ANCHORAGE, ALASKA, M_w 7.1 EARTHQUAKE OF NOVEMBER 30, 2018 LIFELINE PERFORMANCE

The Council of Lifeline Earthquake Engineering

TCLEE No. 5

September 19 2019

Lifeline Performance

A strong earthquake occurred at 8:29 am, November 30 2018 local time. The moment magnitude of the main shock was $M_w = 7.1$. The epicenter was located at 61.346° N, 149.955° W at a depth of 47 km. The epicenter was about 10 km northwest of downtown Anchorage, just on the west side of the Knik Arm to Cook Inlet. In this report, we call this event the 2018 Anchorage Earthquake.

The 2018 Anchorage Earthquake was the largest earthquake to impact the Anchorage area since the Great Alaska M 9.2 earthquake in 1964. This report addresses the damage to lifelines in the 2018 Anchorage earthquake. The information in this report is based on inspections of the lifelines in 2018 / 2019 and editorial comment.

At the time of the Anchorage Earthquake in late 2018, the population of the greater Anchorage area was about 370,000 people. This includes about 300,000 people in Anchorage (including the adjacent military bases), and about 70,000 people in the Matanuska Valley (Palmer, Wasilla and adjacent communities, to the north of Anchorage).

Ground Motions

This earthquake was an Intraslab event, occurring within the Pacific plate that is subducting under Alaska. The epicenter was about 47 km deep. Aftershock sequences indicate that that rupture fault plane propagated to the north.

The main shock was recorded by 28 strong ground motion instruments in or very near to the City of Anchorage and 2 strong ground motion instruments in the Matanuska Valley. The average recorded by these 30 instruments (maximum of North-South and East-West components) was PGA = 0.29g and PGV = 31 cm/sec.

The duration of moderate to strong shaking (PGA > 0.05g) was commonly 15 to 20 seconds. Some people reported that they felt the earthquake last for as long as 45 seconds. Some people reported that they felt the earthquake last as short as 10 seconds.

Several of these instruments recorded strong motions:

- In the North-South direction there was one free field instruments that recorded PGA = 0.5 – 0.6g; one instrument recorded PGA = 0.4 - 0.5g; five instruments recorded PGA = 0.3 - 0.4g . Peak recorded North-South velocity was ~40 cm/sec.

- In the East-West direction there were two free field instruments that recorded PGA = 0.4 - 0.5g; five instruments recorded PGA = 0.3 - 0.4g. Peak recorded EW velocity was ~42 cm/sec.

The earthquake triggered some liquefaction and landslides. PGDs in liquefaction zones were commonly settlements on the order of an inch to a few inches. Landslides included rockfalls, snow avalanches and some deep seated slides. Rockfalls did not impact urbanized areas, but it was reported that falling rocks just missed some people.

A few road embankments slumped downwards and sideways, with movements of 10 feet or more. These road embankment failures were amongst the most spectacular soil failures in this earthquake. A 4-inch diameter steel natural gas pipeline was embedded in one of these embankments, and the pipe underwent lateral displacements on the order of 14 to 16 feet; the pipe remained in service with no leaks; this reflects the rather gradual curvature of the soil movements over a span of more than 330 feet; the high quality of construction of the pipe; and the very soft / weak nature of the soils along this pipe alignment.

There was no observed surface faulting in the 2018 Anchorage Earthquake.

In the Great Alaska earthquake of 1964, there were no working strong motion instruments that recorded the shaking anywhere in Alaska. Given the distance from Anchorage to the ruptured subduction zone, it is estimated that in the 1964 earthquake, the ground motions in Anchorage were about PGA = 0.2g±, with durations of 4 to 5 minutes of shaking. The Great Alaska earthquake caused severe ground failures at a few locations in Anchorage (permanent ground movements over 10 feet) and a variety of lesser ground failures at several locations in Anchorage.

For the most part, the so-called "Bootlegger" formation that underlies parts of Anchorage that failed in the 1964 earthquake did not fail again in the 2018 earthquake. This might reflect the shorted duration of strong shaking in the 2018 earthquake, meaning that the area remains vulnerable from future soil failures in future M 8.5 – 9.0± interslab events, which are nearly sure to occur in the next few hundred years.

Electric System Performance in the 2018 Anchorage Earthquake

There are three electric systems that provide power to the greater Anchorage area: Chugach Electric Association (CEA, serving southern Anchorage and southern outlying rural areas); Anchorage Municipal Light and Power (ML&P, serving downtown Anchorage); and Matanuska Electric Association (MEA, serving Eagle River, Palmer, Wasilla and other rural areas to the north). All three electric systems suffered power blackouts; power was restored to most customers within a day or so. CEA had about half their customers out for up to 12 hours. ML&P had nearly all their customers out initially, with most outages restored within a few hours and a few lasting just over a day. MEA had about 90% their customers out for up to 24 hours. The reasons for the power outages varied based on location, including:

- Functional damage to substation equipment. Functional damage includes broken porcelain equipment; fallen rigid bus; broken post insulators. The known quantity of broken components includes: 115 kV Circuit Breakers (3); 115 kV Surge Arrestors on transformers (at least 9); 230 kV Disconnect Switches (14 positions); 115 kV Potential Transformers (2); 115 kV Current Transformers (3); 115 kV Transformer bushings (1); many broken rigid bus runs at all voltage levels, including 230 kV. This equipment will need to be replaced in the long term. In the short term, to restore power, some of this equipment was bypassed, some equipment was replaced with spares, and one 230 kV substation was bypassed entirely.

- Some of the damage of this equipment at substations was due to inertial overload, while some was due to insufficient slack between adjacent pieces of equipment (flex bus), and some was due to adverse interactions between rigid bus and adjacent equipment.

- All transformers that were inspected are three phase transformers. Many 115 kV power transformers (about two dozen) tripped within several seconds of the start of the earthquake. This included 2 of 3 115 kV transformers at MEA's ESA 171 MW power plant. These trips were due to sloshing of oil within the transformer, which resulted in "false positive" signals of low- or low-low oil within the transformer. This was common in the CEA and MEA systems; ML&P set the low oil pressure settings to "alarm" and none of ML&P's transformers tripped. When the transformers tripped, this resulted in immediate outage for all downstream customers on the related low voltage feeders. After the earthquake, each power utility inspected the tripped transformers and then re-set the transformer if no damage was observed (with a few exceptions, no damage was found).

- Many transformers at older substations were unanchored. A few of these slid (usually 1 to 3 inches or so) or rocked. For at least one transformer at the Beluga power plant site (25 kV to 12 kV), core damage was observed a few months after the earthquake; the observations suggested that an internal core slid during the earthquake, resulting in increased stress on internal wiring; over time, the internal wiring failed, which will require replacement of the transformer.

- Several 115 kV surge arrestors on booms on 115 kV - 12 kV transformers failed. These failures occurred on three transformers; all surge arrestors were damaged on these transformers. All of these surge arrestors were porcelain, mounted on steel channels that cantilevered off the top of the transformer. All these transformers were unanchored, and exposed to PGA in the range of 0.25g to 0.35g or so. All installations had flexible bus conductor attachments, with limited cable slack (commonly under 2 inches of so). We observed a few similar surge arrestors on other transformers that did not fail. The reason(s) for these failures could have been: inertial overload (though less likely); inadequate slack (likely); rocking of the transformer that resulted in impact loading and excessive slack demand (likely).

- There are two sets of submarine power cables that cross the Knik Arm. One set of cables operate at 138 kV (two circuits), from the Point MacKenzie landing (northwest side of Knik Arm) to a landing just north of the International Airport in Anchorage. One set operate at 230 kV, from the west side of Knik Arm about 10 km north of Point MacKenzie to the eastern side of Knik Arm within the Elmendorf Military Base. The 230 kV potheads at the east landing of the 230 kV cables were found to be leaking oil after the earthquake; the bolts on these pot heads were tightened after the earthquake and the pot heads and 230 kV circuit were then put back in service.

- None of the submarine 138 kV or 230 kV cables across the Knik Arm are known to have been functionally damaged by the earthquake. These cables were originally laid in submarine trenches and backfilled. It is thought that under normal conditions (without the earthquake), high tide velocities alternately cover and uncover the cables over time. Several of these cables are Pirelli oil-filled cables. The owner of these cables, CEA, reports that they have not inspected the condition of the underwater cables since the earthquake. While all these submarine cables remained functional, there have not been detailed post-earthquake inspections of the cables and soils around them to determine of there were underwater soil movements or other phenomena that occurred along the cable alignments.

- At the Point MacKenzie substation (CEA), 14 of 22 230 kV disconnect switches failed and adjacent 230 kV rigid bus was damaged. This 230 kV yard remained entirely out of service seven months after the earthquake, and jumpers were installed post-earthquake to temporarily bypass the damaged 230 kV yard. This substation has 2 230 kV lines and 1 138 kV line delivering power to the yard from the Beluga power plant, 2 138 kV lines connected to western Anchorage, 2 230 kV lines connected to northeast Anchorage and to the Teeland substation in the north, supporting MLP, MEA and GVEA (Fairbanks). CEA plans to re-build the yard in early 2020, more than a year following the earthquake. The approach to re-build the yard will likely not follow the requirements of IEEE 693 (seismic guidelines for substations), in order to reduce the re-construction cost by perhaps several million dollars.

- The underlying root cause of the damage at the Point MacKenzie yard, namely seismically-weak design of the bus, is not unique to this substation; similar details are found at other substations in the greater Anchorage Area, including yards in the MEA system. Damage to the bus occurred at one Douglas substation, using similar bus details as at Point MacKenzie. MEA's EGS yard also uses similar bus details, but the EMD substation was exposed to shaking levels perhaps one-half those at Point MacKenzie. The adequate performance in the 2018 earthquake at the EGS yard (by "adequate", it is meant that the various damage at the yard was not so severe as to preclude re-energization within a day post-earthquake) should not be construed to mean that this yard will not have significant damage in future larger earthquakes.

- Various amounts of relatively minor damage occurred at power plants. The 40 MW Eklutna hydroelectric plant tripped offline due to high-frequency protection; load served by this unit had dropped nearly immediately after the earthquake; also, three pieces of 115 kV equipment atop the powerhouse building were functionally broken.

- The 171 MW EGS natural gas engine power plant remained in service after the earthquake, even though 2 of its 3 step-up transformers tripped due to oil sloshing; the third step-up transformer remained on line, and was able to support the remaining greatly-reduced power demand. There was various types of non-structural damage at the EGS power plant, including several failed space heaters; a broken water pipe in the control room due to differential motions between two adjacent buildings; minor number of items spilled from book shelves. While the 115 kV switchyard had no damage in this earthquake (motions on the order of PGA = 0.2g) this 2016-vintage yard uses similar rigid bus detailing as at the Point MacKenzie substation and could be vulnerable to damage in future larger earthquakes.

- There was minor damage reported at the Beluga power plant, including an outage on a distribution-level voltage transformer.

- There was various types of damage in the low voltage (typically 12 kV) distribution systems. MEA's distribution system is about 95% overhead and 5% underground. ML&P's distribution system is about 25% overhead and 75% underground. CEA's distribution system is about 85% overhead and 15% underground. Generally, the damage was confined to the overhead wire systems. ML&P's distribution system remained energized immediately post-earthquake, as ML&P's transformers did not trip. ML&P's distribution damage included wire slapping, blown fuses, failed cutouts. A few at-grade distribution transformers slide a few inches, but in no case did that fault the cables / wires. Almost all distribution power poles are wood. No power poles were exposed to significant PGDs due liquefaction or landslide / avalanche. No power poles are known to have toppled or broke. No pole-top transformers fell to the ground; all appeared to be anchored directly to the poles. No pole-top platform-mounted distribution transformers were observed.

- The inventory of on-land buried power cables includes both older PILC and newer XLPE type. Common burial depths are 4 feet of cover. At the time of the earthquake, the ground had not yet frozen. No underground cable faults were reported. The oldest buried cables were installed using direct burial. Most of the underground cables are now installed in conduits (commonly PVC or HDPE). Thermal concrete backfill is not used in Anchorage, in part because the colder / frozen ground in the wintertime (the season of peak power demand) helps dissipate cable heat. If the earthquake had occurred after the time the ground was frozen to a depth of 4 feet (common for a few months each winter), it is speculated that there might have been more buried cable failures, especially those installed by direct burial and exposed to ground deformations.

- The number of substations with functionally damaged equipment included: MEA (4 substations, Pippel, Douglas, Briggs, Anderson), CEA (4 substations Point MacKenzie, Latouche, Beluga power plant yard, 230 kV east cable landing), ML&P (1 substation Eklutna). CEA also had various types of relatively minor damage (oil leaks, cracked foundations, etc.) at several substations: Latouche, Rutherford, Klatt, Huffman, Hillside, University, Dowling, Boniface, Point Woronzol, International, Airport, Teeland.

- Each of the 3 power companies had "all hands on" emergency response. Each power company supplemented their in-house workforces with 1 or 2 extra crews from local contractors. No mutual aid from other utilities was used (it was offered), largely because power was restored mostly within one day.

- No transmission towers (115 kV to 230 kV) were functionally damaged. There are no (or very few) four-legged steel lattice towers in the area; most transmission structures are either 1- or 2-pole structures, either wood or steel. The common wind speed design for newer transmission towers is 132 mph, All transmission towers are also designed for heavy snow loads as well as glaze ice loads. Rime ice is known to occur in the area, with historic reported Rime ice instances on overhead conductors of about a foot total diameter. In the 1964 Great Alaska earthquake, 3 transmission towers collapsed due to snow avalanche impact at the Knik Arm inlet crossing, and several transmission towers collapsed due to liquefaction soil failures at the eastern end of Turnagain Arm.

- No distribution poles are known to have broken. A few poles in zones with PGDs may have become tilted.

- No low voltage transformers or regulators are known to have fallen off their wood poles. All are thought to have been well anchored to the poles.

- Due to the loss of most customer load immediately after the earthquake, system frequencies increased in all three systems. The Eklutna hydropower plant tripped off line due to over-frequency.

- The residual power plants used in the days after the earthquake, once the distribution feeders were repaired, were the SPP (200 MW capacity, natural gas) and EGS (171 MW capacity, natural gas with backup diesel fuel), ML&P Units 1, 2, 2A (natural gas). Combined, these power plants had more than enough capacity sufficient to carry the load. The Beluga power plant (350 MW) was initially isolated from the grid due to the severe damage at Point MacKenzie substation; with some peaking power still available via the single 138 kV line from the plant. Hydroelectric plants in the Kenai Peninsula were not damaged.

- Natural gas supply to the operating power plants was not disrupted. Three of five compressors from the Belugas gas storage facility were reported to have gone offline. This would have which reduced gas supply via the gas transmission pipeline along the north side of Knik Arm. An alternative gas supply from Kenai Peninsula was not impacted. At no time did power plant operations have to be curtailed due to loss or reduction in gas supply.

- Total estimated repair costs for the three power utilities is about $9.2 million. This includes: $1.6 million (MEA); $6.3 million (CEA, could increase to > $12 million pending final re-construction of the Point MacKenzie substation); $1.3 million (ML&P).

- There were no reports of damage to photo-voltaic power installations. PVs are not in common use in Anchorage, in part due to the long dark winters.

- There is one commercial scale wind farm in the area, with about 17 MW of wind turbines on Fire Island. Fire Island is located in Cook Inlet, southwest of Anchorage. The level of shaking at Fire Island might have been about PGA = 0.15g±. The power is delivered to Anchorage by submarine cable. We did not interview the owner / operators of this system; however, local officials reported that they knew of no known damage to this wind power system.

Gas System Performance in the 2018 Anchorage Earthquake

The natural gas system is owned and operated by Enstar. Enstar's service area includes all of Anchorage, Eagle River and the Matanuska Valley. The gas system in Anchorage was developed beginning in 1961.

The gas system includes steel transmission mains (about 440 miles) and HDPE distribution mains (about 3,200 miles). At the time of the earthquake, there remained about 1,000 copper service laterals.

Over time, Enstar has been replacing copper service laterals, owing to their relatively high vulnerability to corrosion and requirement for ongoing repairs. At the time of the earthquake, there were about 1,000 remaining copper service laterals. Enstar has an ongoing program to replace these copper service laterals, averaging about 100 replacements per year.

The gas system suffered a variety of impacts. Overall, the level of impacts was not serious.

- Surveyors were initially dispatched to look for leaks. Areas perceived to be relatively higher risk (high population density areas) were prioritized.

- It was found that the gas system damage was relatively concentrated in the Eagle River area.

- About 2,000 orders were received to check for gas leaks. Most orders were "called in" by gas customers requesting assistance either for gas leaks (or perceived gas leaks), or requests to reset pilot lights for gas appliances.

- Frost heave is an important issue for normal design of buried infrastructure. To accommodate frost heave, there are flexible connections on service lines to customers. These flexible connections may also have helped reduce damage to service connections during this earthquake.

- Some customers were turning off gas valves, including both their own and their neighbors. The reason(s) for turning of the gas valves apparently had to do with perceived instructions from other municipalities, such as in the Los Angeles area, where this action is often discussed in the media. Shutting off gas valves is not a recommended practice by Enstar, unless there is a gas leak (usually smelled by the odorant, or otherwise observed). Enstar issued public notifications to tell its customers not to turn off their gas valves unless there was a gas leak.

- After assessing all the damage post-earthquake, Enstar reported that there were 3 repairs to the gas pipe system needed due to earthquake damage, and another 12 repairs due to corrosion or other effects. The 3 earthquake-related repairs were all on service lines / taps, and non on the gas mains.

- There are no regional plans by government authorities to shut off the gas supply while looking for gas leaks.

- There were no requirements to install automatic gas shut off valves in the Enstar service area; after this earthquake, no state or local building official thought that future installation of such valves would be needed based upon what happened in this earthquake. No such valves (or very very few) of such valves are known to have been installed for any Anchorage area residential customers. A few automatic shut-off valves were known to be installed (falling ball -type, activated by high inertial shaking) at large commercial / industrial / education customers; those customers usually have on-site maintenance engineers capable of address the shut-off / restart issues related to gas system isolation. No fires are known to have been fed by natural gas at any location. Natural gas is considered essential in the area for providing space heat, and due to the seasonal cold temperatures in the area, shutting off gas supply using automatic gas shut off valves is thought to be a practice that presents more life-safety issues than perceived seismic "benefits".

- Enstar reports that they had on the order of $1 million in damage / repairs / inspection costs due to this earthquake.

Water and Wastewater System Performance in the 2018 Anchorage Earthquake

The City of Anchorage and adjacent Eagle River is supplied by the Anchorage Water and Wastewater Utility (AWWU). AWWU operates two water treatment plants that take water from surface water (Eklutna reservoir and Ship Creek), as well as several moderate- to high-flow wells. Much of this area is also served by a piped wastewater collection system with a waste water treatment plant.

The Matanuska Valley (Palmer, Wasilla and nearby communities) and other rural areas have potable water served primarily by private low-flow wells. There are thousands of these wells. After initial commissioning, most of these wells are unregulated. Septic tanks are used for most of this area.

There is no storm drain pipe collection system for the bulk of the area impacted by the earthquake.

The AWWU water system suffered a variety of damage.

- About 50 water pipes were damaged and had to be repaired. This includes damage to Asbestos Cement (AC), Cast Iron (CI), and Ductile Iron (DI) mains (commonly 6-inch to 24-inch diameter) as well as Copper service laterals. DI pipes had the largest number of repairs. Most water pipes and laterals are buried with 10 feet cover; this reflects that the ground freezes during the winter, and the depth is selected to keep the pipes below frozen ground.

- AWWU considers the bulk of the soils in the area as being corrosive.

- DI pipes were installed with plastic bag liners. This apparently did not limit damage either due to accumulated corrosion or due to ground shaking or due to permanent ground deformations. There were no "seismic-designed" water pipes in Anchorage at the time of the earthquake.

- No municipal wells were damaged (no broken casings). All these wells use direct drive pumps. Water quality from AWWU's wells was not impacted (no appreciable sanding).

- The water supply into AWWU's system at the time of the earthquake was about 19 MGD. With the exception of larger commercial and multi-unit residential customers, water is not metered in Anchorage. Due to the damage of the water pipes, water supplied into the system rapidly increased to over 45 MGD over the course of several hours after the earthquake. One distribution water tank drained completely after the earthquake, caused by rupture of a water main near Eagle River.

- With the exception of customers in Eagle River, very few AWWU customers lost water supply. This reflects that almost all of Anchorage's piped water system is looped, and almost all water customers can be fed by pipelines in two directions.

- There are many pressure zones in the AWWU system. This reflects that the topography varies from near seal-level to almost 2,000 feet above sea level.

- AWWA has a total of 73 MG of water storage in 22 surface level distribution water tanks. All but one of these tanks is welded steel; all the steel tanks are reported to be unanchored. There is one circular post-tensioned concrete tank. All steel tanks rest on concrete slabs that extend completely under the tanks, not just under the steel shell as is common in the lower 48 states; there is a bottom level steel plate to provide the leak-tight water boundary for all steel tanks; this plate sites atop the concrete slab. None of these tanks were damaged.

- Summertime water demand in Anchorage is about 23 MGD. This reflects that while there is some use of water for irrigation during the summer months, it is not an exceptionally high amount.

- With a total storage volume of about 73 MG and typical demand of about 20 MGD, there is nearly 3.5 days of storage. Over recent years, AWWU has recognized that this is more storage than commonly needed for operational and regular emergency usage. Therefore, AWWA adopted a policy that the tanks would only be filled to 60% to 80% of their capacity, with highest fill levels commonly occurring in the early morning hours, then drawn down somewhat during the day, then re-filled overnight. Equipment have been installed in all tanks to provide mixing to improve water quality. From perspective of the earthquake, this was fortunate, as no water sloshing impacts to the underside of steel tanks was known to occur, reflecting that there was commonly 5 feet or more free space above the water levels at the time of the earthquake. The lowered volumes of water likely also helped reduce the tendency for unanchored tanks to have wall lift, reducing the potential for damaging attached pipes or damaging the tank wall – base plate welds.

- An ongoing issue for water tanks is that a layer of ice tends to form atop the water during colder winter months. As the water levels rise and drop, this ice-cap also moves up and down, with the ice scraping the insides of the tanks. This scraping action results in ongoing maintenance issues, having to repair the paint systems inside the steel tanks.

- Out of the thousands of privately-owned wells, building officials report that only a few (possibly 4, possibly more) were functionally damaged. There were many reports of sanding in privately-owned wells; with water quality clearing after a few cycles of well start-up operations. There was no report of any appreciable change of work for drilling new wells after the earthquake.

The AWWU wastewater system suffered some damage.

- About 20 wastewater pipes were initially identified as damaged and then repaired due to the earthquake.

- In the spring, a wastewater pipe that was laid across the bottom of a lake, floated up to the lake surface. This pipe was ductile iron with rubber push-on joints. The pipe was operated in open channel flow. The reason(s) for the pipe to float are not certain, but might have been due to liquefaction during the earthquake that resulted in upwards buoyancy forces that were initially insufficient to overcome the frozen soil overburden forces; but when the soils eventually thawed in the warmer spring months, the pipe lifted up. According to AWWU, the uplifted pipe was not leaking. Review of photos of the uplifted pipe showed it was uplifted in a reverse catenary shape, with relatively small angle changes at each pipe joint. The repair was quite involved: the lake had to be drained; then the pipe re-buried into a trench.

Most rural homes obtain water by privately-owned wells. We do not have a specific count of these wells, but the total inventory in the greater Anchorage / Palmer / Wasilla area might be on the order of many tens of thousands of such wells. Commonly, the wells are from 100 to 200 feet in depth. Water quality is usually good, and treatment of well water is not prevalent.

Area officials suggest that perhaps there were on the order of "a few" wells with material damage; there was no known material increase in effort to drill new wells after the earthquake. Sanding of wells is thought to have been relatively common; no instances are known where sanding was especially problematic, and usually resolved after a few start-up cycles of the wells.

Fire Following Earthquake

There were "about" 2 known fire ignitions in the Anchorage area due to this earthquake. Natural gas was not a factor in either of these fire ignitions. Neither fire spread. At the time of the earthquake (8:30 am), winds were calm; wind speed picked up during the course of the day.

Port

The Port of Anchorage did not suffer material damage in this earthquake. However, it is commonly thought that the Port remains seismically vulnerable, especially for ground failures that are thought to be likely in the event of a longer duration earthquake.

Communications

The Anchorage area has both landline and cell phone telecommunication services. Voice Over Internet Protocol is common.

During the earthquake, phones remained almost entirely in service. No cell phone sites are known to have gone offline, reflecting that while many sites had lost commercial power, available battery backup power was sufficient to last until commercial power was restored.

Call saturation did occur, lasting for about 1 to 2 hours after the earthquake. The increase in call demand is common after earthquakes, and call saturation occurs when the demand to place calls exceeds the phone switch capacity. Prioritized access to phone call completion for emergency responders was in place.

Utilities and emergency responders also use radios for day-to-day as well as emergency response communications. Some radio repeater sites are in relatively remote locations at mountain tops, etc., and these sites are often difficult to maintain in the winter due to blockage by heavy snow. For this reason, remote radio repeater sites are often outfitted with emergency generators with lots of fuel, sufficient to last through long storms (reportedly, at some sites, sufficient to last an entire winter season). Overall, most radio repeater sites remained operational during the day or so post-earthquake; it was reported that MEA might have lost some repeaters.

Email remained on line throughout the earthquake.

General Building Stock and Related Issues

There were no fatalities caused by this earthquake. Hospitals did not report any surge in the number of people admitted with serious injuries post-earthquake.

The response of lifelines can be impacted by the performance of the general building stock. For example, collapse of a portion of the general building stock can lead to many impacts to lifelines, such as: no access to equipment (cell phone sites, etc.) within / atop buildings that are "yellow tagged" or "red tagged"; serious damage to buildings will lead to damage of the utility's service line connections; partial or full collapse of buildings leads to a higher chance of fire ignition; etc.

Building and emergency response officials reported the following:

- There were about 13,000 building owners that requested some form of assistance. This included tagging (red / yellow / green tagging); requests for reimbursement for repairs.

- Of these ~13,000 requests, FEMA approved about 3,000 requests for some amount of financial reimbursement from FEMA. These reimbursements were approved only if the type of damage was attributable by the earthquake, and was sufficient as to warrant a potential life safety issue (including loss of space heating, loss of utilities, etc.).

- The State of Alaska and FEMA combined have tabulated about $100 million for homeowner damage that is eligible for reimbursement from State of Federal authorities. This amount is through to be only a small portion of the overall damage.

In the Anchorage area, there are relatively very few buildings that are especially vulnerable in earthquakes. There are almost no unreinforced masonry / brick / clay tile buildings in the area, reflecting that there is almost no sources of clay in the area, and import of these building materials is relatively expensive, and it has been long recognized that these materials are especially vulnerable in earthquakes.

Two other styles of buildings are also especially vulnerable in earthquakes:

- Buildings with unreinforced brick chimneys

- Mobile homes (manufactured housing)

In past earthquakes in California it has not been uncommon to have hundreds to thousands of brick chimneys fail. Such failures present a risk to people due to falling debris. Chimney failures also present an increase chance of fire ignition.

Anchorage area building officials reported that there is an extremely small inventory of brick chimneys, perhaps in the range of 20, in the entire area. In the 2018 Anchorage earthquake, building officials reported that there were "perhaps" 1 instance where a permit was required to repair a brick chimney. We visually surveyed portions of the older neighborhoods in Anchorage, and confirmed that there are in fact very few brick chimneys.

There are perhaps 6,000 to 9,000 mobile home buildings in the Anchorage area. Our team surveyed several of the mobile home parks and discussed seismic issues with some park operators. They generally reported that they thought that all of their mobile home installations were seismically anchored. However, upon more detailed discussion / review, it appears that some of the oldest mobile homes (1970s vintage) might have been resting only on a stacked set of concrete masonry units (or similar), without formal seismic tie down devices.

Anchorage building officials suggested that there was not a single instance in the entire Anchorage area that a mobile home "collapsed". By "collapse" it is meant that the structure toppled off its foundations. However, there were about 200 to 300 reports where mobile homes were perceived to have "shifted" in a manner that would require re-leveling. There were cases where there was damage within the mobile home that resulting in openings / cracks to the outdoors, making the homes "too cold to live"; such building separations were common at add-on vestibules. None of the lifeline operators interviewed for this report mentioned any material damage to their service line connections (water, gas, sewer, power) to mobile homes that was due to shifting of the structures.

There was a significant number of people who requested and used temporary shelters after the earthquake.

Observations and Recommendations

The Anchorage area is one of the most seismically-active places in the United States. The 1964 earthquake was a major catastrophe in the area. People in the area are well aware they live in "earthquake country".

In the intervening time from 1965 through 2017, the various lifeline operators in the area have constructed much of today's infrastructure. But, from what we observe, what has been built has not always been done to the latest seismic standards.

No one in the greater Anchorage area should believe that the lifelines that support their community are seismically "invulnerable". The November 30 2018 earthquake showed that damage to lifelines did occur.

The relatively good performance of the lifelines in the November 30 2018 earthquake may not be indicative of what might happen in future earthquakes. Lifeline damage in future local M 7± crustal earthquakes or M 9± interplate earthquakes could cause much more damage to Anchorage-area lifelines and much longer outages.

Anchorage - area electric substations have significant seismic weaknesses. The seismic design practices recommended by IEEE 693 and 1527 and similar industry guidelines have not been widely implemented. For the most part, repairs to the substations in the 2018 earthquake were simply to get power flowing again; many of these repairs have not cured the underlying seismic weaknesses. The 2019-vintage bus work at various 60 kV to 230 kV substations throughout the greater Anchorage area appear to still have seismic deficiencies. Each of the three utilities, CEA, MEA and ML&P, should conduct thorough evaluations of their substations, identify the weak components, and upgrade where appropriate; this could be done in 2 to 5 years, at modest cost.

Underground utilities (water, gas, buried cables) performed reasonably well in 2018. For the most part, this reflects that there were very few ground failures (liquefaction, landslide) in the vicinity of the utilities this earthquake. But, in future earthquakes, ground failures on a widespread basis cannot be ruled out, and this will lead to much worse performance of the buried utilities, and many more and much longer outage times. Each utility (especially water, gas, electric) should review its current inventory of buried pipelines / cables, and determine how they might perform with ground failures; and then replace the older infrastructure with new earthquake-resistant infrastructure, where cost effective. Given the normal replacement cycle of buried pipelines / infrastructure, this effort could be accomplished in 10 years (for the most critical parts of the networks) to 50 years (for the bulk of the network), without resulting in excessive high costs by the customer.

Who pays? and What to do?

In 2019, the Federal Emergency Management Agency (FEMA) has various programs to pay for repairs and mitigation of publicly-owned infrastructure. If the President declares a disaster, then FEMA is allowed to pay a large portion (often 75% or higher) for many kinds of disaster-related repairs and mitigation. Most, but not all, of the Anchorage-area utilities are eligible for funding from FEMA.

- Having the FEMA resource should not be considered as the only source of funding. FEMA's budgets are set by Congress, and can change every year.

- FEMA funding should not be considered the only form of "insurance". While FEMA funding can be useful, the bulk of the funding, and the most importantly, the will to implement, must come from the local community.

- The technology exists today to make electric, gas, water and communication utilities seismically resilient. The Anchorage utilities need to adopt these technologies into their ongoing design practices.

- It takes many years to build and re-build a lifeline. Incorporating seismic design at the time of original construction, is the least cost way to make the lifelines more resilient. If the utilities don't start to implement seismic design for their new construction, the lifelines will never become resilient.

Acknowledgements

This report has been prepared by John Eidinger with input from John Dai (Southern California Edison) and Bruce Maison (Structural Engineer); collectively, "we".

In this report (TCLEE No. 5), we document the performance of lifelines in the 2018 Anchorage earthquake. Several lifeline operators in the Anchorage area supported this investigation, we would like to especially thank MEA, ML&P, Enstar and AWWU for their support.

Officials at CEA have been reluctant to share all the details of the damage at the Point MacKenzie 230 kV substation with the public. A thorough investigation is called for to publicly examine the root causes of the damage at Point MacKenzie, determine if other Anchorage - area substations (and other substations around the world) have similar seismic vulnerabilities, and then take suitable mitigation action.

We acknowledge the fact that all incur a cost in the effort to document the performance of lifelines in earthquakes, with the hope that all will recognize this as an investment for resilient lifelines and our intent to achieve a long term gain in increasing our understanding of the issues.

As is not uncommon in post-earthquake reconnaissance, incomplete information in the weeks and months after the event can lead to omissions and misunderstandings. We apologize if the findings in this report are incomplete, and the reader is cautioned that it may take months to years of post-earthquake evaluations before a comprehensive understanding of lifeline impacts is available. Should readers uncover new information, which would improve the findings in this report, we request that they forward that information to the authors, and we will then update this report as suitable.

Respectfully submitted,

John M. Eidinger, September 19 2019

Endorsements

Nothing in this report should be considered as an endorsement of any particular product or company.

While we believe the information contained in this report reasonably reflects what occurred (or did not occur) in the November 30 2018 earthquake that affected the greater Anchorage area, there is no doubt that this report does not contain all possible information, and it may contain inaccuracies.

This report makes mention of various corporate and local government entities; some are listed on stock exchanges. While these entities shared information with us, the readers should know that none of these entities have endorsed the facts, conclusions or recommendations in this report.