbound highway off-ramp at Minnesota Boulevard and International Airport Road (Lat/Long: 61.1713, -149.9155). The failure was caused by lateral spreading or slumping failure of the off-ramp fill resulting in cracking and settlement of the road, making it impassable. AKDOT had the road repaired and restored to service by December 4 (prior to our arrival), and our team was unable to observe and document the damage. Due to the cold weather and snow, the current repairs are temporary until permanent stabilization methods can be implemented in warmer weather. Based on inspection of photographs provided to our team, the failure was associated with back tilting and down dropping of the roadway of at least 2.4 m and was approximately 30 m in length. Additional cracking of the roadway on the highway side of the off ramp was approximately one meter wide and deep over a similar length. Figure 26 presents an image provided to our team of the Minnesota Boulevard embankment failure.

**Figure 26.** Aerial image of the Minnesota Boulevard embankment failure (Lat/Long: 61.1713, -149.9155). Photo source: Ryan Marlow, Alaska Aerial Media.

## River View Heights, Eagle River

Landsliding along the eastern side of River Heights Loop road in the River View Heights residential area in Eagle River resulted in the yellow-tagging of numerous homes and elevated concern regarding the potential for additional landsliding (Figure 27). Our team observed several landslide scarps along the steep slope extending above the eastern margin of the neighborhood. A small slump block (Lat/Long: 61.3123, -149.5714) approximately 24 m long released from the basal part of the slope and was associated with a 1-1.5 m high head scarp. The toe of this slide displaced a small shed from its foundation and buckled the fence. The scarp associated with this slide projects obliquely up the slope and aligns with major cracks in the flat graded property above the crest of the slope (Lat/Long: 61.3121, -149.5704). Cracks in the upper surface were observed to be about 10 cm wide and up to 1 m deep and extend for over 100 m subparallel to and 18 m east of the crest of the slope. The cracks intersect a warehouse building where 10 cm of separation were noted between the building and the soil. At the southern edge of the graded property, the crack was associated with 23 cm of vertical separation. The cracking of the surficial materials along the crest of the slope raised concerns regarding the potential for additional landsliding hazards for the residences below. Landslide cracks were visible through the snow along the edge of the slope for approximately 100 m before disappearing beneath the snow. Our team imaged the slope with a UAV for subsequent evaluations and modeling, which will be presented in the Version 2.0 report.

**Figure 27.** Photographs of the Riverview Heights landslide in Eagle River. Cracks at the crest of the slope extend for 100 m from the north (A) to the south (B) part of a flat graded residential property (Lat/Long: 61.3121, -149.5704). The cracks extend down the slope and intersect the head scarp of a small landslide (C) at the base of the slope (Lat/Long: 61.3123, -149.5714) that is associated with a 1-1.5 m high head scarp.

## Ptarmigan Drive Neighborhood, Eagle River

Wall cracking was observed at several residences in the Ptarmigan Drive neighborhood in Eagle River, likely related to strong ground shaking. Rock walls surrounding properties were noticeably shaken, with loose rocks dislodged from several walls. At one residence (Lat/Long: 61.3049, -149.4958), extensive cracking and failure of the brick facade was observed (Figure 28). At this house, a large back patio was associated with fence buckling, subtle backtilting of the yard surface, and cracking of the patio. The cracks projected to the margin of the house where a small side room was displaced from the house. A steep slope extends to the west of the slope, suggesting that the failure was related to landsliding along the steep valley margin.

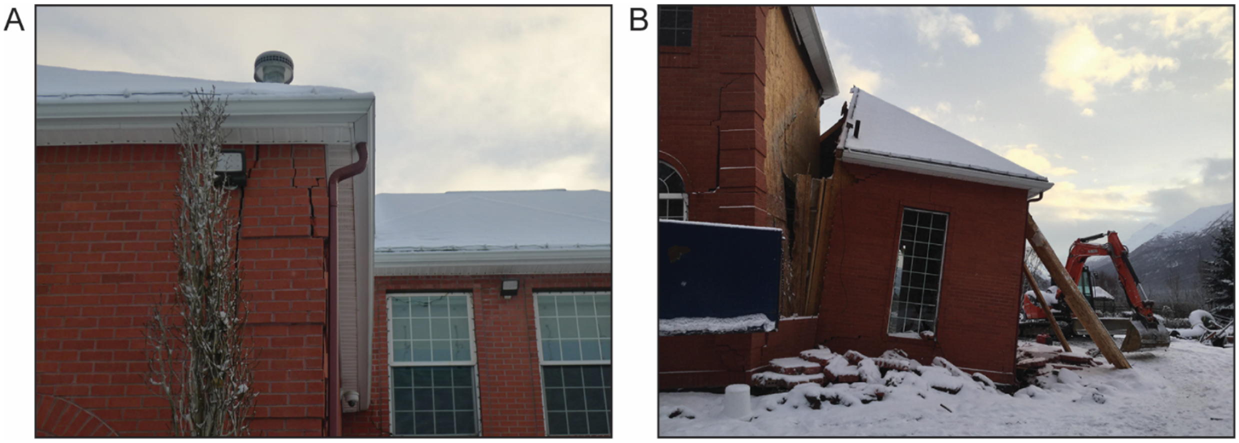


**Figure 28.** Damage to residence in the Ptarmagin Drive area of Eagle River (Lat/Long: 61.3049, -149.4958). Extensive facade cracking (A) and fill failure related tilting of a room associated with complete facade brick failure (B).

## Vine Road, Wasilla

The failure of the road surface and embankment fill along Vine Road (Lat/Long: 61.5686, -149.6022) south of Wasilla received considerable media attention and numerous dramatic photographs were circulated on social media (Figure 29). The failure was confined to where it crosses a small peat bog and had been repaired with a temporary stabilization by the time our Phase I team evaluated the site. However, deformation of the ground surface was still clearly evident to the west and east of the road at the time of our team's visit. Preliminary visits to the site were performed by team members and collaborators on December 2 (prior to the arrival of the Phase I team). They observed that the failed segment was 93 m long with a maximum lateral movement of the centerline of 3.8 m to the west and a maximum settlement of up to 1.8 m. Boring logs provided by Mat-Su Borough engineers indicate that the substrate consists of gravelly silt deposits and a 1.8-m-thick layer of silty peat. Field observations indicate that the road fill is composed of rounded gravels and cobbles with a silt matrix. The failure appears to be caused by a cyclic softening of the soft, saturated peat substrate beneath the road embankment, leading to a lateral squeezing bearing capacity failure in these organic soils. This lateral squeezing bearing capacity failure in the fibrous sphagnum peat resulted in arcuate 1m-high compression mounds that extend about 18-21 m from each side of the road.

A B

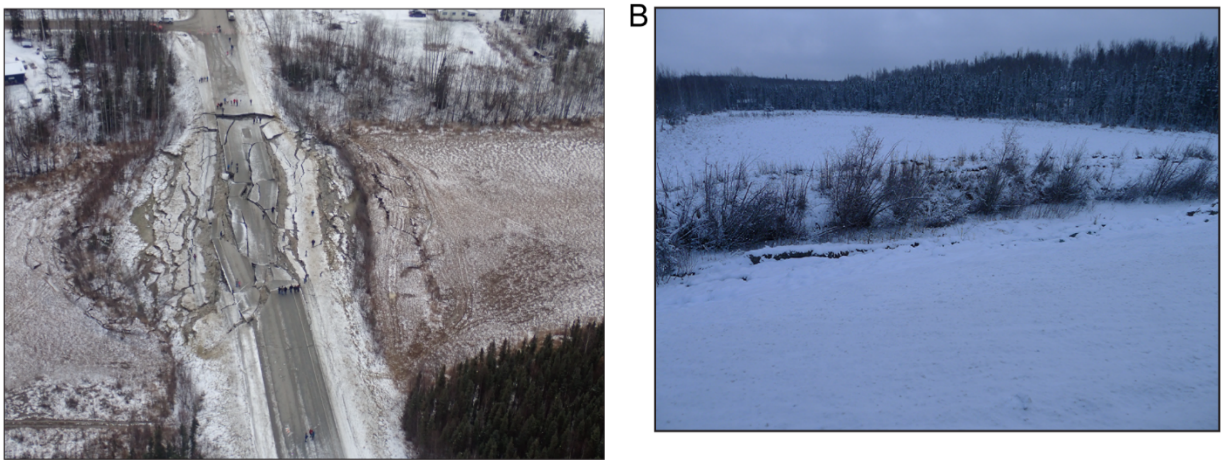


**Figure 29.** Damage to Vine Road (Lat/Long: 61.5686, -149.6022) south of Wasilla (A) immediately after the earthquake (photo taken by Rob Witter (USGS) during helicopter reconnaissance). (B) Pressure ridges (peat mounds) west of the road formed by lateral motion of the road fill. Note back-tilted trees.

## Rail Embankments and Support Roads for the Port Mackenzie Rail Expansion Project

The support roads, embankments, and railways related to the under-construction Port Mackenzie Rail Expansion project were inspected with Mat-Su Borough engineers. On the day our team visited these sites, there was significant snowfall and it was difficult to observe individual features. Furthermore, the majority of the road damage had already been repaired. Borough engineers provided our team with pre-snow photographs. Along the rail alignment, only two locations experienced earthquake effects including one location where the embankment fill settled a few inches (Lat/Long: 61.4376, -150.0822) and another where minor settlement occurred along the support gabions at a bridge crossing (Lat/Long: 61.4643, -150.1001). Major cracking and settlement of the Port Mackenzie roadway at mile marker 15.5 (Lat/Long: 61.3158, -150.0263) was associated with cracks up to 0.6 m wide and 1.2 m deep and was apparently related to shaking and lateral squeezing of the soft peat substrate (Figure 30). Another failure along the Lou Young road (Lat/Long: 61.2818, -149.9300) occurred along a cut and fill slope. This failure was arcuate in shape and approximately 10 m long (Figure 30). Approximately, ten additional locations of minor road cracking were also observed. Minor settlement associated with an approximately 30m-long crack was observed in the fill platform (Lat/Long: 61.2682, -149.9180) at the main port along its northeastern margin. Large light poles were tilted adjacent to this crack.


**Figure 30.** Road failure along the Port Mackenzie industrial area access road (Lou Young Road, Lat/Long: 61.28178, -149.9300) before (A) and after (B) repair. Road failure at mile 15.5 of the Port Mackenzie Road (Lat/Long: 61.3158, -150.02623) before (C) and after (D) repair. Pre-snow photographs courtesy of Bob Walden of Mat-Su Borough.

# Soil Liquefaction and Lateral Spreading

## Liquefaction Observations

Within populated areas of Anchorage, surface evidence of liquefaction was difficult to discern. Our team began site visits on Monday December 10, ten days after the November 30 event. Several centimeters of precipitation (rain, ice, snow) had covered the ground since the earthquake, obscuring much of the potential surface evidence such as sand boils, ejecta, cracking, or settlement. Limited to no ejecta was observed by our team in the free field. Settlement and cracking were observed directly adjacent to many residential and small commercial structures and may be indicators of possible liquefaction. Our team focused reconnaissance in the areas noted by local engineers and geologists to have liquefaction damage observations - primarily the Sand Lake and Eagle River areas of Anchorage. Observations for each area are described below.

USGS conducted helicopter fly-overs of the non-populated coastal and tidal flat areas surrounding Anchorage and reported numerous liquefaction observations including sand boils and cracking. The majority of these features were located in intertidal areas and were eroded and largely removed by tidal processes by the time our team commenced its investigation. These areas identified by the USGS are only accessible via hiking or helicopter, and our team did not seek to investigate them because of their insignificance to infrastructure.

## River View Heights, Eagle River

Several single-family residential homes in River Heights were red-tagged as being unsafe for occupancy, with two red-tags noting observations of liquefaction. At one red-tagged home (unoccupied), ejecta was observed at one location along the foundation perimeter (Figure 31). At this home, the red-tag notes that the north foundation wall buckled/collapsed due to soil liquefaction. At a second red-tagged home (occupied), the ground surface was not visible due to snow cover but the red-tag notes that the north foundation wall has been "compromised/broken by extreme ground pressure and soil liquefaction." The resident allowed a GEER team member into the backyard to observe the ground failure and damage at the back of the house. Some evidence of subsidence and cracking was visible beneath the snow and the wooden deck structure was damaged significantly (Figure 31). Two homes were yellow-tagged, with the tags noting "ground fissures present" and "possible shifting of foundation." The garage floor slabs at these homes had appeared to settle (<1-2"), separating from the garage door at the edges and with one garage door frame showing minor buckling of the sash. Soil that was possibly ejecta was observed at the ground surface under the entry walkway at one yellow-tagged home.

Although red- and yellow-tagged, several homes in River Heights were still occupied by residents when our Phase I team was onsite.

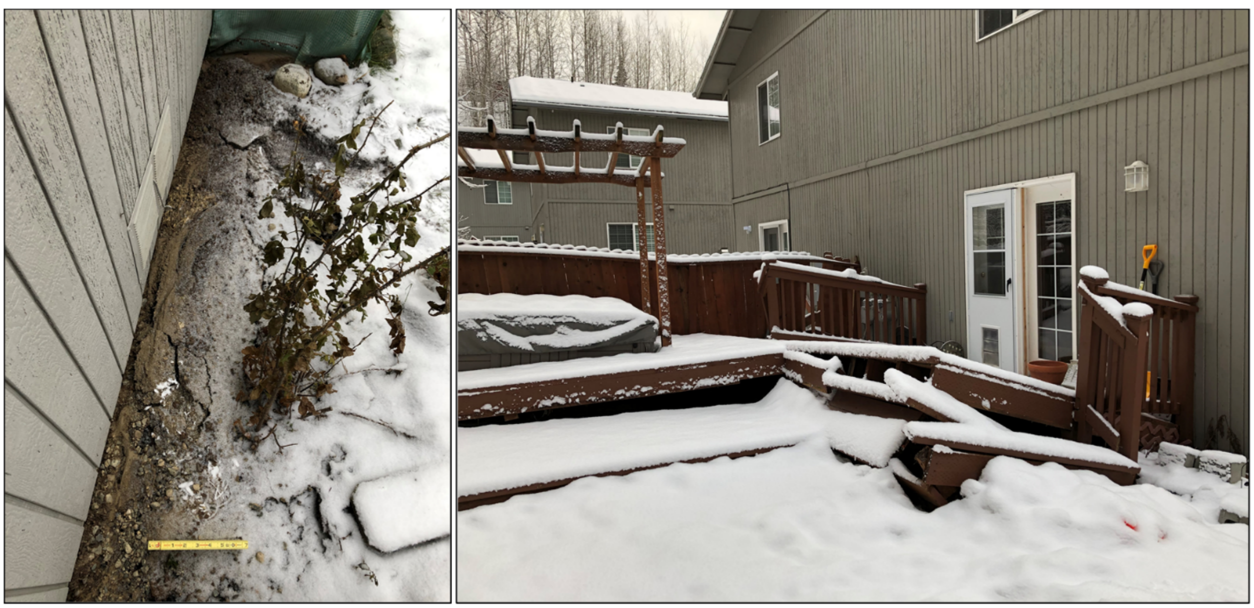


**Figure 31.** (Left) Ejecta observed at red-tagged home (Lat/Long: 61.3121, -149.5714); (Right) Backyard damage at another red-tagged home (Lat/Long: 61.3121, -149.5721).

## Ptarmigan Drive, Eagle River

Severe cracking and lateral movement indicating slope instability were observed behind two properties on Ptarmigan Drive at the top of a slope. Settlement (up to 13 cm) was observed in the walkway at one home (Figure 32), with horizontal movement at another location in the walkway of about 3 cm. Ground failure and possible ejecta were observed under the deck (Figure 32). It was unclear if liquefaction had occurred or if movements were solely due to the position of the properties at the top of the slope.


**Figure 32.** Ptarmigan Drive residential settlement (left) and ground failure (right) (Lat/Long: 61.3067, -149.4968).

## Sand Lake – Jewel Lake - Campbell Lake, Anchorage

Settlements of approximately 30 cm were reported for residential properties in Sand Lake, Jewel Lake, and Campbell Lake areas. Many of the damaged homes in Sand Lake suffered settlement and minor tilting but remained occupied by residents at the time of our team's visit. Our team members were allowed onto one residential property in the Jewel Lake area, between Dimond High School and Campbell Lake. The resident shoveled snow away from the foundation to show us the settlement that had occurred (~8 cm, with crack depths of 5-15 cm; Figure 33a). Our team members were also granted access to the crawl space beneath the house to observe the ground failure and possible ejecta (Figure 33b). Settlement and damage to the back patio were observed, as was cracking in the concrete backyard walkway (Figure 33c). The house remained inhabited.

Significant settlement of single-family homes and duplexes was observed directly north of Campbell Lake. One home (Lat/Long: 61.1334, -149.9313) experienced settlement that was associated with backtilting of the home towards the road. Ground cracking roughly followed the original foundation excavation. In the front of the house, the driveway settled about 30 cm and was associated with a crack up to 15 cm wide and 60-90 cm deep (Figure 34A). Cracks around the sides of the house were up to 8 cm wide and 20 cm deep. Both sides of the house exhibited evidence of vented sand, likely sourced from the sand backfill materials used during foundation construction. Cracking and surface bulging were also observed in the backyard and along the margin of the lake.

Nearly all of the duplexes on another nearby cul-de-sac experienced some degree of settlement and were yellow tagged by the Municipality of Anchorage. Wall separation and settlement was inspected at one duplex unit (Lat/Long: 61.1379, -149.9380). Several adjacent street light poles were tilted. Several duplexes appear to have settled downward approximately 30-60 cm. The settlement was confined to the margins of the duplex foundations and caused deformation of stairways and formation of ground cracks that projected towards the driveways (Figure 34B).


**Figure 33.** Jewel Lake residential damage: (a) settlement along foundation perimeter, (b) ground failure and possible ejecta in crawl space under the home, (c) settlement relative to back porch. Lat/long: (61.1380, -149.9380).

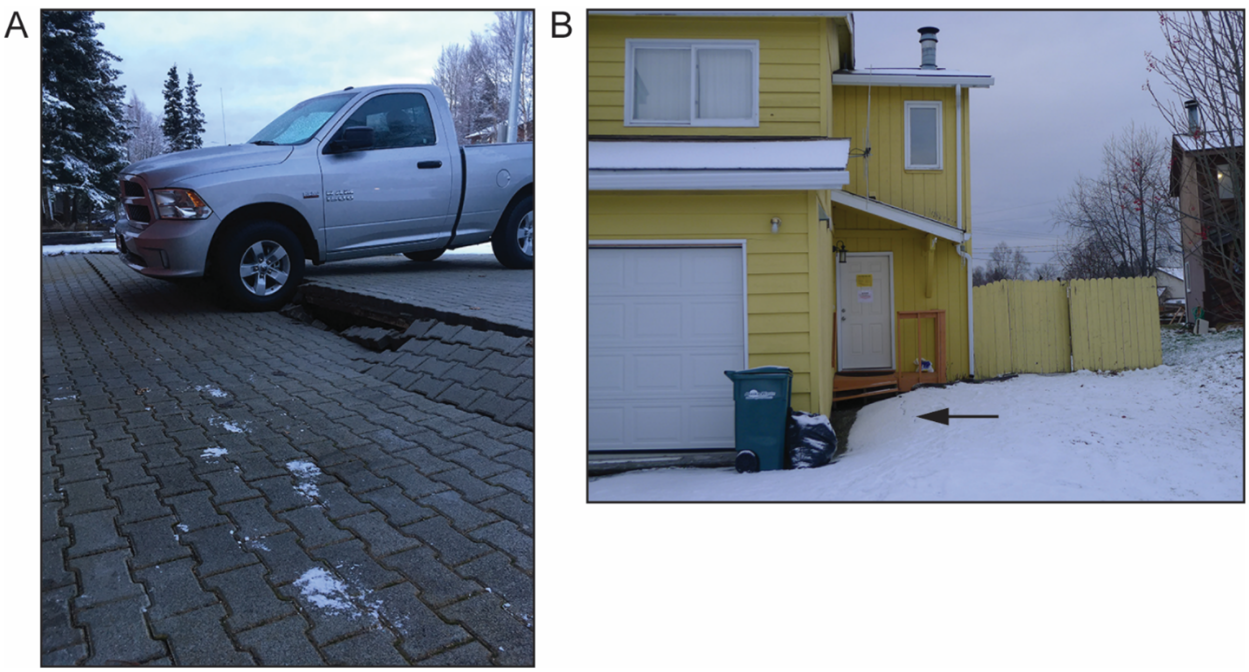



**Figure 34.** Typical foundation settlement damage in the Campbell Lake area of south Anchorage. (A) Drive way settlement (Lat/Long: 61.1334, -149.9313). (B) Duplex settlement along arrow (Lat/Long: 61.1379, -149.9380). Settlement was about 30 cm at each site.

## C Street & Dowling Road Intersection, Anchorage

Our team received reports of settlements of 30-45 cm at the intersection of C Street & Dowling Road. At the time of our visit to the site, no settlement was visible below the snow or at traffic sign and signal pole foundations for the majority of the intersection and approximately 50 m down each of the intersecting roads. A concrete footing for an electrical junction box located at the northwest corner of the intersection experienced settlement of 5 cm at the northwest corner and 2.5 cm at the northeast corner (Figure 35), tilting preferentially towards the adjacent ground behind the sidewalk that sloped down to a small open culvert and marshy area. The open pipe culvert did not appear to be damaged. From the intersection sidewalks, a large crack running north from the south approach and arcing west through the center of the intersection could be observed; however, measurements of differential settlement or crack width could not be made due to the active traffic within this intersection.

**Figure 35.** C Street & Dowling Road Intersection - settlement at electrical junction box (Lat/Long: (Lat/Long: 61.1670, -149.8870).

# Next Steps

We continue to communicate with our collaborators on the ground in Alaska. Reports of new damage continue to be received by municipalities nearly each day. Our team is evaluating the numerous UAV images that were collected from several of the sites described in this report. These images will be processed using structure from motion (SFM) computer vision, and three-dimensional point cloud and meshed models will be generated. These models will ultimately be shared with the broader engineering community through NSF-NHERI DesignSafe.

Evaluations regarding the need and timing of the Phase II remote and geophysical sensing team are ongoing. GEER is in communications with other organizations regarding data collection activities and potential collaborations. However, we can say definitively that most additional data collection activities will be delayed until spring or early summer – when the snow melts.

Following the New Year, the Phase I team will commence in preparing the more extensive Version 2.0 report. This report will contain more details regarding the sites that were investigated and initial design/as-built details (as available). The Version 2.0 report will likely be released during the winter of 2019.

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