Major Earthquakes and

The Renovation and Expansion of the Royal BC Museum

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Abstract

The Royal BC Museum could face considerable consequences in the event of any severe seismic activity due to its proximal location above the Devil's Mountain Fault. Drawing on recent and historical earthquake data, this literary paper will investigate a collection of secondary sources of information on the nature of museums experiencing partial or complete devastation due to a natural disaster. Listed sources such as thesis papers, documents, reports and policies will be used so as to analyze and support the problem statement and conclusion. The research will provide insight towards earthquakes and museums and highlight the considerable heritage, social memory, and sense of community that is equally as vulnerable and threatened as the physical structure. Narrowing the scope, the research will be applied towards the current difficulties facing the renovation and expansion of the Royal BC Museum; exploring what kinds of emergency planning measures can be put in place to help mitigate the destruction of BC's history and cultural heritage, and save lives.

Keywords: earthquake, museum, Devil's Mountain Fault

Introduction

In December of 2012, The Royal British Columbia Museum, located along the Inner Harbour area in downtown Victoria BC, announced they would be expanding the museum to include two new 12 and 14 story towers on a part of the 2.7-hectare museum property (Wilson, 2012). In June of 2015, Natural Resources Canada released an official study detailing a previously unknown fault line, Devil’s Mountain Fault, in the bedrock below the Strait of Juan de Fuca. The results of this study represented a great risk for future museum plans, revealing that this fault line runs straight through the city of Victoria, and as such is capable of producing potentially devastating shallow thrust earthquakes (Broadland, 2016). Shallow thrust earthquakes, like those that often strike Greece, Turkey and the one that affected Christchurch, New Zealand in 2011, could have devastating effects on the city of Victoria and on the Royal BC Museum, as the building contains not only the historical and cultural relics of British Columbia, but is also the official repository of the BC provincial government archives. In light of this recent earthquake data, how can museum staff, consisting of designers, engineers and emergency planners, utilize research from other areas that suffer similar types of seismic activity, in order to plan for, prepare, mitigate and respond to this threat as they move forward to build the new towers? This paper will examine some of the projected effects from the eruption of the Devil’s Mountain Fault, and will examine planning, preparation and mitigation measures that can be utilized in order to save lives and prevent the destruction of BC’s history if an earthquake should occur.

Analysis of the Literature

Earthquakes are one of the leading contributors to damage and loss for museums and archives around the world, and this in turn has led to several methods of emergency management planning in order to safeguard patrons, employees, exhibits and archives (Erturk, 2012, pp. 1-2). While the frequency and risk for earthquakes is not the same everywhere, potential losses due to breakage, loss of power to climate regulated exhibits, archive loss, and injury or loss of human lives are of crucial concern (Erturk, 2012, p. 290). Key commonalities found within the research was the need for proper emergency planning which included: building measures for seismically active areas, training for museum staff, establishment of emergency protocols for evacuations and patron safety, mitigation factors for safe exhibit displays, digital backups of archives and collections, planning for relocation of collections to secure secondary sites, and backup power (Erturk, 2012; Hunter, 2017; Podany, 2009; Spyrakos, Maniatakis & Taflampas, 2008). Within the International Council of Museums' (ICOM) UNESCO supported *Museum and Security Protection Handbook*, it is recommended that museum curators and specialists should receive some level of formal emergency management training, allowing them to utilize their specific expertise to help plan for and prevent exhibit damage, in addition to response, recovery and removal of artifacts after a major event and in conjunction with official emergency management response teams (Hunter, 2017, pp. 13-16).

Drawing from the readings, certain trends have emerged with regard to museum emergency response and earthquake mitigation efforts. Of primary note, is the fact that many museums are located in historical buildings, and if not upgraded would be more structurally susceptible to damage from major seismic earthquakes (Lesniak, 2015, pp. 8-12). Commonly, museum funding is largely based on donations and patronage which negates costly building upgrades and the purchasing of secondary power supplies and special protective exhibit cases and stands (Lesniak, 2015). The RBC Museum however, is subsidized by the BC government so may be in a better financial position to focus staff hours to plan for, prepare, mitigate and respond to earthquakes (RBC Museum, 2018). One noteworthy trend regarding the protection of collections and archives from earthquake damage is the digitization of displays, exhibits, and archives. Originally considered a modern and efficient method of record keeping and handling insurance claims, many museums have found it to be a useful tool to protect fragile records and artifacts while still allowing access to archivists and researchers. Allowing access to digitized records through museum internet sites has led to a new way of attracting visitors, primarily through websites and virtual exhibit tours (Erturk, 2012, pp. 294-299). The digitization of records has also opened up a secondary revenue stream, as access to archives and records is now available to researchers around the world (RBC Museum, 2018).

Devil's Mountain Fault and its Seismic Impact to Greater Victoria

Positioned in the Strait of Juan de Fuca, just 5 kilometers out from Victoria, is a physical imperfection so great that Natural Resources Canada scientists believe could one day transform the spectacular beauty of Victoria, over the span of a mere 10 or 20 seconds, into a scene of property devastation with crippled infrastructure, severely disrupted utilities, potential injury and loss of life (Broadland, 2016). Senior scientist Dr. Vaughn Barrie from Geologic Survey Canada (GSC) conducted the seismographic study on the previously unexplored deformation in the bedrock below the Strait of Juan de Fuca. Assisted by marine scientist Dr. Gary Greene, they analyzed sediment cores and multi-beam bathymetry scans (a method which uses a number of sound pulses from a device mounted on a ship's hull to produce multiple views of the sea floor) of the bedrock below the strait in an area just southeast of Victoria (Barrie & Greene, 2015, p. 2).

From this data Barrie was able to create a 3D map displaying a short section of the Devil's Mountain Fault Zone (represented in red on the map inset below), establishing it as a deep crack in the Earth's crust that runs for about 125 kilometers from near Darrington in the foothills of the Cascade Mountains in Washington, to just south of Victoria.

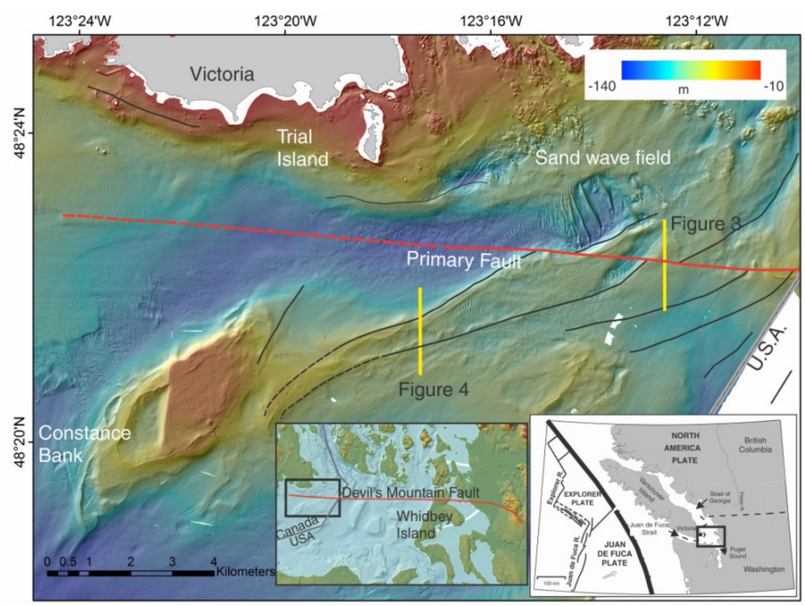

Figure 1: The Devil's Mountain Faults, indicated here by a red line, is actually made up of a series of faults that run from Washington to Victoria. Reprinted from Ministry of Natural Resources, Government of Canada https://www.canada.ca/en.html

Prior to Barrie's analysis, previous calculations based on the presumed length of the fault had suggested that if it ruptured along its full length, an earthquake of magnitude 7.5 could be generated (Broadland, 2016). Barrie and Greene's work confirmed a potentially grave risk for Victoria and in a summary of the scientist's report they stated,

> Based on recently collected geophysical and sediment core data, the western extent of the active Devil's Mountain Fault Zone has been mapped for the first time, offshore the city of Victoria. The occurrence of this active fault poses the real possibility of an earthquake,

similar to the devastating 2011 Christchurch, New Zealand earthquake, occurring near the city of Victoria (Barrie & Green, 2015, p. 9).

Barrie noted that the 2011 Christchurch earthquake killed 185 people and caused damage assessed at $40 billion (NZD). He observed that the earthquake had an effective magnitude of 6.7 and was approximately 5 kilometers from central Christchurch at its closest approach. In comparison, it is important to note that the scientist also stated that the Devil's Mountain Fault Zone is less than 5 kilometers from central Victoria, and appears to have the potential of producing a strong earthquake adjacent to Victoria, perhaps as large as magnitude 7.0 or greater (Barrie & Greene, 2015. p. 13). In light of this data, museum staff and emergency planners will need to consider these factors when planning for and building the two multi-story buildings. Museum staff should also review existing emergency management procedures and reassess current displays and exhibits in order to strengthen measures and further mitigate possible damage from this new earthquake risk.

Building the RBC Museum for Seismic Stability

When it comes to the seismic stability of present and future buildings in Victoria, the Structural Engineers Association of BC (SEABC) (2017) note that the type of seismic ground motion at a building site is dependent on a number of factors, including:

- Distance of the building from the earthquake rupture zone;
- Magnitude of the earthquake;
- Depth of the earthquake rupture;
- Soil conditions at the building site (p. 1-12).

The association further notes that earthquakes affect buildings differently depending on the type of ground motions and characteristics of the building structure. Seismic ground motion is typified by both vertical and horizontal shaking; for which, the horizontal shaking is generally larger, and causes damage (SEABC, 2017). NRCan states that large distant earthquakes contain long-period energy that can impact larger (taller) structures, whereas smaller nearby earthquakes generally contain more high-frequency energy which can damage smaller (shorter) structures (NRCan, 2018).

For the RBC Museum's expansion to include two multi-story towers, this type of information will need to be factored into their planning, preparation and mitigation designs. Additionally, the museum staff must remain aware that if the ground motion is strong enough, it will move a building's foundation, and that while inertia tends to keep the upper stories in their original position, it will cause the building to distort (SEABC, 2017). Since inertial forces are greater when objects are heavier, earthquake forces will be greater in heavier buildings, and higher ground accelerations will create more stress in a structure. It should also be noted that buildings shake with different natural frequencies, making it possible for shaking of one building to be out of phase with its neighbor (SEABC, 2017). Because RBC Museum staff want to build two multi-story towers within a 2.7-hectare area, the two buildings could be close enough to each other to cause "pounding", resulting in damage to both (SEABC, 2017).

In order to properly plan, design and build new museum towers that will safeguard museum staff, patrons, exhibits and archives, engineers must first predict the intensity of shaking and damage the city of Victoria is susceptible to. Fortunately for the RBC Museum staff, planners and engineers, VC Structural Dynamics Ltd prepared and submitted a report, *Citywide seismic vulnerabilities assessment study - City of Victoria* (2016) to the city of Victoria, considering three scenario earthquakes based on the three sources of seismic activity in the Pacific Northwest region: a shallow crustal event, a deep in-slab event, and a large magnitude subduction event. To accurately obtain its information, the company implemented HAZUS (Hazards United States), developed by the Federal Emergency Management Agency (FEMA), as the primary software for damage assessment; HAZUS is a standardized methodology that contains modules for estimating damage and potential losses from earthquakes and other natural hazards (FEMA, 2003). HAZUS uses Geographic Information Systems (GIS) technology to estimate physical, economic and social impacts of disasters such as earthquakes, and was modified to reflect the seismicity and construction practices of BC by NRCan (VC Structural Dynamics, 2016, p. 26). The attenuation (decay) of shaking from the source to the city of Victoria was predicted using the relationships developed for the 2015 Geological Survey of Canada (GSC) seismic hazard model, a state-of-the-art model used for developing seismic hazard maps for Canada for the 2015 National Building Code of Canada (VC Structural Dynamics Ltd. 2016. p. 26). This report is invaluable to museum staff, planners and engineers because the relationships aspects for this study were specifically modified to make the results more accurate in relation to the site conditions specific to the Victoria region. This provides design engineers with the information needed to design the towers in a way that encourages resistance to the impacts of earthquakes, potentially saving lives and lowering the risk of injuries and damage to exhibits and archives.

Having gathered the information above, the RBC Museum staff can look to incorporate more advanced techniques for earthquake resistance into their future building and planning designs with a goal of reducing the earthquake-generated forces acting upon it. Among the most important advanced techniques to-date for earthquake resistant design and construction are Base

Isolation and Energy Dissipation devices (Bhandari, et al, 2016, p. 2). For the museum towers, a base isolated structure would be supported by a series of bearing pads which are placed between the building and the foundation, with the bearing being very stiff and strong in the vertical direction, but flexible in the horizontal direction, as shown in Figure 1.

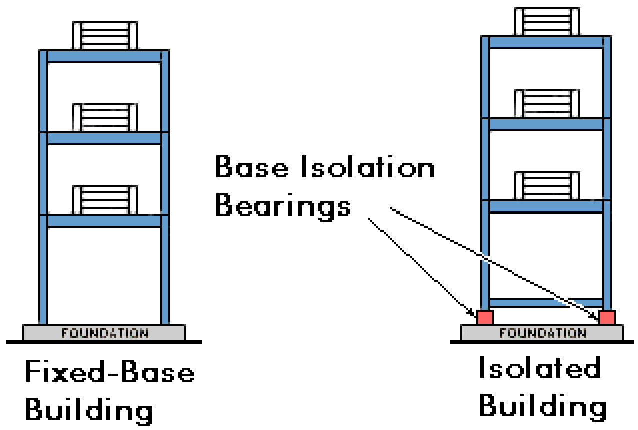

Figure 1: Base-Isolated and Fixed-Base Buildings. Reprinted from Earthquake Resistant Design Techniques for Buildings and Structures. Retrieved from https://theconstructor.org/earthquake/earthquake-resistant-techniques/5607/

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In the event of an earthquake, the ground beneath each building begins to move and each building responds with movement which is opposite of the ground motion due to inertia**.** The inertial forces acting on the towers are the most important of all those generated during an earthquake and are proportional to the building's acceleration during ground motion (Bhandari, et al, 2016. pp. 2-3). The museum's engineers and designers must also note that the towers won't actually shift in only one direction because the complex nature of earthquake ground motion means that the towers will actually tend to vibrate back and forth in varying directions, as seen in Figure 2.

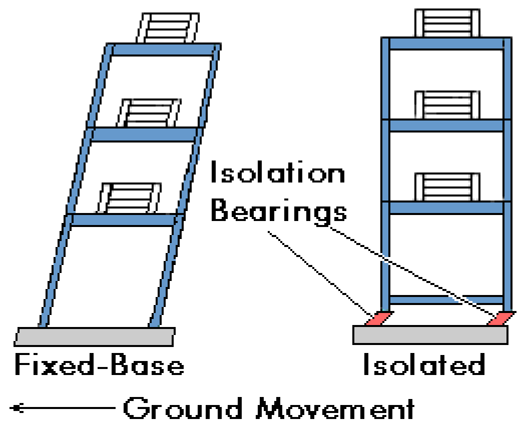

Figure 2: Base-Isolated, Fixed-Base Buildings. Reprinted from Earthquake Resistant Design Techniques for Buildings and Structures. Retrieved from https://theconstructor.org/earthquake/earthquake-resistant-techniques/5607/

In their study, *Performance of Base Isolated Building for Extreme Earthquakes*, presented at the 2016 Structural Engineering Convention in India, Bhandari, et al. (2016) state that the primary cause of earthquake damage to buildings is the deformation which the building undergoes as a result of the inertial forces acting upon it. As can be observed in Figure 2 by contrast, even though it too is displacing, the base-isolated building retains its original, rectangular shape due to the lead-rubber bearings supporting the building being deformed since they are highly elastic; however, the rubber isolation bearings don't suffer any damage making them both cost and design effective in mitigating seismic impact.

In addition to the use of the Base Isolation, RBC Museum staff should also incorporate the second of the major new techniques for improving the earthquake resistance of buildings, which also relies upon damping and energy dissipation, but it greatly extends the damping and energy dissipation provided by lead-rubber bearings. As previously mentioned, a certain amount of vibration energy is transferred to the building by earthquake ground motion, and while most buildings possess an inherent ability to dissipate, or damp, this energy, the capacity of buildings to dissipate energy before they begin to suffer deformation and damage is quite limited (Bhandari, et al, 2016. pp. 2-3). To compensate, the building will dissipate energy either by undergoing large scale movement or sustaining increased internal strains in elements such as the building's columns and beams; both of which result in varying degrees of damage. RBC Museum designers and engineers will be able to choose from a wide range of energy dissipation devices that have been developed and are available for installation as part of the two new multi-towers currently being considered. The following energy dissipation devices (damping devices) work most effectively with base isolation technologies, they are: (a) friction dampers; utilizing frictional forces to dissipate energy, (b) metallic dampers; utilizing the deformation of metal elements within the damper, (c) viscoelastic dampers; these utilize the controlled shearing of solids, and (d) viscous dampers: these utilize the forced movement of fluids within the damper. If the museum designers and engineers equipped the towers with additional devices which have high damping capacity, they can further greatly decrease the seismic energy entering the building, and thus decrease building damage, possible injuries to staff and patrons, and damage to exhibits and archives.

Risk Management and Mitigation Measures

There is no question that a building which houses a collection must be made safe from the forces generated by an earthquake. However, it must also be kept in mind that seismic design and retrofits of buildings alone do not guarantee the safety and security of the people and contents within. There are many approaches and methods available for the protection of heritage objects and collections from earthquake damage, with most being relatively inexpensive yet effective. To be effective, museum staff must have a general knowledge of how given types of objects and assemblages of objects and exhibition furnishings and fixtures, as well as collections held in storage will respond to earthquake forces (Podany, 2009, p. 3).

RBC Museum staff will need to consider storage and displays in their design plans and execution, benefitting from valuable insight and lessons learned from the earthquake experiences of other museums. Based on a survey study of 92 museums conducted throughout Turkey from 1999 to 2009, Erturk (2012) concluded in his paper, *Seismic Protection of Museum Collections*, that objects in the Turkish museums were damaged from earthquakes primarily due to artifacts tipping and falling, shaking, crowding and colliding; and, from improper shelf loading, insufficiently restrained objects, and the storage of objects in inappropriate areas (p. 293). One of the keys to his findings, and a factor of importance to RBC Museum staff, is that Erturk also made note that while museum staffs were well aware of the risks earthquakes posed, the desire to have impressive exhibit displays in conjunction with an overabundance of cultural artifacts in storage often added to unnecessary damages (2012, pp. 291-298). This observation was also noted by Spyrakos, et al (2008) in his paper, *Assessment of Seismic Risk for Museum Artifacts*, presented at the World Conference of Earthquake Engineering in Beijing China in October of 2008, for which he noted that works of art were severely damaged by overturning or sliding and impact due to overcrowding and lack of proper anchors (p. 3).

By identifying a major earthquake as a threat to the new museum towers, RBC Museum staff will need to determine the level of risk when it comes to display and storage of its collections. Based on his work in the Department of Antiquities and Conservation at the John Paul Getty Museum in Los Angeles, California, Podany (2009) suggests in his book, *Earthquake Damage Mitigation for Museum Collections*, that when museums are determining the degree of risk, they should apply a simple formula of Acceptable Risk equals Tolerable Loss (p. 3). For

RBC Museum staff, this means that the less risk the museum wants to take, the more the plan has to take into account the rare occurrence of a major seismic event such as the eruption of the Devil's Mountain Fault. While planning for a large devastating event means more effort for museum staff, the higher level of mitigation effort helps ensure that the museum collections are at less risk of damage over a longer period of time, and are protected from large scale events and more common occurrences too (Podany, 2009, p. 3).

In determining the vulnerability of its collections to earthquake forces, the RBC Museum will have to take into consideration the stability of objects or object assemblies; exhibition and storage fixtures and furniture (display cases, pedestals, shelving, and drawer units, etc.); and, the inherent material vulnerability of objects or the collections themselves. For example, glass and stone works may be highly susceptible to damage due to the impact or vibrations of an earthquake, while books may not be; however, museum staff must also be mindful of fires or water damage that may result as a secondary cause of earthquakes (Podany, 2009, p. 4). In Canterbury, after the Christchurch earthquake of 2010, museum staff at University of Canterbury's Logie Building discovered that glass shelving and display cases had shattered and that objects had smashed into each other due to the intensity of the vibrations from the earthquake (Moore, 2015). What is of particular note for RBC Museum staff is that while the displays were well anchored, the damage that occurred became more severe the higher up in the building, and that the intensity of vibrations on the sixth floor were such that glass shelving concertinaed (Moore, 2015).

Discussion

Having established potential vulnerabilities for the new towers, RBC Museum staff can establish a mitigation plan of action. In order to create such a plan, Podany (2009) recommends that everyone working within a collection be involved, including curators, designers, security and conservators (p. 5). RBC Museum staff could observe and adopt a three-prong mitigation plan for the protection of their collections, similar to that of the J. Paul Getty Museum in Los Angeles, such as:

- Lowering an object or object's assembly's center of gravity by adding weight. Examples of this are such low-cost items such as placing sand bags inside objects, attaching objects to heavy bases, and adding lead bricks or weights to the inside bottoms of pedestals or cases;
- Restraining objects by firmly securing them to the floor, pedestals, shelves, walls, and/or supporting mounts;
- Use of base isolation methods (p. 8).

Figure 1. Example of a rigid artifact display stand. Weights can be inserted inside the display or in the void below for extra stability. Reprinted from Artifacts Display Stands. Retrieved from http://ancientartifax.com/stands.htm

Figure 2. Example of a base isolation stand for exhibits. Retrieved from https://www.bing.com/images/search?view=detailV2&ccid=U7eDC9Ak&id=E18B6E2CA9B6638CDBC3AA117E9E92FB3BFB77CC&thid=OIP.U7eDC9Akl84UAANbwb0TOAHaFj&mediaurl

Simplistic and inexpensive mitigation methods are also available to RBC Museum staff, such as decreasing the number of objects on display so as to avoid overcrowding, padding and boxing objects, and implementing the use of restraints across open shelving units. Erturk (2012) points out that museums throughout Turkey have had a great deal of success in securing and protecting objects from seismic damage with the use of monofilaments (fishing line) (p. 298). It was from these studies of Turkish museums that Erturk (2102) began to feel the magnitude of transition towards digitization; museums making moves to protect their collections in completely different way. Many levels of precautions are needed to mitigate the effects of earthquake, with new and emerging technologies now available worldwide, coupled with many practical and inexpensive measures that can be taken (p. 248).

Staff Training, Preparedness, Response and Recovery

Preparing for disaster is one of the most important things a museum can do in order to safeguard its collections and protect staff and visitors from hazards. A disaster preparedness/emergency response plan, commonly known as a disaster plan, is a series of written policies and procedures that prevent or minimize damage resulting from disasters (either manmade or natural) and help a museum recover (American Alliance of Museums, 2012, p. 1). While all museums are expected to have plans that address how the museum will care for staff, visitors and collections in case of emergency, they also need to be tailored to the museum's specific circumstances and facilities; and, they should cover all relevant threats or risks to the museum, its collection and its people (Hunter, 2017, pp. 2-3). This includes evacuation plans for staff and visitors and plans for how to protect or recover collections in the event of disaster. The plan should also outline the responsibilities of each involved party.

While it is important to the success of these plans that museum staffs are trained and familiar with the disaster plans, evacuation policies and routes, it has been noted that there is a need to provide key staff in formal emergency management training that helps in the planning process, as well providing a level of expertise that can assist and supervise response and recovery efforts. Erturk (2012) noted that museum staff participants concluded that the emergency management seminars, meetings and workshops had been extremely helpful; and that, several museums in Istanbul followed up by sending key museum staff to take *Basic Disaster Awareness Training* programs (p. 245). He went on to state that the staff who took the more formal emergency management training gained valuable knowledge that they were able to utilize for earthquake preparedness measures in their respective museum exhibition and storage areas (Erturk, 2012).

Further supporting the push for this type of formal emergency management training comes from the International Council of Museums (ICOM), who recommends, in their UNESCO supported *Museum and Security Protection Handbook* that,

> museum curators and specialists should receive some formal emergency management training that allows them to utilize their specific knowledge and expertise in areas that can help plan for and prevent exhibit damage, as well as response, recovery, and removal of artifacts in conjunction with official emergency management response teams, after a major event (Hunter, 2017. pp. 13-16).

Hunter (2017) also noted that while the primary function of an effective emergency management plan will always be for the safety and well-being of staff and patrons, the secondary concern is focused on the building, archives and exhibits and how to not only protect them, but to salvage them (p. 2).

The American Alliance of Museums' *Alliance Reference Guide: Developing a Disaster Preparedness/Response Plan* mentions that it is important to clearly identify those to contact for help, such as first responders (e.g., police, fire fighters), and those who can help in recovery (e.g., area museum professionals, conservators), before a disaster strikes; and who will be critical to exhibit and archive salvage after an event (p. 4). By ensuring museum staffs are formally trained in emergency management procedures, they can more effectively assist first responders. Once people have been evacuated from the area, the museum's emergency teams are in a better position to help direct the responding teams to the best place to enter the property and building, guide them to the emergency area, provide them with information about the property, and ultimately coordinate their work in salvaging property (Hunter, 2017, p. 5).

Evaluation and Recommendations

Based upon the literature reviewed and presented within this paper, it is established that earthquakes are a leading contributor to damage and loss for museums and archives around the world. It has been demonstrated that shallow thrust earthquakes tend to have the most devastating effects (Barrie & Greene, 2016, Moore, 2015). This in turn has led to several methods of emergency management planning in order to safeguard patrons, employees, exhibits and archives. While the frequency and risk for earthquakes is not uniform, potential losses due to breakage, loss of power to climate regulated exhibits, archive loss, and injury or loss of human lives are of crucial concern (Erturk, 2012, p. 290). For RBC Museum staff involved in designing and building the two new towers along the Inner Harbour of downtown Victoria, the effects, damages and lessons learned from shallow thrust earthquakes experienced by museums in Turkey, Greece and New Zealand become notably more relevant with the discovery of the Devil's Mountain Fault in 2015.

While acknowledging the importance of this threat, an assessment of the seismic stability of the future RBC Museum towers requires an awareness that the type of seismic ground motion at a building site will depend on a number of factors, including: (a) distance from the rupture zone, (b) magnitude and depth of the earthquake, and (c) the soil conditions of the building site (SEABC, 2017). It was also pointed out that earthquakes affect buildings differently depending on the type of ground motions and characteristics of the building structure, and that seismic ground motion is typified by both vertical and horizontal shaking; for which, the horizontal shaking is generally larger and linked to damage (SEABC, 2017). Taking this information into account and, in order for RBC Museum staff to properly plan, design and build the new museum towers, it was established that they will first have to predict the intensity of shaking and damage the City of Victoria may experience. Fortunately for the RBC Museum, the City of Victoria commissioned VC Structural Dynamics Ltd to study, prepare and submit an official report covering the entire city. In 2016 the, *Citywide seismic vulnerabilities assessment study - City of*

Victoria, considered three scenario earthquakes based on the three sources of seismic activity in the Pacific Northwest region: a shallow crustal event, a deep in-slab event, and a large magnitude subduction event (VC Structural Dynamics Ltd, 2016). As was shown, the company implemented HAZUS as the primary software for their damage assessments and modified the data sets to reflect the seismicity and construction practices of BC by NRCan (VC Structural Dynamics, 2016). The report that was generated is an invaluable resource to museum staff, planners and engineers because the relationships aspects for this study were specifically modified to make the results more accurate in relation to the site conditions specific to the Victoria region (VC Structural Dynamics Ltd, 2016). With this data in-hand, design engineers will be able to design the towers so that they are more resistant to the impacts of earthquakes, thus saving lives, lessening the risk of injuries and damage to the buildings, exhibits and archives. This paper presented two ways to achieve this through new and important advanced techniques for earthquake resistant design and construction, such as Base Isolation and Energy Dissipation devices (Bhandari, et al, 2016. p. 2). As was demonstrated, a base-isolated building retains its original, rectangular shape due to the use of lead-rubber bearings supporting the building, which are highly elastic and therefore do not suffer any damage, thus making them both cost and design effective while mitigating seismic impact.

As stated earlier seismic design and retrofits of buildings alone does not guarantee the safety and security of the people and contents within. The approaches and methods available for the protection of heritage objects and collections from earthquake damage do not have to be overly expensive or elaborate (Podany, 2009). The majority of the literature reviewed maintained that to maximize effectiveness, museum workers must have a general knowledge of how given types of objects, assemblages of objects and exhibition furnishings and fixtures, as well as collections held in storage will respond to earthquake forces (Erturk, 2012; Podany, 2009; Spyrakos et al, 2008).

The International Council of Museums (ICOM) stated that all museums are expected to have emergency plans that address how the museum will care for staff, visitors and collections in case of emergency; that they need to be tailored to the museum's specific circumstances and facilities; and, they should cover all relevant threats or risks to the museum, its collection and its people (Hunter, 2017, p. 2-3). ICOM also recommended, in their UNESCO supported *Museum and Security Protection Handbook*, that museum curators and specialists should receive some formal emergency management training that allows them to utilize their specific knowledge and expertise in areas that can help plan for and prevent exhibit damage, as well as response, recovery and removal of artifacts in conjunction with official emergency management response teams, after a major event (Hunter, 2017. p. 13-16). Based on other literature reviewed, this concept is best supported from Erturk's (2012) analysis of museums throughout Turkey, in which he noted that museum staff participants found emergency management seminars, meetings and workshops had been extremely helpful; and that, several museums in Istanbul followed up by sending key museum staff to take *Basic Disaster Awareness Training* programs (p. 245). Of particular importance, he went on to state that the staff who took the more formal emergency management training had acquired valuable knowledge they were able to apply to earthquake preparedness measures in their respective museum exhibition and storage areas (Erturk, 2012, p. 245). These observations benefit RBC Museum staff, as they demonstrate the value of leading staff being equipped with some level of emergency management training that assists with planning, prevention and mitigation efforts for the new towers, and also provides additional resources that understand the processes of working with emergency response teams when it comes to re-entering the museum after a major earthquake and salvaging artifacts.

Conclusion

The literature reviewed in this paper offers insights based on various studies from around the world, including New Zealand, Turkey and Greece, where major shallow thrust earthquakes were experienced. As has been established, the location of the Royal BC Museum inside a seismically active zone places the buildings, staff, patrons, exhibits and archives at risk in the event of a major earthquake. Based on the information discussed, RBC Museum staff can gain better insight into the importance of emergency planning, mitigation, preparation and response as they proceed in their plans to build two new towers. By understanding the threat posed by Devil's Mountain Fault, as well as how a shallow thrust earthquake could impact building designs and exhibit displays, the designers and engineers can make use of new technologies such as Base Isolation and Energy Dissipation devices. To help save and protect collections and archives, the RBC Museum must expand its use of digitization technologies and make use of virtual reality tours, while recognizing the possibilities of secondary revenues from its archives collections to researchers. Lastly, the museum should ensure that curators and specialist staff are provided with some amount of formal training in emergency management, so that they may be better prepared to utilize their knowledge and expertise in the museum's emergency preparation, mitigation and response planning. Of all institutions, a museum is arguably the most qualified to recognize the importance of history and learning from the past so as to avoid a similar fate in the future. The literature reviewed has clarified a multitude of ways the RBC Museum can apply lessons learned by other museums and institutions to not only save lives, but to protect and preserve BC's culture and heritage.

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