Redefining Resilience

Leveraging Plant Attributes and Adaptations for Earthquake Resistant Infrastructure in British Columbia

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Abstract

Infrastructural development stands out as one of the most notable innovation indicators within a society. As Canada continues its progress and expansion as a nation, so does our infrastructure and focus on sustainability. With a historic investment of over $180 billion in federal funding directed towards enhancing our built landscape, there's now more consideration given to sustainability and structural integrity than ever before (Gov of Canada, 2021). It must be designed with numerous factors in mind to ensure the optimal performance of all our infrastructure. With thousands of earthquakes recorded globally per annum, averaging around 55 per day (USGS), the demand for earthquake-resistant infrastructure is at an all-time high. Compounded by the current trajectory of the climate crisis, we're witnessing a troubling increase in natural disasters, leading to a spike in seismic activity (Burns, 2023).

A deeper analysis of similar regions with high seismic activity, as well as the structure of the plants that inhabit them, can reveal many design strategies to aid in developing the BC region. We’re looking forward to multiple countries, such as Japan, facing the same struggle as us. Japan has studied earthquake infrastructure models to withstand seismic activity over the past decades. This can provide more knowledge for our research with better efficiency. Additionally, understanding the geographic impacts of earthquakes on the creation of infrastructure to establish an ideal environment for development is also one of our priorities.

Introduction

Beneath the Earth's surface, pressure steadily builds, waiting for release. Whether triggered by the collision of tectonic plates, the eruption of a volcano, the shifting of an earthquake, or the rupture of a fault line, the outcome remains constant: the ground trembles and urban landscapes plunge into disarray. During seismic events, the Earth ripples with two primary types of waves: primary waves (P-waves) and secondary waves (S-waves). P-waves, known for their swift pace, forge through solids, liquids, and gases, employing a compressional motion akin to sound waves. Following closely, S-waves traverse solely through solids, inducing a perpendicular movement of rock particles. Together, these seismic body waves navigate the Earth's interior, while surface waves, skimming along the Earth's surface, contribute to the palpable tremors experienced during earthquakes (Firdaus, 2023).

The Residential Sector

In British Columbia, the average home price has reached $1,020,000, a 6.1% higher year-over-year growth, and the benchmark at $976,400 at 4.0% higher year-over-year growth as of March 2024 (WOWA, 2024). Despite the robust performance of the residential market, the threat of earthquakes looms large over homeowners and prospective buyers in Vancouver. The seismic vulnerability of buildings, coupled with the potential for widespread damage, raises concerns about the long-term stability of the housing sector. To understand the effect of earthquakes on residential properties and the average civilian, it is essential to examine various aspects, including structural integrity, insurance coverage, and post-disaster recovery efforts. People need to have access and affordability in safety, and not have to worry about the added costs of withstanding seismic forces.

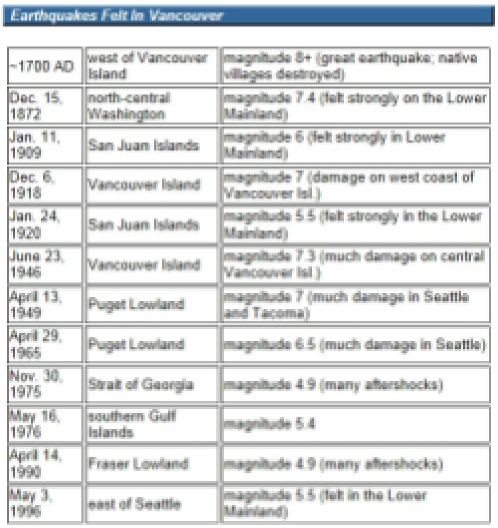
Method

Steps to Approaching the Solution (Research and Procedure)

1. Understanding the current earthquake situation in British Columbia.

Recent View

As of recent analysis, British Columbia has frequent seismic activity. With an average of around 1,200 earthquakes annually, and 50 of them being felt, seismicity in British Columbia is primarily influenced by its location along the Pacific Ring of Fire, where the tectonic plate boundaries of the North American Plate and the Juan de Fuca Plate converge (CGEN Archive). The region's seismicity is further underscored by its proximity to the Cascadia Subduction Zone, known for its potential to generate large, megathrust earthquakes. During 2023, Vancouver experienced a total of 263 earthquakes with magnitudes reaching up to 3.8 within a radius of up to 100 km (City of Vancouver). 3 earthquakes surpassed magnitude 3 and 15 earthquakes fell between magnitudes 2 and 3, but the vast majority, 245 in total, registering below magnitude 2, typically imperceptible to people (Michigan Technological University).



Earthquakes Felt in Vancouver

~1700 AD	west of Vancouver Island	magnitude 8+ (great earthquake; native villages destroyed)
Dec. 15, 1872	north-central Washington	magnitude 7.4 (felt strongly on the Lower Mainland)
Jan. 11, 1909	San Juan Islands	magnitude 6 (felt strongly in Lower Mainland)
Dec. 6, 1918	Vancouver Island	magnitude 7 (damage on west coast of Vancouver Isl.)
Jan. 24, 1920	San Juan Islands	magnitude 5.5 (felt strongly in the Lower Mainland)
June 23, 1946	Vancouver Island	magnitude 7.3 (much damage on central Vancouver Isl.)
April 13, 1949	Puget Lowland	magnitude 7 (much damage in Seattle and Tacoma)
April 29, 1965	Puget Lowland	magnitude 6.5 (much damage in Seattle)
Nov. 30, 1975	Strait of Georgia	magnitude 4.9 (many aftershocks)
May 16, 1976	southern Gulf Islands	magnitude 5.4
April 14, 1990	Fraser Lowland	magnitude 4.9 (many aftershocks)
May 3, 1996	east of Seattle	magnitude 5.5 (felt in the Lower Mainland)

Table 1.1 A Historical view of the most significant Earthquakes of the century (CGEN Archive, 2021)

Historic View

A significant earthquake occurs in this region approximately every 20 years, with the most notable in recent history being the 1946 magnitude 7.3 event beneath central Vancouver Island. If a similar event were to occur today, the damage incurred would amount to billions of dollars—an event that would trigger economic consequences warranting federal-level concern. Scientists have also identified sporadic yet substantial earthquakes, ranging from magnitudes 8 to 9, along the fault line separating the subducting Juan de Fuca and North American plates. The last such event occurred in 1700 AD, affecting the entire coastal region.

The cause of the high concentration of earthquakes in this area is due to the tectonic interactions that occur beneath the surface. The Juan de Fuca plate, an oceanic plate, is moving underneath the continental crust of North America along the Cascadia subduction zone. The occurrence of large earthquakes in the region is attributed to the subduction process and the movement of blocks of the North American plate along crustal faults.

2. Connecting findings to geographically diverse regions with similar seismic activity enables the search for established solutions to the problem. Research shows that around 1,500 earthquakes strike Japan every year, with magnitudes ranging from above 2 to as high as 9.1 (Conroy, 2024). Although the majority are too mild to be felt, most major earthquakes in Japan are caused by the Pacific Plate off the East Coast, which is also a very active seismic area boasting the densest seismic network in the world (Marder, 2011). Due to this, the Japanese government has initiated multiple projects that study infrastructure building models to

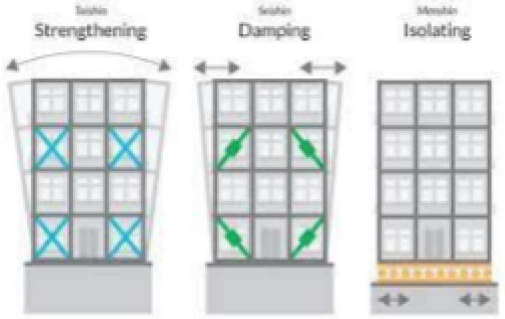


Figure 1.1 Least efficient to most from left to right (Ferrall, 2023)

withstand high-magnitude earthquakes, resulting in the creation of three models ranging from the least efficient to the most efficient: Taisin, Seishen, and Menshin.

a. **Taishin** constructs stiff and strong buildings using reinforced concrete and steel, known for their high compressive strength and flexibility. Advanced structural design techniques like moment-resisting frames and bracing systems further enhance seismic performance, while innovative materials such as fibre-reinforced (Jannah, 2023) polymers or carbon fibre composites bolster seismic resistance. On the good side, Taisin has good strength and durability and is also a requirement for each house in Japan along with effective cost. But the downside can be rigidity leading to potential brittleness and susceptibility to structural failure under extreme seismic forces (Magnitudes 7 and above). Along with limited flexibility, these buildings may not have the flexibility to absorb or dissipate seismic energy leading to more damage. (Housing Japan, 2023)
b. **Seishin** reduces earthquake damage by installing damping devices within the building's structural system, such as tuned mass dampers or fluid viscous dampers, which strategically counteract seismic vibrations, thereby enhancing building resilience. Retrofitting existing buildings with dampers or incorporating them into new designs further improves the building's ability to withstand earthquakes and safety. Ranking higher than Taishin, Seishin has flexibility due to dampers providing a degree of flexibility to the structure, allowing it to sway and deform slightly without sustaining significant damage. On the other hand, maintenance dampers require regular inspection and

maintenance to ensure their effectiveness, Then it also goes with the initial cost, the installation of dampers can be expensive, particularly for larger or taller buildings which can add to the overall cost of building ownership. (Housing Japan, 20233)

c. **Menshin** uses isolation techniques to isolate the building from seismic waves, such as isolation layers or base isolators made of materials like elastomers or lead-rubber bearings. These techniques reduce the transmission of ground motion to the structure, minimizing structural damage by allowing the building to move independently of the ground motion during earthquakes. By separating the building from seismic shaking, the Menshin model helps enhance overall building resilience and reduce the risk of structural failure during seismic events. This goes along with the versatility with which Menshin techniques can be applied to various building types and sizes, making them suitable for various architectural designs and structural configurations. However it has a complexity in which implementing isolation layers requires careful design and engineering, adding complexity to the construction process and potentially increasing upfront costs Space Requirements due to base isolators may require additional space in the building's foundation, limiting their applicability in certain urban or constrained environments. (Housing Japan, 20233)

3. Exploring naturally occurring solutions and understanding seismic waves is crucial for earthquake research to develop a bioinspired design biomimicry has helped us as a society since the dawn of time, supplementing our evolutionary journey every step of

the way. By analyzing the patterns and habits of successful organisms in our natural environment, we can identify elements that contribute to their success and apply them to our designs and strategies to mitigate their impact, thereby disaster preparedness

Plants

Plant cells form a structure (left), illustrating how each cell block is distinguished by the cell wall. Configuration of a plant cell wall (right). When formidable forces (wind, seismic activity, an animal) exert pressure on a plant, the plant adeptly absorbs a significant portion of the energy due to how plant cells glide over each other. Flexion or curvature of the cell wall, among other factors, operates as intended, contributing to the plant's resilience against external pressures (Martinez, 2017). Lastly, we can apply back to our infrastructure to create a better quality.

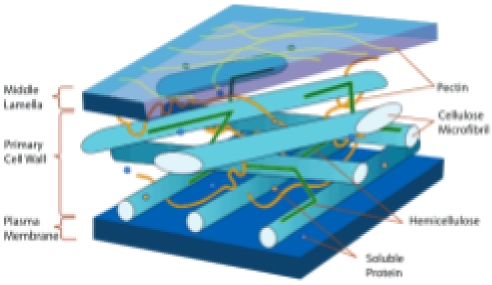


Figure 1.1 Analyzing plant cell block designs to discover how they can resist the motion of earthquakes (Martinez, 2017)

Understanding seismic waves is crucial for earthquake research. Scientists utilize this knowledge to anticipate seismic event behaviourbehaviour. Deep-rooted trees, characterized by extensive and intricate root systems that penetrate deep into the soil, serve as natural barriers against seismic waves (Martinez, 2017). These robust root networks play a multifaceted role in earthquake resilience: they disperse the energy generated by seismic waves, stabilize soil, and absorb shockwaves, substantially reducing the risk of landslides and soil liquefaction during seismic activity. Species such as redwoods, renowned for their towering stature and deep-reaching taproots, along with oaks, pines, bald cypresses, firs, and willows, each equipped with resilient root structures, contribute significantly to strengthening earthquake resilience in vulnerable areas (Firdaus, 2023). Integrating these trees into disaster preparedness plans alongside other measures provides a crucial layer of protection, increasing their ability to withstand the impact of seismic events and safeguarding infrastructure.

One of the last factors is the earth's surface is diverse, ranging from hard rock to dense soil and artificial fill, each impacting how seismic waves propagate during an earthquake. Geological variations in soil type within small areas can lead to significant differences in earthquake effects between locations. These differences, known as 'side effects,' are primarily influenced by two factors: the softness of the sediment and the thickness of sediment layers above the bedrock. Seismic waves travel faster through hard rock than soft soil, but when waves transition from hard to soft earth, they increase in amplitude, causing stronger shaking. Similarly, deeper sediment layers above bedrock result in more soft soil for seismic waves to travel through, leading to stronger shaking amplification. Therefore, areas with softer and thicker soil tend to experience greater shaking and amplification of waves during earthquakes, resulting in more

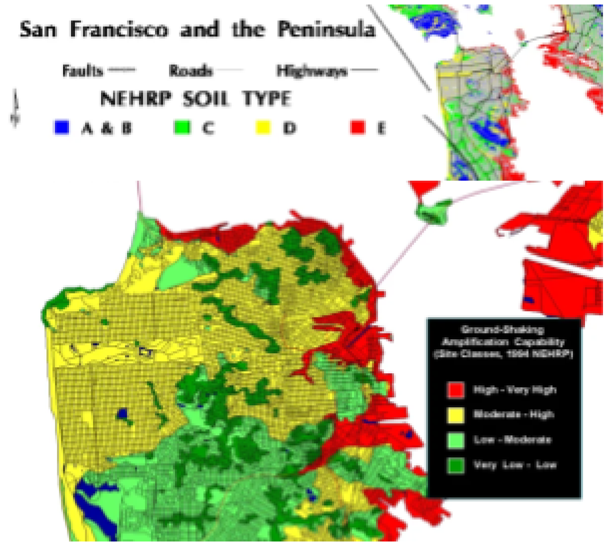


Fig 1.2 A Map of the Clear Correlation between Soil Makeup and Earthquake Impact in a Region **(Nolan, 2022)**
(The higher the ground shake the softer the soil)
A - Hard rock (igneous rock)
B - Rock (volcanic rock)
C - Very dense soil and soft rock (sandstone)
D - Stiff soil (mud)
E - Soft soil (Artificial fill)
F - Soils requiring site-specific evaluations

significant building damage (Nolan, 2022).

To classify earthquake-prone areas based on soil type, the National Earthquake Hazards Reduction Program (NEHRP) defined six site classifications ranging from A to F, with A representing the hardest soil and F the softest. Site classifications correlate with shear-wave velocity and indicate the level of wave amplification expected in the area. But it's not the sole determining factor, other factors, such as fault orientation, surface irregularities, and subsurface structures, also influence earthquake effects, creating unique damage patterns for each event. Tools like the Earthquake Risk Tool developed by WSRB subsidiary BuildingMetrix provide insurance experts with customized data to assess earthquake coverage and educate policyholders about their risk exposure, by understanding the impact of soil type and other factors, and measurements to protect against earthquake damage and enhance overall resilience (Nolan, 2022).

Discussion and Solution

In developing a solution for this issue, we turned to biology for some key attributes to contribute to our design. “The environment is a source of data, it forces us to follow its behavior.” (Pedras, 2021). Specifically, we plan to incorporate flexible building materials and innovative architectural techniques that mimic the adaptive features observed in trees. This includes the implementation of shock-absorbing mechanisms within the building's framework, such as dampers and flexible joints, to dissipate seismic energy and minimize structural damage during earthquakes (Nolan, 2022).

Additionally, we will explore the use of reinforced concrete and steel reinforcement techniques inspired by the robust root systems of trees (Nolan, 2022), which provide stability and support to the building's foundation. By drawing on nature's blueprint for resilience, we aim to create buildings that not only withstand seismic forces but also promote sustainability and longevity in Vancouver's urban landscape.

In alignment with our research into Japanese infrastructure models, specifically the Seishin, Menshin, and Teishin approaches, we plan to adopt a holistic framework that encompasses both structural and non-structural measures to enhance building resilience. This includes the implementation of Seishin principles, focusing on the use of advanced materials and construction techniques to improve structural integrity and reduce the vulnerability of buildings to seismic events. Additionally, we will integrate Menshin strategies (Housing Japan, 2023), which prioritize the development of community-wide disaster preparedness plans and evacuation protocols to ensure the safety of occupants during earthquakes. Furthermore, our approach will incorporate Teishin principles, emphasizing the importance of ongoing monitoring, maintenance, and retrofitting of existing buildings to ensure their continued resilience in the face of evolving seismic risks.

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