Seismic Resilience and Adaptation of Arctic Infrastructure and Social Systems

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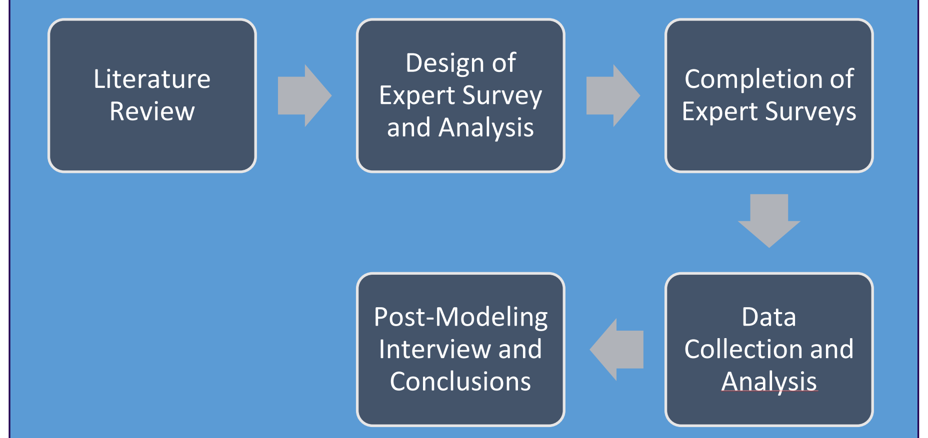
Background

Seismic activity has a powerful impact on infrastructure which consequently affects the community, environment, and piping, being especially vulnerable. Providing essential needs after a seismic event such as food, water, clothing, shelter, and communication systems is important to begin the recovery process. Community preparedness can drastically decrease the effect on the community. It is important to have a basic understanding of disaster psychology and ethics when analyzing this situation from the community perspective. Climate change poses a threat to the initial damage and recovery process of infrastructure assets. For example, temperature increase of Arctic regions has been linked to an increase in moderate to severe seismic events. There is also a connection between climate change effects and the increased vulnerability of infrastructure (e.g., permafrost recession).

Process:



Project Goal

The goal of this project is to create a system of measuring seismic resiliency of infrastructure assets using expert interviews that could theoretically be applied to actual seismic events in the future. This system will consider how functionality may be defined for each asset, which parameters constitute functionality, and how climate change may impact each parameter in the future. A sample process was completed to determine the seismic resilience of three lifeline assets (water resource treatment and transmission, hospitals and emergency departments, and roads and bridges) following the 2018 7.0 magnitude earthquake near Anchorage, Alaska.

Expert Survey

The four types of expert surveys to be conducted are:

- Preliminary (define functionality, select parameters)
- Location Based (confirm functionality, weigh parameters)
- Climate Change (determine climate change coefficients)
- Post-Modeling (review effectiveness of model)

Analysis Methods

With the information gathered from the expert interviews, a model can be created to determine:

- Robustness (initial drop in functionality)
- Rapidity (slope of a linear regression of the first and last points)
- Recovery time (the time it takes to regain pre-event functionality)
- Overall resilience of the system (how well infrastructure performs after a seismic event).

Pre-Modeling (Excel):

C = Climate Change Coefficient (determined through interview)

W_I = Initial Parameter Weight (through expert interviews, 1-10)

W_S = Scaled Parameter Weight

Ex. $W_{S1} = \{ W_{I1} / \sum_{i=1}^{n} W_{I1} + W_{I2} + W_{I3} + \cdots + W_{In} \} * 100$

f = Current Functionality (determined through infrastructure reports)

n = Number of Important Parameters in Specific Infrastructure (determined through expert interviews)

Q = Summed Functionality at a point in time (when testing without considering climate change, $C_i = 1$)

$$\sum_{i=1}^{n} C_1 * f_1 * W_{S1} + C_2 * f_2 * W_{S2} + C_3 * f_3 * W_{S2} + \cdots + C_n * f_n * W_{Sn}$$

If no daily data reported, it is assumed that the parameter regains 0.5% functionality per day (linear recovery).

Post-Modeling (MATLAB):

B = Robustness; the functionality remaining after the initial drop

Rapidity = The average recovery rate of the system (slope D(t))

D(t) = Linear recovery model as the system's average recovery rate

Q(t) = The percent functionality of the infrastructure system at time t

R = Resiliency of the system

t_i = Time when event occurs

t_o = Time when functionality is returned to the pre-event state

$$R = \int_{t_i}^{t_o} (Q(t))dt$$

Expert Survey Results: Water Resouces		
Parameters Selected	Scaled Weights (Ws)	Climate Change Coefficients (C)
Pipes/Connections	44.44	0.950
Storage Tanks	33.33	0.950
Municipal Waste Treatment Structures	22.22	0.955

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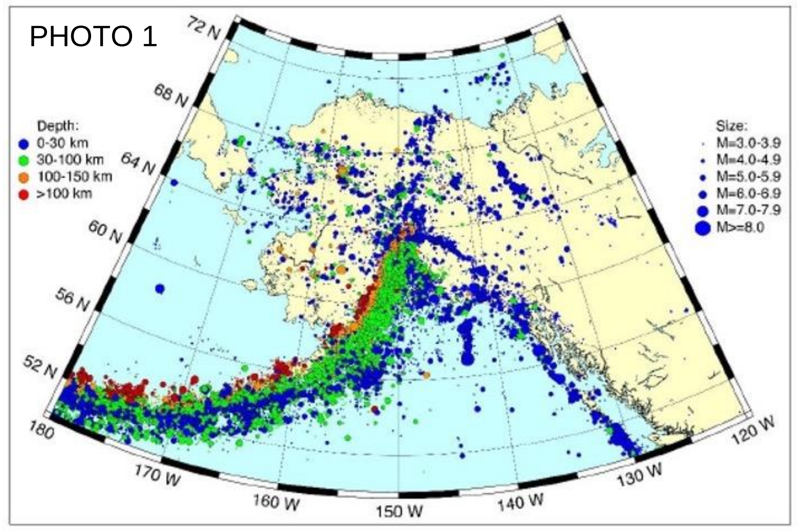
Municipal Waste Treatment Structures	22.22	0.955

Expert Survey Results: Roads and Bridges		
Parameters Selected	Scaled Weights (Ws)	Climate Change Coefficients (C)
Accessibility to critical infrastructure	15.00	0.95
Detour length	5.00	0.95
Network redundancy	10.00	0.98
Impassable area	10.00	0.95
Bridge condition and age	9.00	0.96
Vertical deformations, fissures, cracking	9.00	0.95
Bridge foundation stability	9.00	0.95
MBE assessment of key bridges	10.00	0.96
Areal distance-based accessibility	10.00	0.97
Key road/bridge identification	5.00	1.00
Speed reduction	8.00	0.98

Analysis and Conclusions

The analysis was a qualitative assessment of regression type as well as a quantitative assessment of recovery time, robustness, rapidity, and resilience using MATLAB for each asset type (showed to the right). The scaled weights and climate change coefficients determined for each parameter from the interviews are shown above. While each parameter was impacted by climate change, the most notable impact was on robustness, which thus increased recovery time and decreased resilience. Additionally, the MATLAB program can be used to develop a predictive model to calculate the resilience of infrastructure assets based on linear, trigonometric, and exponential recovery patterns. When logarithmic regressions were used in Excel, trigonometric regressions were used to calculate resilience in MATLAB.

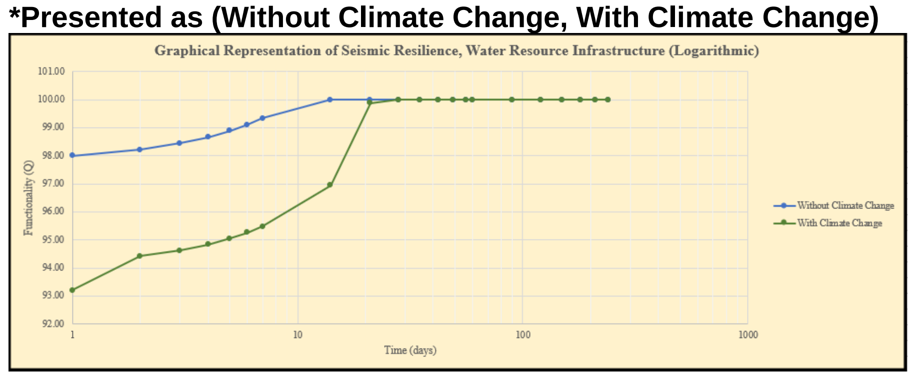
The purpose of this protocol was to develop a system of measuring and analyzing seismic resilience of Alaskan infrastructure assets. Since data for these assets were not directly provided during the 2018 7.0 magnitude earthquake near Anchorage, Alaska, data was retroactively assumed based on literature review and Geotechnical Extreme Events Reconnaissance (GEER) reports. The accuracy for this model highly depends on the collected data, which was unfortunately unattainable within the scope of this project. Nevertheless, the sample process demonstrated that the program could calculate the resilience values if proper data is provided. In practice, these values would be compared to those of comparative seismic event in a similar region. Once a scale is established, the range of acceptability can be determined.



Next Phase

This protocol can be used to assess seismic resilience of other Alaskan infrastructure. For increased accuracy, multiple events and specific climate change trends should be considered and more experts should be consulted.

*Presented as (Without Climate Change, With Climate Change)



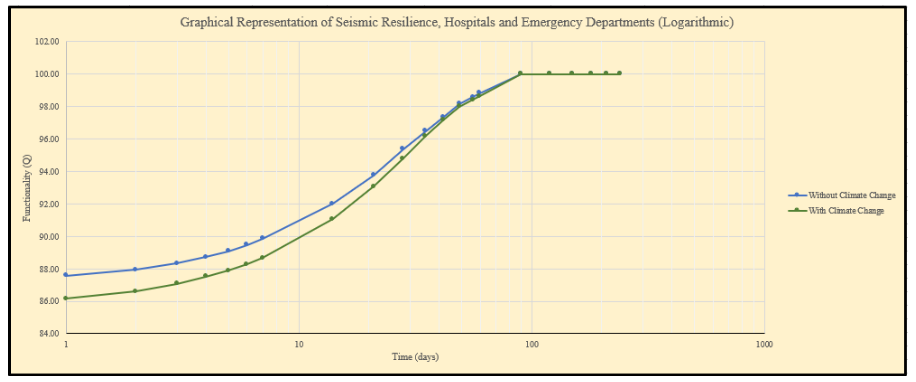
Recovery Time (T_o): (10,20) days

Robustness (*B*): (98.00, 93.21) percent %

Rapidity (D): (0.20, 0.34) percent recovered per day

Resiliency (R): (1891, 1,836) U_R

Visual Regression – Trigonometric, Logarithmic



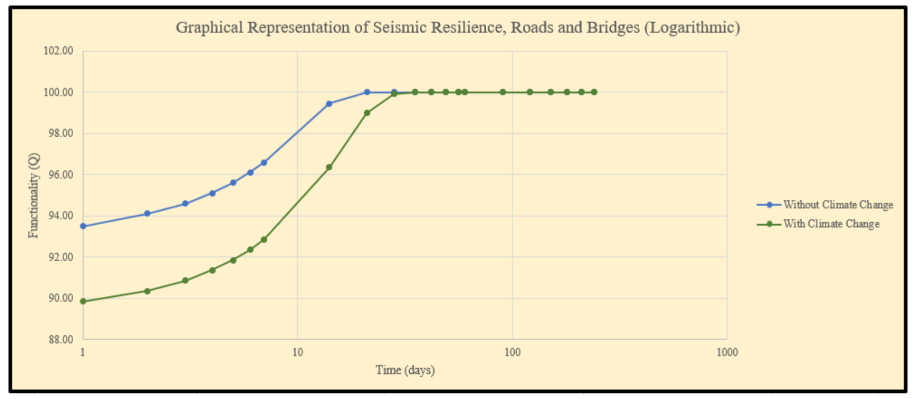
Recovery Time (T_o): (80,83) days

Robustness (*B*): (87.57, 86.16) percent %

Rapidity (D): (0.1556, 0.1670) percent recovered per day

Resiliency (R): (7709, 7633) U_R

Visual Regression – Logarithmic, Logarithmic



Recovery Time (T_o): (20,29) days

Robustness (*B*): (93.51, 89.86) percent %

Rapidity (D): (0.3245, 0.3497) percent recovered per day

Resiliency (R): (2,738, 2,658) U_R

Visual Regression – Trigonometric, logarithmic

Acknowledgements:

Matthew Turner, B.S.

Dr. Majid Ghaayoomi, B.S., M.S., Ph.D

CEPS professors interviewed

University of New Hampshire

PHOTO 1: Masih, A. (2018) Historical Map of Earthquakes, AEC

PHOTO 2: Frank, K.W. (2018) 2018 Anchorage Earthquake