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LESSONS ON RECOVERY OF FUNCTION FROM ANCHORAGE, ALASKA AFTER THE 2018 COOK INLET EARTHQUAKE

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Abstract

The magnitude 7.1 Cook Inlet Earthquake of November 2018 greatly affected Anchorage, AK area residents. Although shaking likely did not exceed the hazard level for which most newer buildings are designed, disruption to normal operations was significant due to varied impacts across the built environment. In January 2019, the National Institute of Standards and Technology (NIST) deployed a reconnaissance team to Anchorage, AK to learn about damages, collect data from seismically instrumented buildings, evaluate the performance of fiber reinforced polymer (FRP) retrofitted structures, and to study risk perception and issues related to re-occupancy timelines and the recovery of function for buildings and infrastructure. This paper discusses findings from interactions with representatives from the Anchorage School District, the Alaska Department of Transportation, and the Municipality of Anchorage Building Safety Department regarding aspects of recovery within their sectors. Key topics explored in this paper relate to barriers for building re-occupancy, procedures for deployment of response and assessment teams, expectations regarding timelines for returning to normal post-earthquake, as well as data needs for risk mitigation action. These areas of practice, which are somewhat outside the control of designers and engineers of buildings and infrastructure, are critical to understanding specific reasons for delays or inefficiencies in recovery of function and can be used by planners and policy makers to improve post-earthquake recovery. So, while shaking from the Cook Inlet Earthquake was not seen as a true test for modern engineered buildings, it did pose a challenge for individuals and organizations in the Anchorage area and should be assessed to determine what measures could help to support return to function after earthquake events. The impressive post-earthquake efforts and accomplishments made in Alaska provide several clear examples to inform preparedness and response and recovery best practices elsewhere. This is valuable knowledge upon which we can build to support society's desires to move beyond the life-safety performance objective currently targeted in building codes and standards.

Keywords: Cook Inlet earthquake; functional recovery; re-occupancy; transportation; schools; building inspection

1. Introduction

This paper discusses aspects of recovery for buildings and critical infrastructure systems from the 2018 Cook Inlet Earthquake in Anchorage, Alaska, U.S.A. The purpose is to highlight information relevant to the recovery of function of the built environment after an earthquake. The authors explore lessons learned from the earthquake and highlight takeaways from the Cook Inlet Earthquake necessary to develop effective procedures to mitigate risk from earthquakes. Findings from this paper will be of interest to federal agencies and stakeholders involved with the U.S. National Earthquake Hazards Reduction Program (NEHRP), earthquake risk mitigation professionals across multiple sectors, as well as personnel at state and local levels involved with planning for, or recovering from, earthquakes. Findings are the result of a preliminary reconnaissance mission undertaken by staff at the National Institute of Standards and Technology (NIST), a measurement science agency of the United States government. Discussion and findings offer insights on areas of current policy and practice that may be improved to enable quicker return of operations and functions provided by the built environment, and important to the U.S. society and economy.

2. The 2018 Cook Inlet Earthquake

The magnitude (M_w) 7.1 Cook Inlet Earthquake that took place on November 30, 2018 deeply affected Anchorage, AK area residents. Earthquake shaking is reported to have lasted for almost one minute [1]. Videos show strong movement of buildings, drastic shifting of contents, and falling ceiling tiles or other highly placed objects on shelving or in kitchen cabinets [2]. Video, audio, and other sources highlighted the reactions of people that were highly stressed, and in some cases screaming and scrambling to collect pets and children [3]. This earthquake was the strongest earthquake to hit the Anchorage area in several decades, and many residents reported never having experienced anything like it.

The earthquake occurred at 8:29 AM local time at coordinates 14.5 kilometers northwest of Anchorage [4], at a depth of 46.7 kilometers [5]. These characteristics of the earthquake's location, its distance combined with depth, means that shaking experienced from the M_w 7.1 was less than might have been expected had the earthquake been shallower and closer to populated areas in and around Anchorage [3].

As with most large earthquake events, the November 30th M_w 7.1 Cook Inlet earthquake was only one earthquake within a series of other seismic events. Anchorage area residents experienced more than 40 aftershocks by Dec. 1, 2018 (10 with a magnitude above 4.0), and over 5,000 aftershocks within 18 days of the earthquake [6,7]. At the time they were experiencing each event, residents were uncertain whether the earthquake that was occurring was weaker or stronger than the previous earthquake, creating a situation of constant psychological stress, and impeding the flow of the recovery process [8]. Even a month and a half after the earthquake, at the time of NIST's visit, residents described being in a state of trauma from repeated aftershocks, further damage, and recovery proceeding slower than they would like.

Anchorage's experience of this earthquake also interesting because the city endured another large earthquake in 1964. This earthquake, the magnitude 9.2 Good Friday Earthquake, spurred the development of modern seismology and earthquake structural engineering. The 1964 earthquake was significantly stronger, and caused damage across the region, with substantial damage occurring within the Anchorage area due to both building and ground failures, despite the fact that the earthquake epicenter was about 120 kilometers from Anchorage [9]. Photographs show shifting ground that displaced entire neighborhoods, streets that dropped up to 2 meters trapping cars, and multiple other damages [10]. The fatality estimate for the event ranges up to nearly 140 individuals, and most were killed either by landslides, ground deformation, or tsunamis [[11]. Impacts to society, including the economy, were so severe that there was a national-level response of media coverage, emergency response, and science and technology policy creation [12]. Since 1964 there have been significant protective advances in building design and some hoped the Cook Inlet earthquake could show that these seismic advances have been successful [12].

In the aftermath of the Cook Inlet Earthquake, multiple types of impacts were reported across components of the built environment (buildings and infrastructure). Water and wastewater were minimally impacted across the region, and power and full telecommunications were restored within hours for most of the Anchorage area [15,16, 17, 18, 19]. Transportation networks were impacted, but the port, airport, and rail network regained services quickly, in most cases less than one day [20]. Damages to the road network most impacted the community, and these will be discussed further below [21]. For buildings, the majority of damages were non-structural and included the shifting or breaking of building contents. Schools suffered non-structural damage (*e.g.* fallen ceiling tiles), and some structural damages (*e.g.* walls moved out of place); all were immediately closed after the earthquake [22]. Aspects of school inspection and closure will also be discussed in this paper. The majority of larger public-use buildings withstood the earthquake with minimal damages. Areas reporting the most significant damages include communities located to the north of Anchorage where ground failures led to partial collapses of some residential units. In addition, more damage may have been seen in these areas of lesser building code and standard adoption and enforcement [23, 24].

The lack of deaths and injuries in Anchorage after the Cook Inlet Earthquake may give the U.S. public a false sense of security in their ability to withstand a magnitude 7.1 event [23, 25]. The particular conditions of the earthquake, its distance from the urban center and mitigation due to depth and the particular geological conditions of the area, are unique. A similar magnitude event in a different location would produce effects, damages, and impacts that may be much worse because buildings are older and the area more densely populated [3, 25]. For this reason, enhanced data that can better communicate shaking intensity at particular locations across the earth's surface, rather that energy release, may be helpful.

Alaskans are also aware that their experience could have been different if shaking had been worse or had occurred under different environmental conditions. If the port, airport, or telecommunications networks were more significantly damaged, deliveries of food, medical supplies, and emergency aid and response could have been negatively impacted. Or, if there had been significant snowpack causing additional weight loads to roofs the numbers of damaged or collapsed buildings could have been higher, spurring more significant economic impacts and possibly cause long-term exodus of residents. And, in another hypothetical example, children could have experienced ill effects if they had to spend more time outside of evacuated schools in sub-freezing temperatures. These kinds of potential impacts are interesting to consider for planning purposes.

In addition, the actual damage and impacts experienced on November 30, 2018 caused dramatic, if temporary, disruption to normal operations. Assessing areas where return of function and normal operation was impeded or expedited in the Cook Inlet Earthquake can be instructional and will indicate areas where further work may be necessary to minimize long-term post-earthquake impacts across the built environment.

3. Improving Recovery Timelines and Outcomes

This paper is designed to help identify key lessons that can be used to produce a desired future state of practice to mitigate negative physical and social impacts to humans and the built environment after an earthquake. The purpose of this broad-scale effort is to make it possible for people to quickly return to their buildings, with operational infrastructure services (*e.g.* water, power, and communications), in order to facilitate physical and economic health, shelter, and security, and to lessen disruptions to society. A closely linked term is "functional recovery," which is developing within the U.S. engineering community to denote the improved post-event performance of both engineered buildings and critical infrastructure systems. See Sattar et al. 2020 [26] for more details related to functional recovery. For the purposes of this paper, the focus is expanded beyond a functional recovery performance objective (improvement to a single building) to look at broader and related aspects for improving recovery outcomes for society.

There has been an increased level of interest by earthquake professionals in recent years to improve the current level of protection provided from impacts of natural hazards. A 2018 NIST report [27] outlined a plan for future research to develop a new performance objective that could be included in codes and standards to provide *immediate occupancy* after natural hazard events. Many realized that this goal of producing immediately occupiable buildings may be too difficult to attain at this time. In particular, the inability to ensure that infrastructure can supply critical services to buildings may still render a building unusable, but also because of the large stock of existing buildings designed under outdated codes. And even recent earthquake events have demonstrated the extent to which modern building codes cannot prevent serious, and even catastrophic impacts to society's social and economic functions [28, 29]. Evidence that society is unwilling to accept significant impacts to social and economic functions suggest that improvements to modern building codes and standards are needed [30].

In the 2018 NEHRP Reauthorization [31], NIST and the Federal Emergency Management Administration (FEMA) received a mandate from the U.S. Congress to establish a Committee of Experts to develop a report outlining options to *improve reoccupancy and functional recovery timelines* after earthquakes (see NIST Special Publication 1254). It is important to note that this reauthorization language expanded the scope of work from the earlier 2018 NIST report on immediate occupancy to include existing buildings, as well as critical infrastructure (*e.g.*, power, water, transportation, and telecommunications networks). The level of coordination necessary to produce these outcomes for areas that are vulnerable to strong earthquake shaking will require the involvement not only of structural engineers, but also municipal planners, government officials, infrastructure professionals, professional associations across multiple sectors, as well as involvement of many kinds of service providers. The experience in Anchorage after the Cook Inlet Earthquake provides a perspective on areas important for future development of functional recovery.

4. NIST Deployment to Anchorage

In January 2019, the National Institute of Standards and Technology (NIST) deployed a team to Anchorage, Alaska to observe damage and characterize impacts from the November 30th Cook Inlet Earthquake. NIST followed accounts of damage from the media as well as other organizations and through coordination calls since the earthquake occurred. Topics of interest to NIST included: damages to the structural integrity of buildings from shaking, damage to building components and contents that impede resumption of services, as well as other social science aspects that may be relevant to the recovery of building operations.

NIST has a threefold interest in the deployment of teams to post-disaster areas. After the events of September 11, 2001 and collapse of the World Trade Center towers, NIST was given authority by the United States Congress to convene a National Construction Safety Team (NCST) to investigate significant building failures across the United States [32]. NIST NCST members have an obligation to investigate and report findings that can improve the nation's building stock in particular to lessen the chances of, or impacts, from building collapse and failure in the future. When disasters occur, NCST managers assess impacts to see if preliminary reconnaissance and subsequent full NCST investigation is likely to result in novel information that could help prevent future building failures. In the case of the Cook Inlet Earthquake, a preliminary reconnaissance mission was authorized, but not a full NCST investigation, for reasons described below.

The second reason that NIST has interest in an information gathering post-earthquake deployment is because NIST is the lead Federal agency of the National Earthquake Hazards Reduction Program (NEHRP; www.nehrp.gov). This program was enacted by Congress in 1977 and is operated by four primary federal agencies: NIST, FEMA, the National Science Foundation (NSF), and the United States Geological Survey (USGS). These agencies have been directed to conduct specific kinds of activities that mitigate risk from earthquakes. More specifically, NEHRP activities relate to research, data collection and dissemination, response, and recovery. The USGS has the authority to convene official NEHRP post-earthquake investigations. The USGS did so, and each agency planned to respond through appropriate channels to engage local and regionally based networks in Alaska.

The final reason that NIST had interest to send personnel to Anchorage is due to its expertise in structural engineering with regard to earthquakes. NIST's Earthquake Engineering Group conducts research and development of knowledge and tools to improve codes, standards, and practices for buildings and lifelines and supports the development of cost-effective and affordable performance-based seismic engineering tools. This group employs seven structural engineers and one social scientist and has particular areas of expertise in concrete and steel structures, as well as risk mitigation policy. Thus, the Earthquake Engineering Group staffed the majority of preliminary reconnaissance team positions, consisting of four structural engineers, a materials scientist, a social scientist, and a data management and IT specialist.

Objectives for NIST's visit to the Anchorage area included: to learn firsthand about damage, particularly those not highlighted in media coverage; to collect data from buildings instrumented to record motion from earthquake shaking; to assess structures reinforced with fiber reinforced polymer materials [33];

and to study risk perception and issues related to re-occupancy timelines and the recovery of function for buildings and operations. Meetings with key organizations were scheduled ahead of time by deployment team leadership. Other meetings were arranged on-site, through connections made in the field. Additional details regarding these visits are provided in Section 5. The team visited January 7-11, 2019.

5. Research Methods and Areas of Observation

This paper will discuss findings related to risk perception and other insights that can help to facilitate quicker re-occupancy and functional recovery timelines for buildings and operations. These findings were collected during observation and interaction with individuals and organizations in the greater Anchorage metropolitan area. Social science methodologies of participant-observation and informal discussion [34] were utilized to gather information during participation in pre-arranged meetings, site visits, and ad-hoc conversations.

Therefore, readers should be aware that content presented here is preliminary in nature, for the purposes of provoking thought and spurring future inquiry. The experience of the Cook Inlet Earthquake, as with all earthquakes, is highly context specific. The particular organizational structures, agreements, and interactions that led to recovery pathways are unique to the Anchorage area. However, the rich qualitative insights from this experience are relevant to risk mitigation strategies in future earthquakes, and in particular can help to inform improvements to post-earthquake recovery in other communities.

This paper describes findings gleaned from interactions with representatives from the following organizations: Municipality of Anchorage Building Department, Alaska Division of Homeland Security, Regional Emergency Management from Anchorage and Matanuska-Susitna Borough, Anchorage School District, Alaska Department of Transportation, Central Region, Regional Structural and Geotechnical Engineers, and others: Building Owners, Facility Managers, and a Construction Contractor.

During these meetings, NIST's preliminary reconnaissance team members listened, asked questions, and took notes regarding their observations and findings related to earthquake impacts as well as experience in the days and weeks following the earthquake. In addition, the team went on visits to multiple areas of Anchorage, to Eagle River (a community located northeast of Anchorage and within the Municipality of Anchorage) and to Wasilla (a community within the Matanuska-Susitna Borough located northeast of Anchorage and Eagle River). Discussions and findings presented in this paper are the result of the authors' analyses and should not be understood to be representative of any of the organizations listed above. Instead, our purpose is to better understand barriers and complications experienced in the recovery from the Cook Inlet earthquake that may be useful in preparation for other U.S. earthquake events. Key areas of consideration were identified that can help others involved with earthquake risk mitigation at federal, state, and local levels make plans to support quicker re-occupancy and functional recovery after earthquakes.

6. Discussion and Findings

The NIST team visited the Anchorage area six weeks after the earthquake. At that time, much of the initial damage and impacts from the large earthquake were known. However, some damages were still being discovered [35] and a number of buildings remained on the list to be inspected. Emergency managers, engineers, and other organizational representatives with whom we met reported being extremely busy with inspection, clean-up, and repair requirements in their effort to get operations and services back to normal. In addition, many shared that the larger community remained traumatized from the shaking as well as their experience of numerous smaller aftershocks. This section discusses information relevant to "getting back to normal", including: transportation networks, schools, building safety, and areas for future research.

6.1 Transportation Network:
The roadways and bridges in Alaska are a key means of transportation, particularly for day-to-day activities in the Anchorage area such as commuting to jobs and provisioning goods and services. In the earthquake, the port and airports were minimally impacted. There was a failure of a train route, but that was quickly repaired

[20]. Most of the damage that occurred to the transportation network was to the roads. Alaska Department of Transportation personnel for the Central Region (DOT) reported 155 sites with some damage after the earthquake. Most of these sites were impacted more by ground failures than by the direct shaking of the roadway or bridges. Notably, many bridges survived the earthquake without damage and enabled access across the region to begin inspection and repair. After the event, damages were reported by road-users, or through the course of inspections conducted by DOT personnel or contractors. The Alaska Department of Transportation Central Region office was able to report repairs to significant locations of impact within four days—an incredible accomplishment in the wake of a natural hazard event of this magnitude.

Four key things were unique to DOT operations which enabled quick return of the road network. First, managers had plans in place to operate after an event such as this, and a means to communicate with one another effectively to ensure the necessary flow of information about the damages being discovered, the repairs needed, and the arrangements being made for repair. Second, personnel deployed to conduct inspections of roadways and damages had the authority to decide what repairs were needed, and to initiate the process to get crews or contractors on site to handle repairs. Third, the DOT had pre-arranged agreements as well as relationships of trust with contractors whose services could be enlisted with a "phone call and handshake"—paperwork and billing was completed afterwards, rather than beforehand. And fourth, in many cases the decision was made to complete a repair that would enable the temporary operation of the road, rather than to complete a permanent repair that would require more time, paperwork, and personnel (and likely need to occur later in Spring due to weather conditions).

Without these critical elements, the repair of roads and return of functionality to the transportation network would have taken significantly longer. Other transportation related organizations in areas of seismic risk should consider how their business and operational procedures might fare in a similar scenario, and what additional planning or collaboration might be necessary to achieve quick functional repair such as the Anchorage Region achieved after the Cook Inlet Earthquake.

6.2 Schools:

The Anchorage School District (ASD) operates 86 schools and has over 48,000 students (per conversation with ASD representatives). The earthquake occurred at 8:29 AM local time, and many of the schools were occupied at the time of the initial earthquake. The FEMA recommended action to "Drop, Cover, and Hold" worked extremely well in this case. Videos taken during the earthquake and portrayed via news media show students scared, and some screaming; but they had practiced what to do and, with teacher prompts, took cover quickly [36]. Only minor injuries were reported across the school system. After the earthquake, schools were immediately evacuated and closed for inspection. Students, teachers, and other personnel went to a secondary congregation location and/or were dismissed to return home without re-entering their schools.

ASD personnel convened at the central office location and organized in teams to deploy for their initial safety inspection of schools within hours of the earthquake. Preparations had been made in advance to complete the necessary inspections. Notably, ASD regularly practices these procedures, and had done so recently. With funding received from FEMA, they already had backpacks with all the necessary inspection materials ready to go for inspectors. Decisions regarding which schools were visited first were based on the results of the USGS ShakeMap [37] that helped to identify which schools were likely to have experienced the strongest shaking. Teams used the standard ATC-20 *Procedures for Postearthquake Safety Evaluations of Buildings* protocol [38] to visually inspect schools and assign a placard that indicates whether the school is safe to occupy due to the severity of damage. Placard levels include: Inspected (green- ok to enter), Restricted Use (yellow- conditions for entering), or Unsafe (red- not to be entered). Within approximately 4-5 days, ASD had completed an assessment for all school buildings.

Most of the schools in the Anchorage area experienced non-structural damage, such as: broken or fallen ceiling tiles, contents shifted or toppled, and superficial cracks in walls [39]. Another type of damage described for several schools is the breaking of pipes that conduct glycol for school heating systems. In more than one school, these pipes burst above gymnasium areas necessitating cleanup and repair. These kinds of damages to non-structural elements hindered the reopening of the schools and led the NIST team to recommend that further guidance may be needed to ensure the proper construction and/or installation and inspection of these items. Isolated structural damage was found in schools, with three schools in the region red-tagged due to structural damages after inspection, meaning they could not be occupied until repairs were completed and the schools reevaluated [40]. The School District had within the two years prior assessed the school buildings for seismic safety following another earthquake that struck southwest of Anchorage in 2016. At that time, a few schools were retrofitted to achieve a "damage control" performance level per ASCE/SEI 41 *Seismic Evaluation and Retrofit of Existing Buildings* [41]. ASD representatives credited these retrofits as contributing to the minimal structural damage seen at those Anchorage schools. It is important to note that ground shaking intensity at the schools was generally less than the intensity that would currently be used to evaluate an existing school or design a new school, which likely limited damage.

All schools, except those with red tags, reopened one week after the earthquake. This was facilitated by having pre-arranged contractual relationships with repair and construction teams that could quickly enter the schools and clean up damages. ASD officials reported that they could have opened a couple days earlier but delayed slightly to allow time for clean-up and minor repair. They wanted to ensure teachers were prepared, and that students were returning to school buildings that were as normal as possible. While ASD felt there would be a psychological benefit for students in returning to a more-wholly recovered school, officials reported that many parents were not as enthusiastic about this decision, and would have preferred to have the students in school earlier so that they could have more quickly returned to work. Through the Cook Inlet Earthquake, the Anchorage School District demonstrated that they:

- prepared students and teachers on how to react in an earthquake;
- organized to effectively deploy and undertake rapid inspections of schools across a wide area;
- mitigated risk ahead of time (through assessment, and where necessary, retrofit);
- developed contractual relationships to quickly get repair and construction teams into the schools;
- mobilized teachers and community members to clean up and prepare schools for students; and
- prioritized the safety and psychological needs of students in evacuation and re-opening.

Each of these actions, in combination with one another, helped ASD withstand and recover from the earthquake as quickly and successfully as it did. These areas of preparation and action should be instructive to other communities with seismic risk looking to support the return of educational function post-earthquake.

If shaking in Anchorage and the surrounding areas had been more severe, it is hard to predict whether all of these actions would have produced as favorable an outcome. Likely, there would have been more damage across the schools and therefore more delays in re-opening. It is important to consider two additional scenarios from which lessons may be learned. First, if there had been stronger subsequent earthquakes following the 7.1, there could have been damage or failure of the secondary congregation/evacuation locations which may have been less seismically robust than the schools themselves. It is important to consider the suitability of evacuation procedures (and locations) to the conditions of a particular hazard (in this case, earthquakes). And second, if there had been more widespread failures across either housing units or critical utilities, it is likely that twenty-two of the schools designated as community shelters may have been needed for emergency shelter operations. This would have resulted in two conflicts, first, a delay in the ability to open the shelters due to school closures and needed inspections, and second, if shelters were needed long-term, this would delay children's return to school. While the Anchorage School District recovered quickly in this event, these additional scenarios help us to imagine ways in which even greater coordination across sectors might be needed to withstand a stronger event.

6.3 Ensuring Building Safety:

In the immediate aftermath of the earthquake, initial coordination of responders and officials was performed largely at Emergency Operations Centers (EOC). This is the location to which representatives of various sectors within a region report, and an initial understanding of the potential magnitude of the damage is formed. The primary consideration in the early hours of a natural hazard event is to ensure the safety of community members, and to understand where building and other failures may require significant emergency response to recover trapped or injured individuals or to avoid subsequent hazards, such as fires. At this stage, the full-scale inspection of the structural stability of buildings is not warranted nor helpful until the community can be sure there are not more critical needs. It is important to consider this first phase of emergency response, and to clearly link it and address it in functional recovery conversations, to better provide a solid pathway for return of operations. Two areas that further support recovery include: data that can be used to predict damage, and the ability of a municipality to conduct building inspections quickly.

In the initial emergency response phase, data that helps identify areas with the most severe damage are needed. Traditionally, EOC personnel have relied upon reports from first responders and community members to understand where and which damage is most critical. Today, emergency personnel are also utilizing other forms of data gathered from on-the-ground instruments and even satellites. In the Anchorage area at the time of the Cook Inlet Earthquake, 32 ground motion stations were in operation to record data that can be used to quantify the shaking experienced at each location. Data from each of these instruments can be combined to create a map that identifies where greater or lesser shaking was experienced [37]. This kind of map is used to predict the areas where more damage is likely, corresponding to the areas where more significant shaking is reported. Early ShakeMaps created for the Cook Inlet Earthquake relied upon only twelve of the stations which had the capacity to transmit data in real-time, rather than through in-person download of data (per conversation with Anchorage area seismologists and engineers). Communities at risk of seismic impacts should consider: the existing coverage of seismic instrumentation, potential needs for expanded coverage to enable the production of useful and accurate ShakeMaps, maintenance to instrumentation that ensures proper operation, and remote and real-time connection of the sensors so that ShakeMaps can be used in the very early stages of response to better predict where emergency and other services are needed after an event (*e.g.*, where roads are likely to repair, or less impacted hospitals).

Seismic instrumentation in buildings, if reported centrally and in real-time, could be used to provide data that would help officials to quickly understand which buildings experienced the most shaking, and are therefore more likely to have sustained damage. Seismic sensors can be mounted at ground level or within buildings and can provide interesting information for seismologists and structural engineers, but also to the broader community via post-event decision making by officials and emergency mangers. In many cities prone to strong earthquake shaking, including Anchorage, seismic sensors are typically only placed in taller buildings that, due to their use, may accommodate relatively large occupancies. For example, only four buildings in downtown Anchorage were instrumented with seismic sensors and all four buildings are considered high-rise structures for the city, ranging between 14 and 21 stories above ground [42]. Seismic response data for shorter, more common structures is not easily extrapolated from the tall building data, making it necessary to instrument a variety of buildings across a metropolitan area, not just tall ones. Thus, building seismic instrumentation should be seen as a resource for a particular building owner or manager, but also as a resource for the greater community—by providing data useful to emergency response as well as support actions towards functional recovery.

Key to getting buildings back into operation are formal structural engineering inspections to ensure buildings are safe to occupy. Municipality of Anchorage Building Department personnel reported that structural building inspection of essential facilities around Anchorage began quickly, 3 to 4 hours after the earthquake, since there were minimal other emergency response actions needed. Inspectors utilized the ATC-20 methodology and reported back to the EOC to catalog information and assign safety categories to buildings during the building tagging process. The Municipality of Anchorage Building Department reported in subsequent days that they developed a centralized reporting location for engineers and others to help coordinate the building inspections that were occurring. In a meeting with engineers in the Anchorage area during NIST's deployment, the question of whether or not the ATC-20 methodology was being uniformly used for inspections was raised. This issue would be of interest to investigate further, to determine if additional training or work is needed to ensure that the methodology is deployed in a basic, acceptable way to produce reliable building inspection results after earthquake events. The Municipality of Anchorage had to hire additional engineers to perform necessary building inspections, but at the time of NIST's visit in January 2019, Building Department officials reported they had only inspected one-half of the buildings on their list for inspection. A primary reason for this may have been budgetary, but this would be another area for future work that could help to identify what mechanisms would better assist building departments so that owners and building occupants can be more certain of the level of safety that their building provides.

The ability to quickly receive robust data about earthquake shaking from ground motion and building sensors, as well as the ability to mobilize for quicker inspections once the initial emergency-response phase of an earthquake occurs, would significantly improve the first stages of earthquake response and would help to support quicker return of building occupancy and functional recovery. These basic ideas are simple, though perhaps not easy to deploy. But they could also lay the groundwork for subsequent and more complex work that could help to pair data about the hazard experienced with building inventory data on the age, building type, and building code to which a building adheres. In this way, building departments could help to better target or prioritize particularly risky buildings for inspection, due either to the hazard experienced or particular attributes of the building asset.

6.4 Other Areas for Investigation:
The Cook Inlet earthquake is relevant because it is the strongest earthquake experienced by a large urban U.S. area in recent decades. Despite the energy released in this event, shaking intensity within the more populated areas was considered below modern design levels, meaning that new buildings designed with seismic provisions did not experience sufficient shaking to be a true test to their designed abilities. While it is reassuring that buildings did not sustain damage in this “below design level” event, from an engineering perspective, there was “nothing new” to learn from the Cook Inlet earthquake that would change building design philosophy or practice. For this reason, NIST chose not to conduct a full NCST investigation and instead only the preliminary reconnaissance trip described above.

However, the performance of other building types and critical infrastructure may be even more instructive to further development of earthquake mitigation practice, particularly to areas extending beyond the scope of codes and standards which largely apply only at the time a building is built. These include: older buildings that did or did not receive retrofits, structures that are not required to have designs specifically targeting seismic resilience, buildings that did not benefit from adherence to seismic provisions in building codes and standards [29], and the performance of key critical infrastructure such as power, water, transportation, and telecommunications networks.

During the deployment, many older buildings that were retrofit with steel bracing and fiber reinforced polymer composites were observed. Since the use of FRP retrofits is a relatively new practice, having only been applied to buildings in Anchorage since the early 2000s, the NIST team visually inspected several FRP retrofits to determine how they performed during the earthquake, particularly with regard to the sub-arctic climate’s effect on retrofit performance. No obvious signs of earthquake damage to the FRP retrofits or surrounding building components were observed and laboratory-based evaluation of any changes to the materials from outdoor weathering is underway. In terms of retrofits, NIST researchers continue to work on publications related to the assessments of fiber-reinforced polymer retrofit performance on buildings and structures in Anchorage [33]. These topics should be further explored and researched if return to function is a goal that the earthquake community would like solved in a reasonable timeline.

7. Conclusion

In January 2019, the National Institute of Standards and Technology (NIST) deployed a reconnaissance team to Anchorage, AK to learn about damages, collect data from seismically instrumented buildings, evaluate the performance of fiber reinforced polymer (FRP) retrofitted structures, and to study risk perception and issues related to re-occupancy timelines and the recovery of function for buildings and infrastructure [44]. The impressive post-earthquake efforts and accomplishments made in Anchorage provide several clear examples to inform preparedness and response and recovery best practices elsewhere. This is valuable knowledge upon which we can build to support society’s desires to move beyond the life-safety level of performance for the built environment, towards achieving some level of functional recovery.

Key topics discussed in this paper relate to barriers for reopening, procedures for deployment of response and assessment teams, expectations regarding timelines for returning to normal post-earthquake, as well as data needs for risk mitigation action. Each of these areas is important to better ensure that improvements to the building stock can, and are, having the desired impact. NIST team members learned several lessons in their brief interactions with Anchorage area individuals and organizations. These takeaway points may be helpful to other communities facing seismic risk.

- Alternate approaches can be taken to restore services and operations. Functionality can be produced through temporary measures, such as those exemplified by the Alaska DOT, or via a more complete repairs, the option preferred by the Anchorage School District. Pre-event scenario planning and strong intra-organizational cooperation are key in either case.
- Preestablished relationships of trust among partner organizations can hasten provisioning of services and promote quicker project completion, if funding and contracts do not pose barriers between organizations that hinder progress. This was seen across all organizations in Anchorage.
- Rigorous procedures and plans before an event can more quickly and effectively ensure timely damage assessments after earthquake events. Key to assessment of damage are mechanisms to a) detect shaking at the ground level and in buildings, and b) to integrate this data so that it can be used by first responders and building inspectors.
- Damage varied because of shaking intensity, but also because of differences in building code and standard adoption and enforcement. To minimize risk and recovery disparities, further standardization of building code adoption and enforcement should be prioritized [29].

The hypothetical and actual damages and impacts experienced in Alaska are instructive to better assure basic functions across society and the economy after an earthquake. The social and economic impacts of the next large earthquake to affect a major urban area are likely to be well beyond what the average citizen can currently envision. The traditional model of waiting to see what broke, and then figuring out how to fix it, will not work for the new paradigm of functional recovery for two reasons. First, much of the work necessary to support this kind of recovery is outside the scope of traditional building design and engineering (requiring significant planning and coordination beyond building design, codes, and standards); and second, because we have not, in recent memory, experienced a true test to modern building codes and standards of strong earthquake shaking in the United States. While innovative advances are being made in terms of building technology [31], there is much work still to be done to produce information, procedures, planning, and data collection that can vastly enhance post-earthquake recovery. The 2018 Cook Inlet Earthquake provided an opportunity to improve understanding of the nature and consequence of non-structural component failures, effects from variability in building code adoption and enforcement, and societal preparedness for this event, as well as case to contemplate society's ability to withstand a greater event.

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