SUBJECT	**SEISMIC RESILIENCE PLAN**
MEETING DATE	**FEBRUARY 7, 2019**

APPROVED FOR SUBMISSION

Forwarded on the Recommendation of the President

Santa J. Ono, President and Vice-Chancellor

FOR INFORMATION

Report Date	January 18, 2019
Presented By	Peter Smailes, Vice-President Finance & Operations John Metras, Associate Vice-President, Facilities Ron Holton, Chief Risk Officer Jennifer Sanguinetti, Managing Director, Infrastructure Development

If this item was previously presented to the Board, please provide a brief description of any major changes since that time.	Since April 2018, the seismic resilience project team has executed several parts of the action plan in all three areas of focus – buildings, utilities and operations. Utilities actions include a full project plan and commencement of the water pump relocation project. Significant work on potable water backup options has been undertaken and significant progress on the provision of new back-up fuel capacity has been made. The Operations priority actions completed include analysis of the relocation of the Emergency Operations Centre, completion of Emergency Response and Crisis Management Plans and significant work on business continuity planning, including IT Disaster Recovery and learning space response plans. For the Buildings area, efforts have been focussed on completing the detailed analysis of the 19 priority buildings, completing concept retrofits where appropriate, completing a draft implementation plan and the development of contents guidelines. Work has also been done to gather more information on those buildings where insufficient record detail was available. Finally, UBCO has prepared a scope of work to undertake their own multi-hazard assessment and anticipate executing the study in 2019-2020.

EXECUTIVE SUMMARY

UBC places the safety of students, faculty and staff as its highest priority. Reducing or mitigating the risk of injury or death as a result of a seismic event is critical. As reported to the Board of Governors in April 2018, the plan for the seismic mitigation of the UBC Vancouver campus is being developed to ensure that this risk is reduced as much as possible and as quickly as possible within the University's logistical and financial capacity.

This report provides an update on key action items from that report, including detailed seismic evaluation of campus buildings identified as highest risk. The detailed seismic evaluations are part of a series of prioritized recommendations, as outlined in the Board report of April 2018. This report provides an update on actions taken on a number of key priorities, addressing campus buildings, utilities and operations.

The process to update the seismic mitigation plan for the UBC Vancouver campus was initiated in May 2016. The goal of the new plan is to incorporate the latest science and best practice and to ensure that that seismic risk is reduced as much as possible and as quickly as possible within the University's logistical and financial capacity. This update is part of a long history of seismic work undertaken at the University. Seismic planning was first undertaken in the 1990s, with seismic upgrades undertaken on over 25 buildings (see Attachment 5).

The need for an update was identified for three reasons:

- The science of different seismic fault lines has evolved significantly since the buildings were originally assessed in 1994 and re-evaluated in 2012. New fault lines and new earthquake intensities are now recognized that are more severe than were identified previously. As a result, the newest building codes are significantly more stringent than the ones used in the previous assessments so the new evaluation reflects these changes.
- The timeliness of the planned seismic upgrades needed to be re-evaluated with a goal to completing all remaining upgrades as quickly as is reasonably possible.
- Best practice thinking regarding resilience, risk assessment and the ability of a major public institution like UBC to respond to a natural disaster such as an earthquake has evolved. This updated practice shows a more nuanced approach to seismic planning, reflecting a risk assessment approach that allows for a spectrum of needs to be addressed. While life safety is paramount, it looks beyond this one aspect to address the ability of an institution to resume operations after a disaster, and addresses broader technical aspects such as utility vulnerabilities and non-structural seismic hazards.

The majority of the priority action items identified by the consultant team have been completed or are well under way, including detailed analysis of 18 priority buildings and the creation of a notional implementation plan, as well as actions related to the utilities and operations vulnerabilities identified on the Point Grey campus. This work reflects the latest thinking in seismic assessment and planning, recognizing that there are different seismic vulnerabilities for different buildings on campus and different levels of criticality for different types of spaces.

The consultant team (ARUP) provided UBC with a set of prioritized recommendations. When the Board of Governors was last updated in April 2018, these recommendations were partially complete. Since that time, significant progress has been made in all three action areas of utilities, operations and buildings.

In addition, a series of principles was developed and reported to inform the Board how decision-making would be undertaken as the project proceeds. That set of principles was used to guide the work of the team as follows:

- *Life Safety:* The safety of students, faculty, staff and visitors is of primary importance.
- *Alignment with Existing Principles and Processes*: The process for prioritizing seismic upgrades and renewals will be completely aligned with, and a regular part of, the University's capital planning process already in place.
- *Bold Vision, Pragmatic Implementation*: The vision presented and supported of a disaster-resilient university that is able to withstand impacts of possible hazard events without harm to people, unacceptable losses to property, or interruptions to our mission is a bold one; however, work done towards this vision must be executed within the financial and logistical constraints of the university.

The results of the detailed building evaluations confirm and identify the specific performance of the 18 priority buildings analyzed in far greater detail than was understood before. These results have also identified collapse potential in areas that would not have been evident under conventional study. This level of understanding also offers the opportunity to pursue near-term, targeted retrofit measures that could significantly improve safety within these high-risk buildings. In addition, the team assessed each building's retrofit feasibility, bringing an understanding of how to optimize UBC's capital investment. Some buildings are appropriate for retrofit but the majority have multiple structural issues that make them better candidates for replacement than retrofit. The team has identified order-of-magnitude capital costs of approximately $1.0 billion for executing the identified combination of retrofits, targeted life-safety improvements and replacements of the high priority buildings.

Next steps for the project include completion of those priority action items that are not yet complete and the consideration of funding options for executing the building-related upgrades within the broader context of the capital planning process. The results of this will be reported on through the capital planning updates to the Board of Governors.

Updates on the remaining priority actions will be provided on a regular basis to the Board of Governors.

The plan currently encompasses University-owned institutional facilities on the Vancouver campus, which represent the highest seismic risk to the University. The Okanagan campus was not included in the scope of work given the substantially lower seismic risk in the Okanagan. The plan also does not include neighbourhood market housing and community buildings or UBC off-site leased spaces, all of which fall outside the direct control of the University. The multi-hazard assessment and planning framework used for the Vancouver campus will be applied to the Okanagan campus and to the neighbourhood facilities. Significant work has been undertaken by and with the UBC Okanagan facilities team and they have a complete scope of work that is ready to be executed. Conversations have been held with UBC Properties Trust to explore options for appropriate implementation of this work in the neighbourhood facilities although all operational measures consider the population of the neighbourhoods as part of the population served by those measures.

Attachments

1. ARUP Detailed Evaluation: Executive Summary Report
2. Table: UBC Seismic Planning: Detailed Analysis of Priority Buildings
3. Table: UBC Seismic Planning: Notional Implementation Timeline for Mitigation of Priority Buildings
4. Campus Map identifying High-Risk Buildings
5. Table: Completed and In-Progress Seismic Retrofits

STRATEGIC CORE AREAS SUPPORTED

a **People and Places** a **Research Excellence** ☐ **Transformative Learning** a **Local / Global Engagement**

DESCRIPTION & RATIONALE

In the present phase of work, seismic resilience planning has progressed in the following areas identified as strategic priorities:

Buildings

Following the completion of ARUP's 2017 Seismic Resilience Study, the following were priority items that have been completed as part of UBC's next phase of Seismic resilience planning.

1. A subset of buildings at the highest risk of collapse (Tiers III and IV) where the vulnerabilities are highest (e.g. a large building population) have undergone a detailed engineering evaluation using advanced seismic modelling, which assists in development of a more accurate probability of collapse, as well as assisting with determining which buildings should be prioritized for retrofit or replacement. Additionally, out of the Arup Report there were 33 Buildings identified as having limited information that should be studied in more detail. Infrastructure Development has created a shortlist of Engineering Firms to engage with these non-detailed investigations this coming year.

2. The non-structural life safety hazards in all campus buildings will be assessed over the coming year and a mitigation plan will be developed.
3. Guidelines for the protection of valuable contents have been developed and are ready to be implemented as a part of the retrofit of existing buildings and as part of the development of new buildings.

The largest focus for this phase of Seismic resilience planning for Buildings has been in the detailed evaluation of high-risk buildings. A shortlist of twenty-two buildings was recommended by ARUP as candidates for this detailed study. Three buildings were not pursued as they were part of UBC Hospital, and therefore not entirely in UBC's planning control. From this list of 19 buildings, 18 detailed studies were pursued. [Building #19, UBC Bookstore, could not be evaluated without modelling the entire building complex and was therefore not modelled in detail. Note that this building will be retained on the list of buildings of concern for future review. It is also worth noting that based on the age and character of the Bookstore and surrounding buildings, the hazard rating is unlikely to change from Tier III.].

Detailed Seismic Evaluations

In the previous phase of the seismic plan project, the seismic risk of 328 buildings for various earthquake scenarios was quantified in terms of probability of collapse, casualties, repair costs and downtime, generally using relatively simple analytical models of the buildings. From that study, ARUP identified a number of buildings that were designated as Tier IV (i.e. having probability of collapse greater than 50% in 2475 year earthquake event). UBC identified a subset of 18 buildings that were studied in greater detail to further refine their collapse probability, ultimately to provide information to aid in decision making.

To follow up on strategic priorities identified in Seismic plan, ARUP's high performance buildings group was commissioned to develop detailed building models of identified high priority buildings on campus. These 3D computer models use a state-of-the-art software to dynamically model building performance of all components under seismic motions. The models are sophisticated models capable of identifying specific weaknesses and points of failure at a number of seismic shaking intervals. The objective of this analysis method is to predict the best estimate for probability of collapse conditioned upon a single intensity of shaking (using a benchmark of 975 year return period), in as realistic a manner as practicable. It should be noted that considerable uncertainties remain in predicting the probability of collapse of existing structures under seismic actions, even when the sophisticated structural analysis techniques employed here are adopted.

To ensure that the study conforms to best practices and highest performance standards, a Peer Review Panel was established to review every step of ARUP's work. This peer review panel included members of the UBC academic community, and practitioners with seismic engineering expertise. The panel provided Infrastructure Development with input on every aspect of the study, including benchmark standards, international guidelines, best practices, and site specific issues to consider. This high degree of rigour ensured that the detailed modelling effort achieved the highest level of performance and output possible.

The Peer Review Panel included:

1. Dr. Carlos Ventura (Professor, Civil Engineering, Director of Earthquake Engineering Research Facility, UBC)
2. Dr. Tony Yang (Associate Professor, Civil Engineering, UBC)
3. Armin Bebamzadeh (Research Associate, Civil Engineering, UBC)
4. Ilana Danzig (Associate Engineer, Equilibrium Consulting)
5. Anthony El-Araj (Principal, Glotman Simpson Consulting Engineers)

The detailed seismic evaluation considered the following buildings:

Building ID	Building name	Previous Tier [2017 Study]	Updated Tier [2018 Study]
022	LOWER MALL RESEARCH STATION	III	V
048	ANTHROPOLOGY AND SOCIOLOGY BUILDING	IV	V
148	CHEMISTRY B BLOCK, SOUTH WING	IV	V
198	J. B. MACDONALD BUILDING	III	III
306	CIVIL AND MECHANICAL ENGINEERING BUILDING	IV	V
308	LEONARD S. KLINCK BUILDING	IV	IV
312	MACLEOD BUILDING	IV	IV
386	H. R. MACMILLAN BUILDING	IV	V
430	ROBERT F. OSBORNE CENTRE - UNIT 1	IV	III
431	ROBERT F. OSBORNE CENTRE – UNIT 2	IV	V
447	CHEMISTRY A BLOCK, CHEMISTRY PHYSICS BUILDING	III	V
523-3	MEDICAL SCIENCES BLOCK C	IV	V
536	WOODWARD BIOMEDICAL LIBRARY	III	V
562	FRANK FORWARD BUILDING	III	V
570	MUSEUM OF ANTHROPOLOGY	IV	IV
575	MUSIC BUILDING	IV	V
732	DOUGLAS KENNY BUILDING	III	V
750	JACK BELL BUILDING FOR THE SCHOOL OF SOCIAL WORK	IV	III

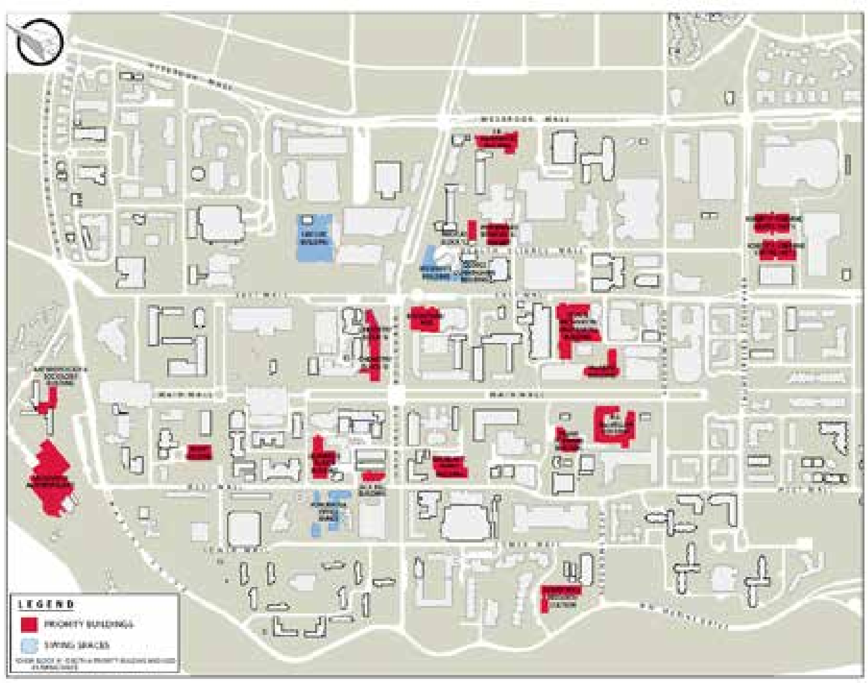

Figure 1.– UBC Campus map showing buildings assessed in Detailed Seismic Evaluation

The detailed modelling effort entailed the following steps:

1. **Site-specific ground motions:** Based on global historic seismic events deemed comparable to predicted events at the UBC Point Grey Campus, VC Dynamics Ltd. developed a suite of seismic ground motions, in order to accurately model predicted dynamic building behaviour under seismic events. A suite of 11 ground motions were developed, drawn from records of past seismic events around the world and scaled appropriately to the magnitude of the events we are expected to experience in Vancouver. The study included a detailed seismic hazard analysis and seismic ground motion information specific to the UBC campus location. These ground motions were commissioned and tailored for optimal performance in the ARUP study.
2. **Basis of Assessment:** A detailed basis of assessment was developed by ARUP to ensure that the seismic modelling aligns with best practices and performance standards held in the engineering community in Canada and internationally. This published basis of assessment provides a baseline that can be brought forward during detailed design and implementation phases for future mitigation efforts, critical for evaluations of campus-wide seismic performance. Furthermore, this Basis of Assessment was reviewed by the Peer Review Panel and went through extensive review and modification to ensure UBC received the best analysis of these high risk buildings to increase the confidence level in the assessment of collapse probability and life risk.
3. **Physical Structural Analysis:** In order to increase accuracy of the developed models, concrete strength testing was carried out in each high-risk building, providing ARUP with data based on the actual materials in place in order to accurately assess collapse potential. This included core samples for concrete strength and other tests on each structure. This additional rigour substantially increased the accuracy potential of the models.
4. **Simulated Structural Performance:** The ARUP 3D models simulate performance under the 11 ground motions developed in the first stage of work in order to evaluate the effects of earthquake shaking. The detailed models are able to accurately capture the stresses, deformation and damage that could lead to progressive collapse of the structures. The outcomes of the simulations were categorized by degree of collapse, partial or full collapse.

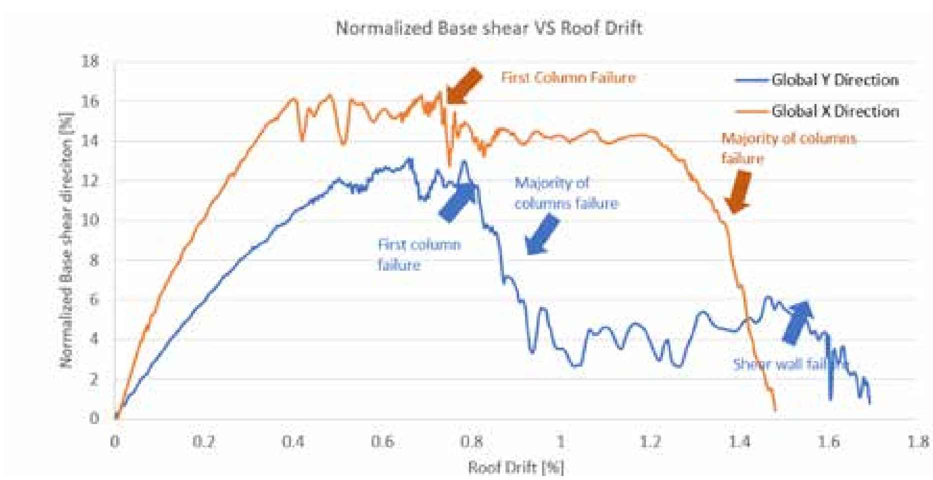

Figure 2. Medicine Block C – Model output diagram isolating detailed patterns of building failure during simulated seismic shaking

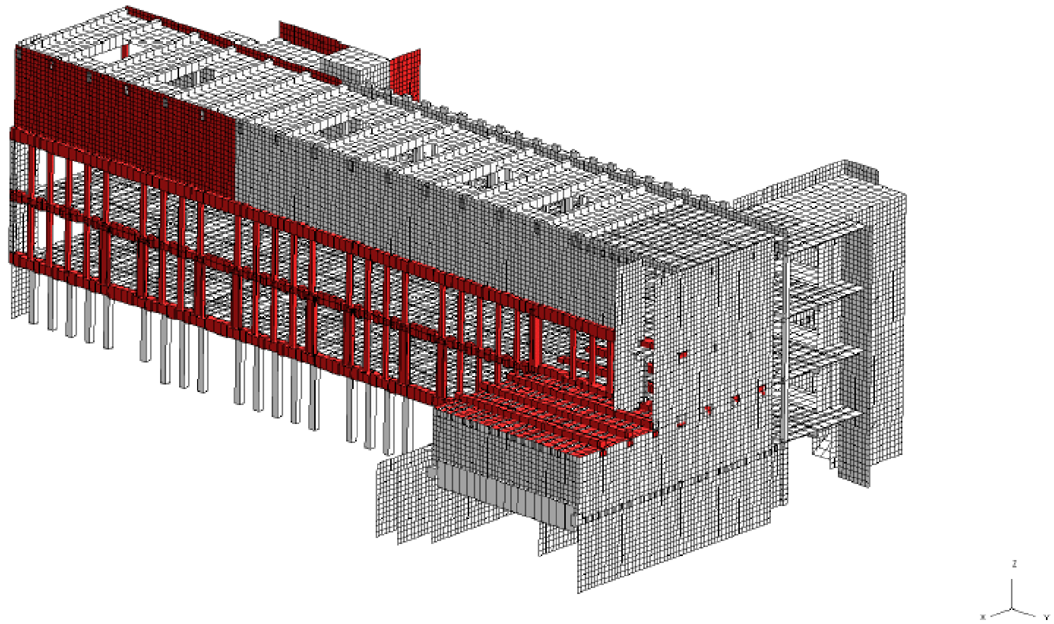

Figure 4. MacMillan Building – Analysis diagram isolating structural elements of risk to progressive collapse

Detailed Seismic Evaluation Key Findings

1. The detailed analysis has allowed for a more nuanced view of seismic risk and assessment of priority for mitigation. The models have provided detailed insight into the extents of structural weaknesses, and in several cases have uncovered areas of high priority to address that would not otherwise have been identified under conventional study.
2. The detailed evaluation of structural frame and element performance helps UBC to consider whether high-risk structures are likely candidates for retrofit, or whether the extents of structural weakness are so prevalent that retrofit strategies would be too costly and invasive to pursue. This information is key to providing strategic seismic information on the vulnerability of the existing structures, and to inform decisions on whether to renew or replace in order to mitigate structural risk.
3. The detailed analysis has provided many insights into building performance that would not have been identified under the screening tool used in previous phases. In several instances, specific building weaknesses were evident at low levels of shaking, highlighting of areas of high vulnerability to progressive building failure. In several buildings these detailed weaknesses have been identified as high priorities for near term measures to mitigate seismic risk.
4. Using an updated life risk matrix allows UBC to consider priorities for mitigation with a more nuanced, detailed assessment of the life risk hazard as it relates to progressive building collapse.
5. The detailed analysis reports provide a rigorous baseline understanding of the existing building and predicted performance, which allows concept retrofit strategies to start from a significantly higher baseline of structural behaviour understanding.

6. The detailed reports include recommendations and issues to consider in concept retrofits, and opinion on the suitability of the structures to be retrofit under conventional means.

An Executive Summary of the ARUP detailed evaluation is included as **Attachment 1.**

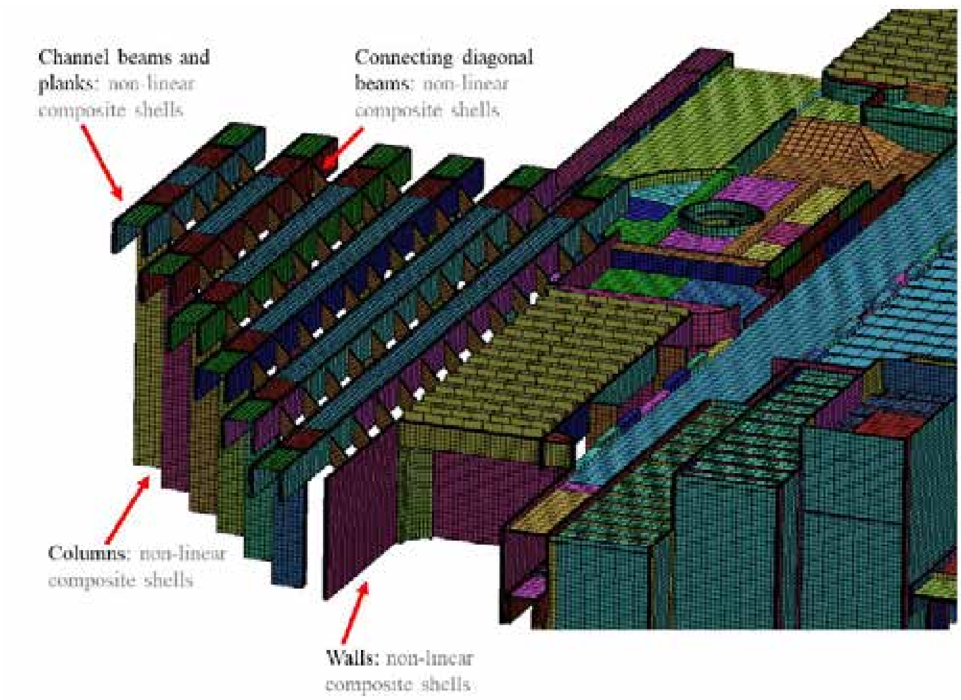

Figure 3. Museum of Anthropology – Analysis diagram isolating structural elements of Great Hall

Concept Retrofit Studies

Using the detailed analysis reports as a baseline, concept retrofit studies have been undertaken on nine of the identified high-risk buildings. Engineering feasibility studies (prepared by RJC Structural Engineering Ltd.) provide an understanding of the specific measures required to bring the buildings to a current standard of seismic safety. The retrofit reports thus allow concept feasibility costing to be assessed, for implementation planning. The results have provided UBC with a thorough understanding of the seismic hazard mitigation opportunities, and the means to retrofit and mitigate.

Key Findings of concept retrofit studies:

1. It is evident that the detailed analysis study can provide design engineers with valuable and key information that would otherwise be unavailable in their feasibility level analysis, and has already been put to use in active projects. For instance, the detailed models can predict frame movement and differential movements of structural frames during seismic events. Seismic behaviour [e.g. drift ratio] can be predicted in detail, providing design engineers with insight into the specific measures that may be required to retrofit.

2. The character of retrofit measures requires direction as to desired level of building performance expected from the remediated structures. In order to have a common baseline for study comparison, current retrofit studies have assumed measures required to bring structures in alignment with the National Building Code 2015 new building construction performance levels.

During the course of the study, design enquiry assistance using the detailed models has been provided to projects currently underway in high-risk buildings, including MOA and the Douglas T Kenny Building 4th Floor Renovation.

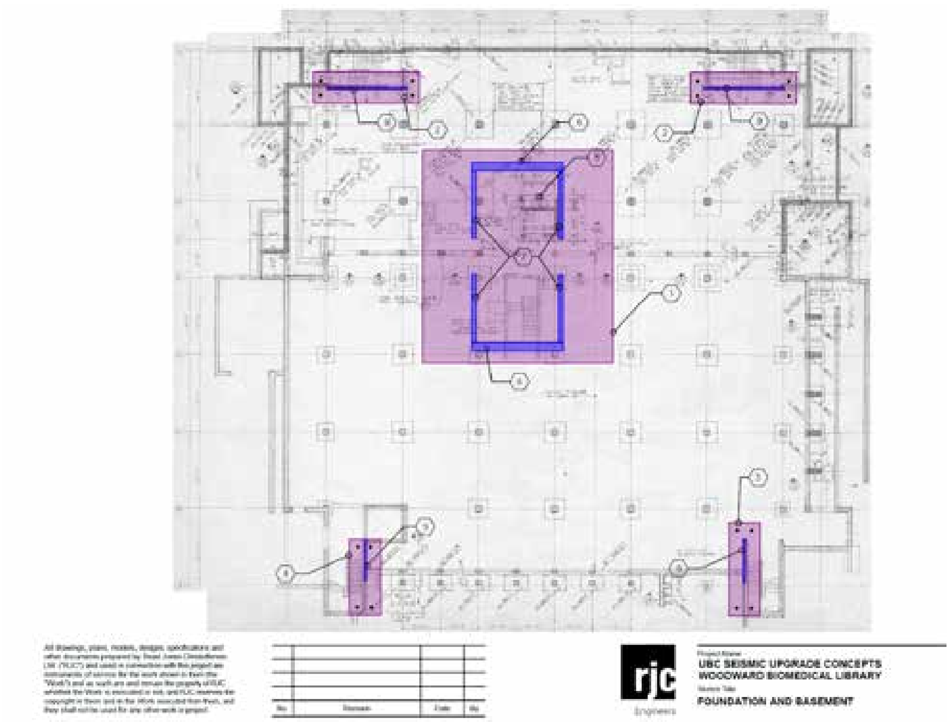

Figure 5. Woodward Building – Concept retrofit diagram at foundation level

Guiding Principles

A series of principles has been developed to guide the work of the Seismic planning team. These principles are as follows:

1. Life Safety: The safety of students, faculty, staff and visitors is of primary importance.
2. Alignment with Existing Principles and Processes: The process for prioritizing seismic upgrades and renewals will be completely aligned with, and a regular part of, the University's capital planning process already in place. The planning principles reviewed and supported by the Board of Governors in December 2014 will also be applied to this work.
3. Bold Vision, Pragmatic Implementation: The vision presented and supported of a disaster-resilient university that is able to withstand impacts of possible hazard events without harm to people, unacceptable losses to property, or interruptions to our mission is a bold one; however, work done towards this vision must be executed within the financial and logistical constraints of the university.

Updated Priority Ranking

Following the methodology used in the 2017 ARUP study, the high-risk buildings studied in this phase of work have been assessed and prioritized using three ranking methods:

1. By probability of collapse under a 975 year return period [using a Tier system]
2. Using ARUP Strategy #1: priority by average annual fatality risk
3. Using ARUP Strategy #2: priority by cost effective mitigation of annualized risk of fatalities

Using the updated detailed evaluation results, the graphs below compare the impacts of these strategies in terms of reduction in fatality risk, and in cost-effective mitigation of average annual fatality risk. This analysis combines the seismic performance details with the estimated costs to mitigate, and each building's population density.

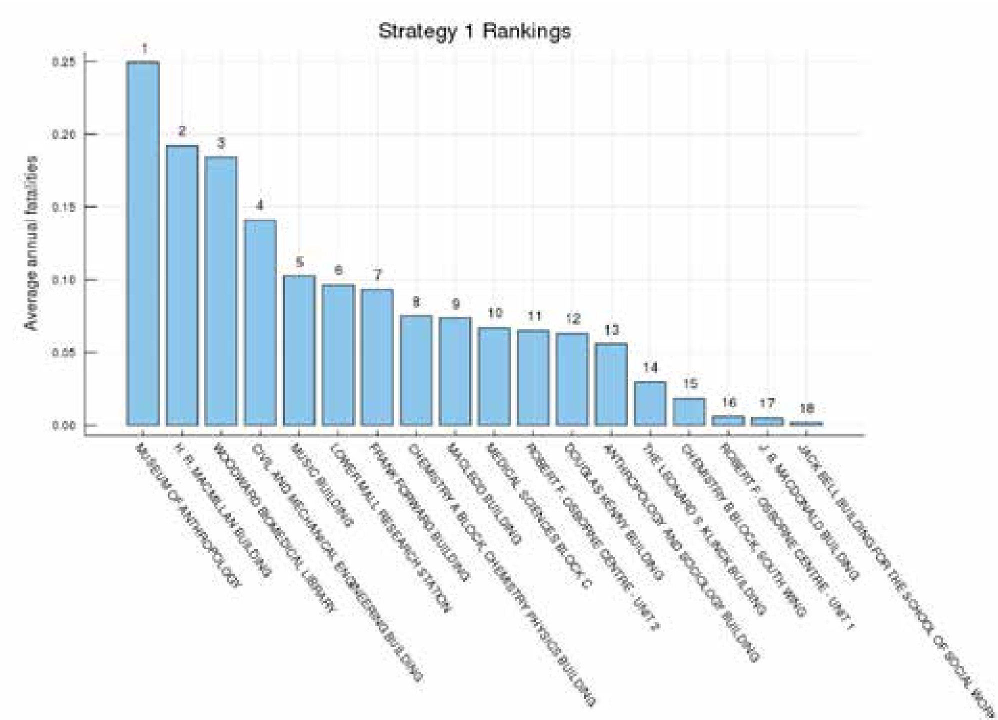

Figure 6. Chart showing priority buildings ranked by Strategy 1: Average Annual Fatalities

In Figure 6 above, the higher ranking indicates a higher priority for mitigation, as relates to reduction in predicted fatality risk. This ranking ignores costs to achieve mitigation and does not compare mitigation by retrofit or replacement.

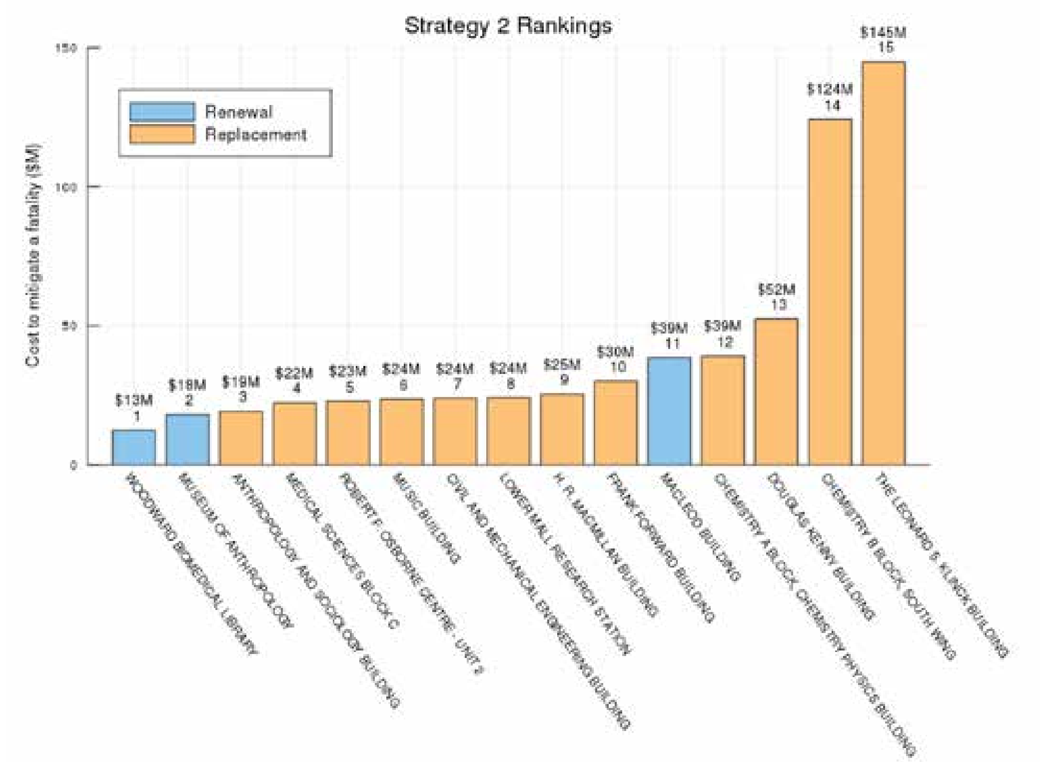

Figure 7. Chart showing priority buildings ranked by Strategy 2: Cost to Mitigate Annual Fatalities

In Figure 7 above, the higher ranking indicates a higher priority for mitigation, as relates to cost-effectiveness in reduction of predicted fatality risk. This ranking also indicates whether the renewal or replacement option is most beneficial from a cost-benefit point of view. While the priority buildings are ranked 1-18, it is interesting to note that ranking by Strategy #2 illustrates that a significant number of buildings are comparable in terms of the cost effectiveness of mitigating fatality risk. Note that fatality risk has been quantified by the term "Average Annual Fatalities" which takes the predicted number of fatalities in a seismic even and spreads them over the life of the building.

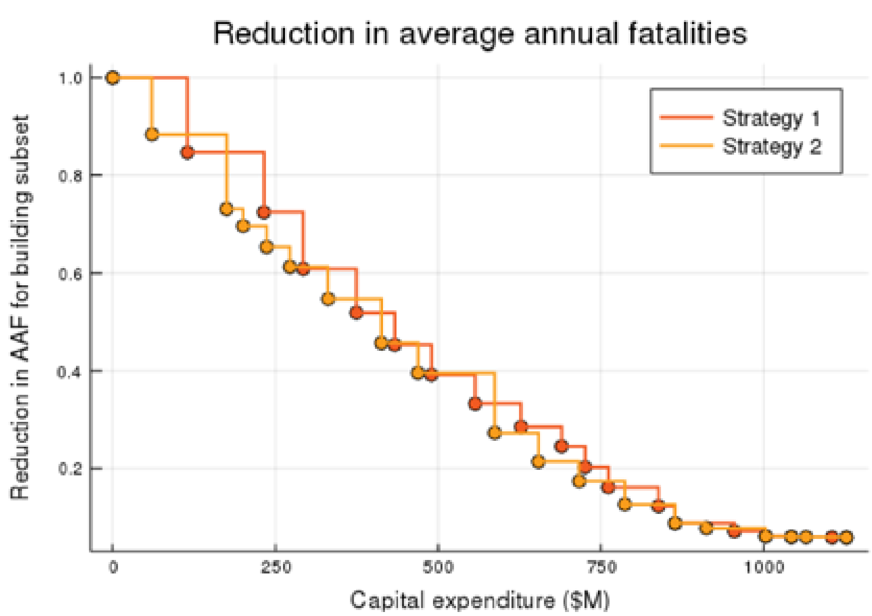

Figure 8. Chart showing comparison of Strategy 1 and 2

Figure 8 illustrates that while Strategy #2 is more optimal, the difference between mitigation by either Strategy is close in effectiveness. Given the close alignment of Strategies 1 and 2, an outcome of the detailed evaluation phase is that the following summary of ranking according to priority (using Strategy #2) can be used as a basis for planning priority:

Building ID	Building name	Updated Rank: Strategy 2	Updated Tier [2018 Study]
536	WOODWARD BIOMEDICAL LIBRARY	1	V
570	MUSEUM OF ANTHROPOLOGY	2	IV
048	ANTHROPOLOGY AND SOCIOLOGY BUILDING	3	V
523-3	MEDICAL SCIENCES BLOCK C	4	V
431	ROBERT F. OSBORNE CENTRE – UNIT 2	5	V
575	MUSIC BUILDING	6	V
306	CIVIL AND MECHANICAL ENGINEERING BUILDING	7	V
022	LOWER MALL RESEARCH STATION	8	V
386	H. R. MACMILLAN BUILDING	9	V
562	FRANK FORWARD BUILDING	10	V
312	MACLEOD BUILDING	11	IV
447	CHEMISTRY A BLOCK, CHEMISTRY PHYSICS BUILDING	12	V
732	DOUGLAS KENNY BUILDING	13	V
148	CHEMISTRY B BLOCK, SOUTH WING	14	V
308	LEONARD S. KLINCK BUILDING	15	IV
430	ROBERT F. OSBORNE CENTRE - UNIT 1	16	III
750	JACK BELL BUILDING FOR THE SCHOOL OF SOCIAL WORK	17	III
198	J. B. MACDONALD BUILDING	18	III

Results & Analysis

Using the guiding principles identified, the updated evaluation ranking, and the framework costs developed from concept retrofit studies, a compiled summary table has been prepared which summarizes the high-risk buildings, their tier of hazard, and current recommended mitigation approaches (See Attachment 2 – UBC Seismic Planning: Detailed Analysis of Priority Buildings). The primary purpose of this table is to summarize the updated priority ranking from the detailed evaluation study, and to outline current recommended measures to retrofit or replace the high-risk structures. Order of magnitude planning cost comparisons are derived from feasibility-level concept retrofit studies. Using these costs, updated seismic assessments and planning criteria frames a recommendation as to whether retrofit, renewal or replacement is the current recommended means of mitigating the seismic risk. In several instances the recommendation is constrained by other factors, for example availability of swing space.

A draft implementation plan outlines a framework for mitigation of the priority buildings, using known possibilities for swing space accommodation, current assumptions for timelines required to plan and resource replacement buildings, and possible sequencing of renewal projects (See Attachment 3 – UBC Seismic Planning: Implementation Timeline for Mitigation of Priority Buildings). Included in this diagram are several near-term measures to consider as mitigation measures, in instances identified by the ARUP study as opportunities for targeted retrofit measures that could improve performance and reduce high-risk collapse potential. The primary objective of this table is to use a planning implementation framework to outline the potential full scope of mitigation required to address high-risk buildings on campus.

Seismic Performance Guidelines

Content Protection Guidelines

A comprehensive guideline for the protection of valuable contents has been completed and is currently prepared to be implemented as a part of the retrofit of existing buildings and as part of the development of new buildings. The study includes standard recommendations for the reduction of risk to Life Safety, Operation Continuity, and Property for a comprehensive list of contents. The costs to implement seismic protection of building contents is relatively low and has been recommended as a key resilience strategy to reduce seismic risk at UBC.

As with all public sector working environments, UBC has engaged in non-structural seismic restraining drives in the past and continues to upgrade work, study and research environments on an ad hoc basis. ARUP's current recommendations call for a more concerted approach towards restraining and securing items to reduce injuries, limit damage and decrease UBC's recovery time. Risk Management Services (RMS) and Building Operations / Infrastructure Development have reviewed and signed off on the ***Guidelines for Seismic Protection of Building Contents*** provided by ARUP and started discussing potential strategies for assessing the scope of the work and developing an implementation plan.

Recommendations and Next Steps

Updated Implementation Planning

Following the notional Implementation Plan, development of an overall implementation plan will require review of potential funding sources, project logistics, planning constraints, and consultation required to advance a strategic plan to mitigate the seismic hazard in the priority buildings. It is highly recommended to maximize the use of the detailed seismic models for high-risk buildings in evaluating mitigation options for implementation. The results of this process will fold into the overall capital planning process for the University.

Non-detailed Building Evaluations

The team is working to complete the non-detailed evaluations of buildings identified by ARUP in the Seismic Resilience Study. UBC has prepared [by RFP] a pre-qualified shortlist of Engineering firms to complete this next phase of Seismic building assessment.

Completion of Guidelines

Retrofit guidelines: This guideline to standardize UBC's approach to the seismic retrofit of existing buildings will include clear performance indicators beyond the current expectation of a certain building code level as well as a set of criteria for seismic retrofit.

New Building guidelines: This guideline for the seismic design of new buildings will include performance criteria that target higher functionality targets than meeting current codes.

Utilities

1. Decommissioning the Power House and relocating the campus water pumps to a new location is a primary recommendation. As part of a larger effort to plan for the West Mall precinct, a site has been identified for the water pumps adjacent to the Henry Angus Tower. The water pump replacement project has received Executive 1 approval and the project team has completed a feasibility study. The project is now part of the Infrastructure Impact Charge (IIC) program and is presented in more detail in the IIC update report presented by Campus & Community Planning in this Board meeting. In addition, the Power House has been completely decommissioned.
2. Provision of backup water supply for firefighting is recommended. This recommendation is being considered. Work has already been undertaken to look at viable options.
3. Providing the physical and operational infrastructure for storing up to three days of diesel fuel for the campus utility systems is recommended. Energy and Water Services and Infrastructure Development have decided upon assumptions, consumption parameters and required storage capacity for campus emergency diesel supply. A Request for Proposals (RFP) to engage a contractor for the design of a new above-ground tank farm on campus has been drafted. The current challenge is identifying an appropriate space for this new fuel facility; two sites are currently under consideration. The new facility will primarily supply diesel for emergency generators and vehicles during an emergency. To simplify delivery requirements and improve available emergency diesel for the Campus Energy Center (CEC), Energy and Water Services will be adding an additional 100,000 litre tank beside the CEC.
4. The final priority recommendation is to develop a strategy and the necessary infrastructure for distributing enough potable water to meet the anticipated needs of the campus population in the event of a protracted disruption to the water supply. UBC commissioned an emergency water filtration trailer capable of processing 150,000 litres of water per day in 2017. Pathway testing in 2017 and 2018 identified challenges related to stream and filtration flow rates, turbidity issues and a lack of distribution capacity. Energy and Water Services has resolved the filtration challenges and received the public health permit to operate the system. A secondary stream location is being developed to increase available water supply. Risk Management Services (RMS) has initiated Emergency Support Function

planning groups to develop distribution plans. Challenges still exist related to requirement assumptions and developing additional water supplies to ensure the University is able to address immediate supply requirements while engaging and setting up the filtration system.

Operations

1. The appointment of a Chief Resilience Officer (CRO) similar to that appointed recently by the City of Vancouver is suggested to ensure that there is one person responsible for implementing the seismic strategy. The appointment of a CRO has been investigated and remains under consideration. It would be premature to move forward on this recommendation until the overall seismic plan (including funding, and prioritized resource allocation) has progressed and other pending organizational matters have been addressed. In the interim, established resilience-related initiatives and capabilities within the Facilities group (Infrastructure Development, Building Operations, Energy & Water Services) and the Risk Management Services (RMS) department, extensive engagement between RMS and the Information Technology (IT) department regarding cyber security and IT's Disaster Recovery Plan, and existing governance structures, including the Emergency Management Steering Committee (EMSC) (which includes senior representation from six Vice-President portfolios and the Office of the President) as well as the Seismic Steering Committee (which is well represented on the EMSC) are providing the effective coordination and integration of seismic and other resilience initiatives which the recommendation was intended to achieve.
2. Life safety risks can be reduced through operational measures. There is a series of suggested actions that are being investigated, validated, prioritized and enacted. As recommended, the primary Emergency Operations Centre (EOC) facility in the University Services Building is no longer in use. Securing permanent, designated EOC space has been challenging due to the space requirements of the facility and the competition for space on campus. Over the past two years, RMS has been working with Infrastructure Development – Facilities Planning to identify potential spaces and has completed feasibility studies on two spaces, both of which were deemed not optimal. RMS has trialed two different spaces during major EOC exercises in 2017 and 2018, and has developed a mobile EOC supplies kit to be deployed in interim EOC spaces, until more appropriate permanent space is identified. This continues to be a challenge for the campus as there is no designated space in a seismically fortified building with back up emergency power. The need for a permanent, dedicated EOC space has been recognized and a potential location in the Copp redevelopment has been identified.
3. RMS has drafted a new Emergency Response Plan and a new Crisis Management Plan. Both plans have been approved by the Emergency Management Steering Committee and the UBC Executive Team. Both plans were enacted and validated in the 2018 emergency exercise "Choke Point". Further development of annexes to these plans is underway.

4. Similarly, the need to prepare, complete and validate business continuity and contingency plans for hastening post-earthquake recovery was recommended as a priority as well. The Office of the Provost in conjunction with RMS, the Registrar, Infrastructure Development and Scheduling Services have engaged in a modeling exercise to explore how to reschedule classes, labs and other teaching activities post-earthquake. RMS continues to re-evaluate how best to incorporate the current continuity planning data and re-engage the campus in continuity planning. RMS has worked with IT to update the IT Disaster Recovery Plan and is in the process of designing a validation exercise.
5. Finally, the recommendation was made to develop an interactive digital risk management platform to capture current building risks and to chart the progress of mitigation. This recommendation will be considered in the context of other information management and IT priorities but is not a priority at this time.

BENEFITS
Learning, Research, Financial, Sustainability & Reputational

The most direct benefit of the updated seismic plan is the ability to better understand and quantify the risks and vulnerabilities associated with the updated seismic events that are likely to strike the Point Grey campus. For the identified high risk buildings, the combination of site-specific ground motions used as a basis of analyis, and a suite of detailed building models capable of study under dynamic load conditions, provides UBC with a clear, detailed and nuanced assessment tool to identify seismic risk and target measures for mitigation.

The detailed evaluation study completed to date represents a remarkable collaboration between high performance consultants expert in the field, and UBC's resident expertise, producing a study that marries international standards of high performance and site-specific, local expertise. The peer reviewed process has ensured a high standard of rigour used in the assessment.

In addition, by engaging in a broader assessment of vulnerabilities associated with seismic resilience, some of the vulnerabilities associated with climate change or other natural hazards will be addressed. Utility vulnerabilities are a clear example where increasing storm intensities and seismic issues can all be addressed at the same time.

RISKS
Financial, Operational & Reputational

The most significant risk to this project is, in fact, the risk of not updating or executing the plan in a timely way. Following best practice would result in a reduced risk of loss of life or serious injury to members of the campus community.

By completing both the multi-hazard assessment and utility assessment, the University will be more holistically addressing strategic risks related to seismic vulerability and interface fires.

Recognizing the financial and logistical constraints of the University, it is necessary to balance the seismic risk detailed in this study with the need to invest capital dollars in other priorities. While life safety will always be recognized as paramount, it is not feasible nor practical to undertake all retrofit work or replacement work at the same time. Clearly, as the plan to execute this work is further developed, the risks associated will be balanced using the three principles identified previously.

COSTS
Capital & Lifecycle
Operating

Costs in next phase of seismic study include:

Completion of guidelines	$ 1.5M
Engineering and planning studies	$ 0.5 M
Resilience planning	$ 0.5 M

The 2018 study has outlined for planning purposes the costs to fully mitigate the highest risk buildings studied in the detailed seismic evaluation. The total in 2018 dollars is approximately $1.0B, or $1.5B when projected out on an implementation timeline to 2040. These are order of magnitude costs that do not include options to expand, change programs or upgrade facilities to house new functions. This is an indicative cost to illustrate the magnitude of the mitigation effort required to address the seimic risk via retrofit, renewal or replacement. This information will need to be incorporated into the capital planning process and reviewed in order to develop funding plans, logistics and consultation required to move to action and implementation.

The work associated with the relocation of the campus water pumps (estimated at $12M) is now carried within the IIC budget.

Further investigation and evaluation will be undertaken to establish budget costs for the other priority recommendations.

FINANCIAL
Funding Sources,
Impact on Liquidity

As costs continue to be outlined and developed relative to strategic directions, avenues for funding and financing will be identified. An approach to government is planned to seek funding in a manner similar to deferred maintenance.

SCHEDULE
Implementation
Timeline

This phase of work was very focussed on the detailed building evaluations, including the site-specific ground motions and other supporting studies required to support this state of the art analysis. Advancing in parallel have been efforts on infrastructure security, risk management and utility infrastructure. The following schedule updates the timeline for the completion of recommended next steps.

Priority Recommendation	Estimated Completion Date
Detailed Evaluation of priority buildings	Complete
Non-Detailed Evaluation of select buildings	September 2019
Non-Structural Hazard Assessment	ongoing
Guidelines for Retrofits & New Bldgs	September 2019
Relocate Water Pumps	2021
Water Supply Option Study	Complete
Diesel Infrastructure Implementation	February 2020
Other Operations Priorities	Some complete; others ongoing

	The next steps also include consideration of funding options within the broader context of the capital planning process. The results of this will be reported on through the capital planning updates to the Board of Governors. Updates on the remaining priority actions will be provided on a regular basis to the Board of Governors.
CONSULTATION Relevant Units, Internal & External Constituencies	The implementation of a Campus resilience plan involves many key stakeholders, academic and organizational units. The work for this investigation is being led by the Seismic Steering Committee. This committee includes representatives from Infrastructure Development, Building Operations, Finance, Energy & Water Services, and Risk Management Services. In addition, the Seismic Steering Committee is working closely with Professor Carlos Ventura and his team in the UBC Earthquake Engineering Research Facility. Project management is being provided by Project Services (Infrastructure Development).

Previous Report Date	April 19, 2018
Decision	Information
Action / Follow Up	Detailed analysis is complete, notional implementation plan is ready for consultation; several action plan priorities have been executed.

Previous Report Date	September 21, 2017
Decision	Information
Action / Follow Up	A series of principles has been developed, the set of recommendations has been evaluated and the execution of the action plan has commenced.

Previous Report Date	April 13, 2017
Decision	Information
Action / Follow Up	Substantial hazard assessment and building evaluation work has been undertaken to inform the seismic mitigation plan update.

Previous Report Date	June 14, 2016
Decision	Information
Action / Follow Up	Project team has undertaken work to update the seismic mitigation plan.

University of British Columbia, Vancouver

Detailed Seismic Evaluation of Buildings

Executive Summary

Issue 2 | January 9, 2019

Job number

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1 Background

The University of British Columbia, Vancouver (UBC) recently commissioned Arup to refresh the seismic risk assessment of campus (link). This included an evaluation of buildings on campus, based upon a "screening-level" assessment that was intended to identify the buildings most vulnerable to collapse with a reasonable level of confidence. These buildings were assigned a Tier IV Structural Vulnerability ranking, having a higher than 50% probability of collapse in 2,475 year earthquake shaking. The quantification of collapse probability was reliant upon engineering demand parameters determined by the simplified analytical method outlined in the Seismic Retrofit Guidelines (SRG-3) for British Columbia Low-Rise School Buildings. These guidelines were established by the Ministry of Education with support from the UBC Civil Engineering Department. The buildings were ultimately assigned prioritization rankings based upon three different mitigation strategies that captured the cost-benefit of retrofitting, renewing, or replacing a particular building. For example, a building in which low-cost retrofit solutions could significantly reduce the risk of casualties would have a "Very High" prioritization ranking.

Arup recommended that further detailed structural evaluation be undertaken for a subset of the highest-ranked buildings identified by UBC as candidates for potential retrofit, since the "screening-level" assessment carried some uncertainty. The purpose of this more refined analysis is to quantify the collapse vulnerability of these buildings with more confidence based upon state-of-the-art computer simulation. The collapse vulnerability results, along with Arup's opinion on potential retrofit options and UBC's evaluation of potential costs (and other factors), would help prioritize and re-rank the order in which the buildings may be retrofitted, renewed, replaced, or left alone.

2 Scope of work

For each of the buildings, a detailed 3D computer model was developed to undertake a nonlinear response history analysis. This analysis method, relative to all others, is recognized to best predict the probability of collapse, given the inherent uncertainties and complexities involved in buildings pushed to the point of incipient collapse.

2.1 Seismic hazard

The original intent of the study was to undertake the structural analysis for earthquakes representing the 2,475 year shaking hazard, since modern building codes have defined "collapse prevention" targets for that level of shaking and because Arup's structural vulnerability tiers were anchored to that level of shaking. However, the first simulations in this study indicated that the buildings were more vulnerable than the SRG-3 results indicated, with collapse exhibited in all eleven simulated ground motions at the 2,475 year shaking level for several buildings. Without previous knowledge of the collapse probability for the remainder of the buildings, and in order to avoid a situation where most (or all) of the buildings exhibited collapse in all of the ground motions thereby preventing prioritization, the seismic hazard level was lowered to 975 year shaking. The 975 year shaking intensity is roughly 70% of the 2,475 year shaking intensity.

The revised hazard level (975 years) has precedence for *existing* buildings that are potential candidates for retrofit. The “Seismic Evaluation and Retrofit of Existing Buildings” guidelines (ASCE 41) are used as the basis of assessment for buildings in the United States and it has been adopted as international best practice. The “Basic Performance Objectives for Existing Buildings” defined in ASCE 41 includes “collapse prevention” at 975 year shaking. In general, the 975 year shaking level was intended by ASCE to represent 75% of the shaking that new buildings are designed for, which was deemed an acceptable target for existing buildings.

Eleven ground motions simulating realistic earthquake scenarios representing the 975 year shaking level were provided by VC Dynamics Ltd., a local seismic consulting firm.

2.2 Structural analysis

The eleven ground motions were used as input to 3D computer models of each building to simulate the effects of earthquake shaking. The analysis can explicitly capture the deformation and damage in each building component, ultimately leading to progressive collapse of the building if the seismic loads cannot re-distribute to other components. The outcome of each ground motion simulation is either deemed non-collapse, partial collapse (where only a portion of the building collapses), or full collapse (where the entire building collapses). Buildings that exhibit full collapse in the most ground motions are the most vulnerable, in general.

In addition, since the detailed analysis relies upon detailed 3D computer models that represent the actual building components, the critical structural vulnerabilities leading to collapse can be identified. This provides significantly more insight into potential retrofit strategies than the “screening-level” study. Other imminent risks – specific components that may fail under lower shaking levels – can also be identified and prioritized. Further information regarding the mitigation measures is presented in section 2.3.

2.2.1 Additional rigor

The detailed structural analyses underpinning this study are based on a number of assumptions. The following sections outline additional items that were undertaken during the course of the project to increase the confidence in the findings.

Concrete strength testing

In order to increase the confidence in the material parameters utilized for the detailed structural analysis, a number of destructive concrete core tests were conducted to measure the existing concrete compressive strength for each building. The concrete core tests result in more reliable numerical modeling as the specified concrete strength on the structural drawings is not necessarily reliable. The concrete strength is one of the most important properties for assessing the collapse potential of a building. In general, three samples in each building were taken. Where buildings were comprised of multiple additions from different construction eras, an additional three samples were taken.

Slope stability study

As part of this study, Arup recommended additional geotechnical investigation of the area adjacent to the cliffs near the Museum of Anthropology (MOA) to determine if earthquake shaking may initiate slope stability concerns and thus undermine the building foundation. Other adjacent buildings that could be impacted include Lower Mall Research Station and the Anthropology and Sociology (ANSO) building.

UBC commissioned EXP Services Inc. to undertake the analysis. Their study concluded that the displacement from slope instability due to earthquake shaking near the MOA was “negligible” and thus no further study of the other buildings were required since they were further from the edge of the cliff. However, they highly recommend “regular monitoring and maintenance” to prevent further erosion.

Seismic peer review

The Basis of Assessment and analysis approach and findings were subject to an independent peer review comprising UBC professors and local practitioners. The peer review panel included:

- Carlos Ventura (Professor of Engineering, Director of Earthquake Engineering Research Facility, UBC)
- Tony Yang (Associate Professor of Engineering, UBC)
- Armin Bebam-Zadeh (Research Associate, UBC)
- Ilana Danzig (Associate Engineer, Equilibrium Consulting)
- Anthony El-Araj (Principal, Glotman Simpson Consulting Engineers).

The peer review panel and consultant team iterated on the Basis of Assessment document based on feedback provided by the panel. An in-person meeting was held at UBC in November to review building analysis models and to resolve outstanding comments.

2.3 Updated cost-benefit methodology

An updated cost-benefit analysis was conducted to re-prioritize the buildings based on the new collapse risk estimates at the 975 year return period earthquake. This was based on the Strategy #1 and Strategy #2 methodology described in the previously published Seismic Risk Assessment and Recommended Resilience Strategy (Appendix G). In this study, only losses due to building collapse-driven fatalities were examined in this study, as the focus was on life-safety risk.

In overview, the cost-benefit methodology implemented in this study uses the updated collapse probabilities and extent of collapse (e.g. fully collapsed or partially collapsed) to calculate the average fatalities anticipated in each structure due to collapse. These values are compared with the average fatalities anticipated in each structure due to collapse if the building were to be renewed or fully replaced. The reduction in expected losses (i.e. average annual fatalities) are assessed in conjunction with the cost of renewal or replacement and the associated asset life extension to prioritize mitigation action (e.g. renewal) and evaluate cost to achieve certain improvements (i.e. cost to mitigate a fatality).

The renewal and replacement costs for each building were provided by UBC. We understand that the renewal costs were influenced by Arup's opinion on seismic retrofit options. As a rule of thumb, buildings should be replaced if the renewal cost exceeds 82% of the replacement cost. This is based on the cost-benefit analysis.

Table 1: Assumed asset life extensions and cost thresholds for cost-benefit analysis

Option	Asset life extension	Cost threshold*
Renewal	40 years	82% of replacement
Replacement	75 years	n/a

**Percent cost at which the specified option is more beneficial than an alternative option*

3 Findings of the study

The following sections outline a summary of the main findings of this study and the basis for the recommendations provided. Arup has developed comprehensive reports for each building that provide more description of the building, seismic deficiencies, analysis assumptions, building performance under earthquake shaking, and recommended mitigation measures. UBC is utilizing this information and integrating it with other factors to develop a capital investment plan.

3.1 Structural collapse vulnerability tiers

The previous study assigned structural vulnerability tiers based on the probability of collapse at 2,475 years. We developed additional collapse probability thresholds for 975 year shaking to facilitate the mapping of the buildings based on the results of the detailed analysis results, adjusted based on material variability. A new tier has been added to the collapse vulnerability tiers for buildings deemed "exceptionally" high risk, corresponding to median probability of collapse more than 70% at 975 year ground motion shaking.

Table 2: Collapse vulnerability tier definitions

	Probability of collapse	
Tier	**2,475 year**	**975 year**
I	0-10%	0-5%
II	11-19%	6-10%
III	20-49%	11-30%
IV	50%+	30-70%
V	n/a	70%+

Table 3: Structural collapse vulnerability tiers before and after detailed evaluation

ID	Building name	Previous Tier	Updated Tier
022	LOWER MALL RESEARCH STATION	III	V
048	ANTHROPOLOGY AND SOCIOLOGY BUILDING	IV	V
148	CHEMISTRY B BLOCK, SOUTH WING	IV	V
198	J. B. MACDONALD BUILDING	III	III
306	CIVIL AND MECHANICAL ENGINEERING BUILDING	IV	V
308	THE LEONARD S. KLINCK BUILDING	IV	IV
312	MACLEOD BUILDING	IV	IV
386	H. R. MACMILLAN BUILDING	IV	V
430	ROBERT F. OSBORNE CENTRE - UNIT 1	IV	III
431	ROBERT F. OSBORNE CENTRE - UNIT 2	IV	V
447	CHEMISTRY A BLOCK, CHEMISTRY PHYSICS BUILDING	III	V
523-3	MEDICAL SCIENCES BLOCK C	IV	V
536	WOODWARD BIOMEDICAL LIBRARY	III	V
562	FRANK FORWARD BUILDING	III	V

570	MUSEUM OF ANTHROPOLOGY	IV	IV
575	MUSIC BUILDING	IV	V
732	DOUGLAS KENNY BUILDING	III	V
750	JACK BELL BUILDING FOR THE SCHOOL OF SOCIAL WORK	IV	III

3.2 Recommended mitigation strategies

The following potential mitigation strategies were considered in the cost-benefit analysis:

- **Strategy 1:** Prioritize mitigation measures for buildings that have the largest fatality risk (i.e. largest average annual fatalities).
- **Strategy 2:** Prioritize mitigation measures for buildings that result in the largest mitigation of fatalities for the least cost

Each building was ranked accordingly for each strategy. These rankings can be visualized in Figure 1 and Figure 2, where a higher rank indicates higher priority for mitigation. While the buildings were ranked #1 through #18, the figures are useful in indicating the relative differences in the rankings. For example, Douglas Kenny is ranked #13 while Chemistry Block B is ranked #14 but Figure 2 indicates the large gulf in the cost to mitigate a fatality in each of the buildings. This suggests that while ranked similarly, Chemistry Block B is a much lesser priority than Kenny. Figure 2 also indicates whether the renewal or replacement option is most beneficial from a cost-benefit point of view.

A summary of all relevant values is shown in Table 6.

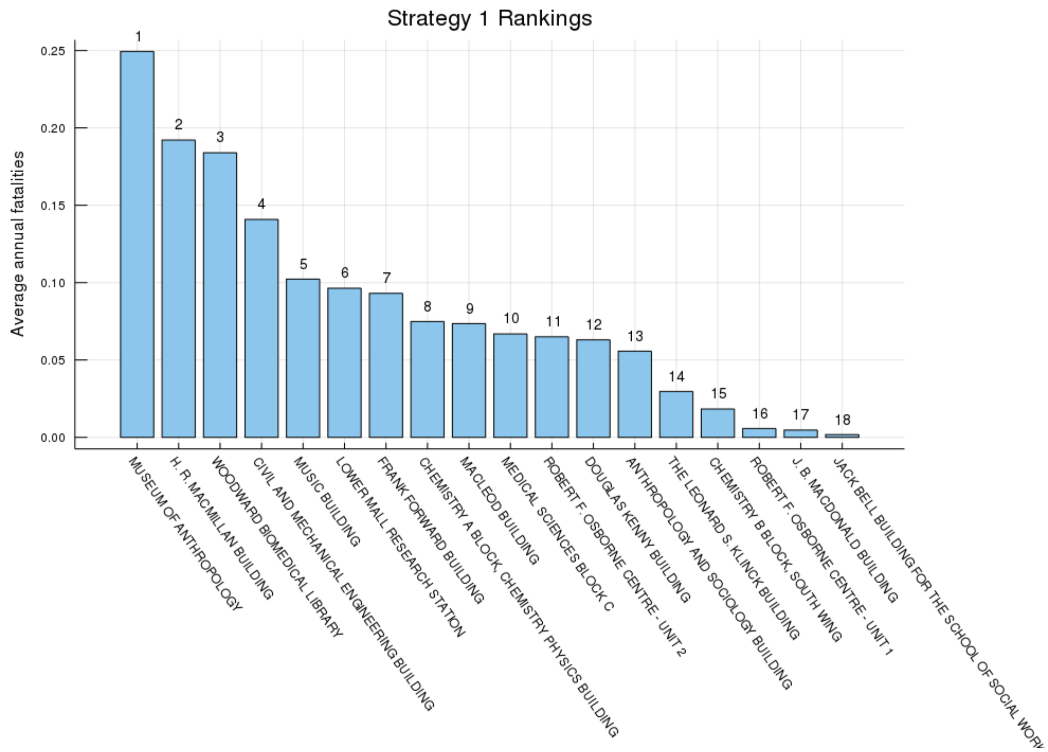


Figure 1: Rankings for mitigation based on Strategy 1 (highest fatality risk)

Table 4: Rankings for Strategy 1 (highest fatality risk)

ID	Building name	Strategy 1 Rank
570	MUSEUM OF ANTHROPOLOGY	1
386	H. R. MACMILLAN BUILDING	2
536	WOODWARD BIOMEDICAL LIBRARY	3
306	CIVIL AND MECHANICAL ENGINEERING BUILDING	4
575	MUSIC BUILDING	5
022	LOWER MALL RESEARCH STATION	6
562	FRANK FORWARD BUILDING	7
447	CHEMISTRY A BLOCK, CHEMISTRY PHYSICS BUILDING	8
312	MACLEOD BUILDING	9
523-3	MEDICAL SCIENCES BLOCK C	10
431	ROBERT F. OSBORNE CENTRE - UNIT 2	11
732	DOUGLAS KENNY BUILDING	12
048	ANTHROPOLOGY AND SOCIOLOGY BUILDING	13
308	THE LEONARD S. KLINCK BUILDING	14
148	CHEMISTRY B BLOCK, SOUTH WING	15
430	ROBERT F. OSBORNE CENTRE - UNIT 1	16
198	J. B. MACDONALD BUILDING	17
750	JACK BELL BUILDING	18

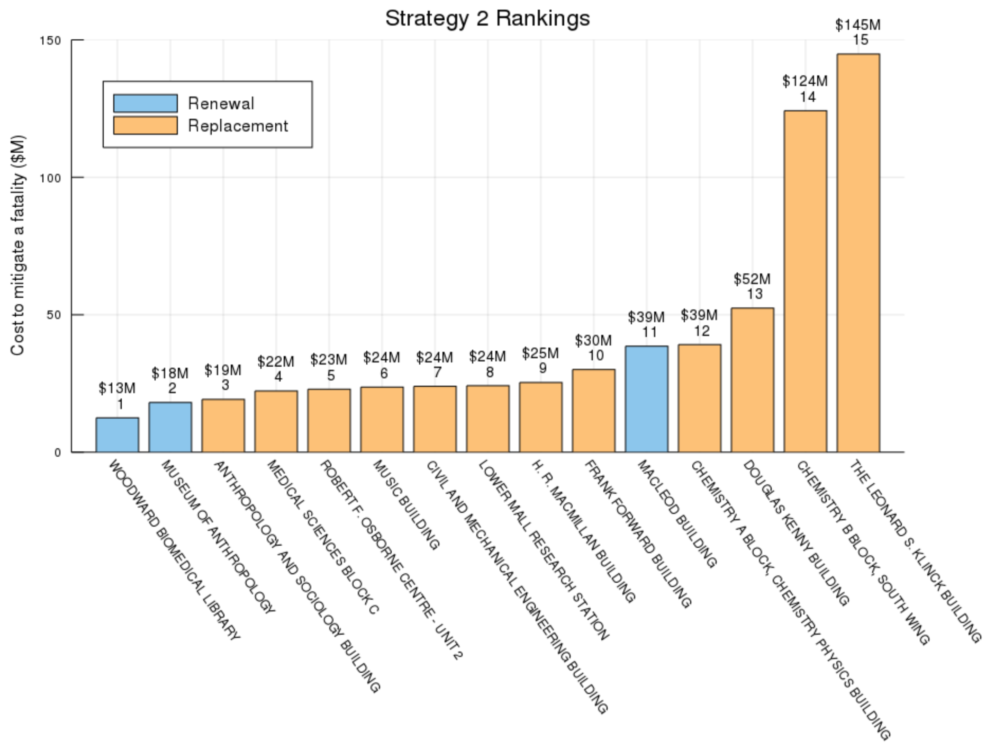


Figure 2: Rankings for mitigation based on Strategy 2 [Tier III removed for clarity]

Table 5: Rankings for Strategy 2 (lowest cost to mitigate a fatality)

ID	Building name	Strategy 2 Rank
536	WOODWARD BIOMEDICAL LIBRARY	1
570	MUSEUM OF ANTHROPOLOGY	2
048	ANTHROPOLOGY AND SOCIOLOGY BUILDING	3
523-3	MEDICAL SCIENCES BLOCK C	4
431	ROBERT F. OSBORNE CENTRE - UNIT 2	5
575	MUSIC BUILDING	6
306	CIVIL AND MECHANICAL ENGINEERING BUILDING	7
022	LOWER MALL RESEARCH STATION	8
386	H. R. MACMILLAN BUILDING	9
562	FRANK FORWARD BUILDING	10
312	MACLEOD BUILDING	11
447	CHEMISTRY A BLOCK, CHEMISTRY PHYSICS BUILDING	12
732	DOUGLAS KENNY BUILDING	13
148	CHEMISTRY B BLOCK, SOUTH WING	14
308	THE LEONARD S. KLINCK BUILDING	15
430	ROBERT F. OSBORNE CENTRE - UNIT 1	16
750	JACK BELL BUILDING	17
198	J. B. MACDONALD BUILDING	18

Figure 3 provides the reduction in fatalities vs cost expenditure for each of the strategies developed. This indicates that while Strategy #2 is more optimal, the difference between the two is fairly small. Therefore, mitigating based on the prioritization of either strategy appears to be reasonable.

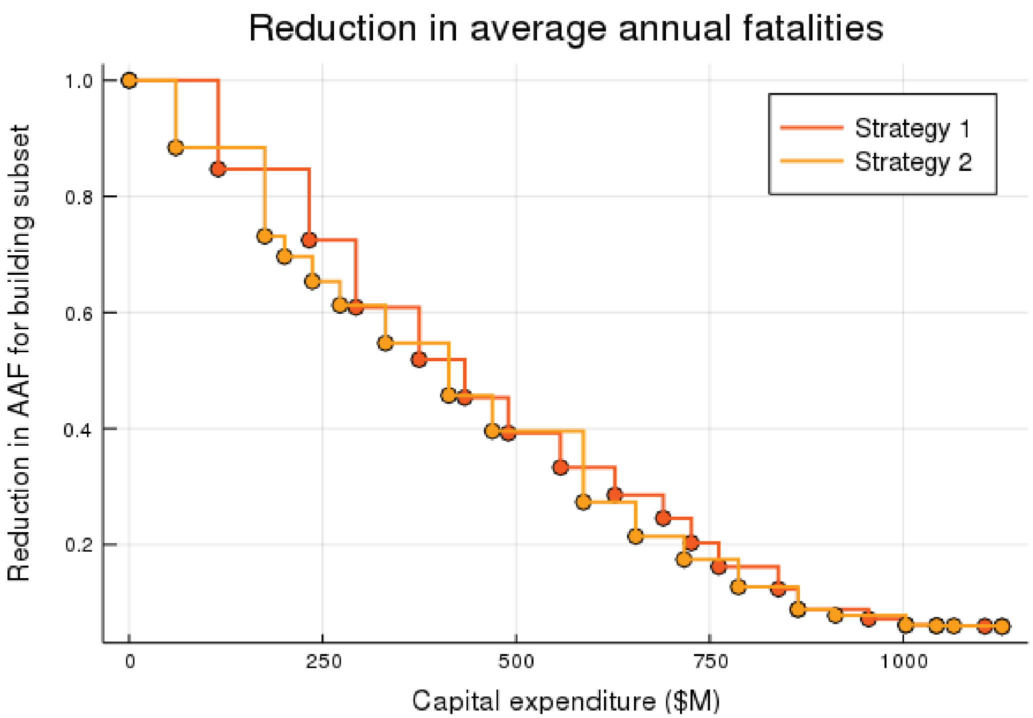


Figure 3: Reduction in average annual fatalities versus capital expenditure for each strategy

Table 6 provides a summary of the building populations, assumed renewal and replacement costs (provided by UBC), the annualized fatalities estimated from the detailed structural analysis, and the findings and prioritization order from the cost-benefit analysis. The equivalent continuous occupancy (ECO) is essentially a measure of the building's average population and is developed based on a building's peak population and its occupancy type. For example, an assembly occupancy may have a very high peak population (during events) but is otherwise not highly utilized so the ECO population is much lower. The reason to use the ECO population is that the time of the earthquake occurrence is random and given that the annualized fatality analysis is based upon hundreds of earthquake simulations of varying return periods, it is unlikely that each of those earthquakes would coincide with peak occupancy.

Table 6: Summary of cost-benefit analysis results for each building

ID	Building name	Equivalent continuous occupancy (ECO)	Renewal cost ($M)	Replacement cost ($M)	Average annual fatalities	Cost to mitigate a fatality ($M)	Strategy 1 Ranking	Strategy 2 Ranking
022	LOWER MALL RESEARCH STATION	69	48	56	0.096	24	6	8
048	ANTHROPOLOGY AND SOCIOLOGY BUILDING	60	24	25	0.056	19	13	3
148	CHEMISTRY B BLOCK, SOUTH WING	60	41	48	0.018	124	15	14
198	J. B. MACDONALD BUILDING	70	50	62	0.005	1592	17	18
306	CIVIL AND MECHANICAL ENGINEERING BUILDING	93	78	82	0.141	24	4	7
308	THE LEONARD S. KLINCK BUILDING	99	87	91	0.030	145	14	15
312	MACLEOD BUILDING	285	48	62	0.074	39	9	11
386	H. R. MACMILLAN BUILDING	139	118	118	0.192	25	2	9
430	ROBERT F. OSBORNE CENTRE - UNIT 1	85	30	40	0.006	776	16	16
431	ROBERT F. OSBORNE CENTRE - UNIT 2	63	32	36	0.065	23	11	5
447	CHEMISTRY A BLOCK, CHEMISTRY PHYSICS BUILDING	66	67	70	0.075	39	8	12

523-3	MEDICAL SCIENCES BLOCK C	42	34	36	0.067	22	10	4
536	WOODWARD BIOMEDICAL LIBRARY	177	45	60	0.184	13	3	1
562	FRANK FORWARD BUILDING	73	64	67	0.093	30	7	10
570	MUSEUM OF ANTHROPOLOGY	389	86	115	0.249	18	1	2
575	MUSIC BUILDING	64	53	59	0.102	24	5	6
732	DOUGLAS KENNY BUILDING	94	65	77	0.063	52	12	13
750	JACK BELL BUILDING FOR THE SCHOOL OF SOCIAL WORK	26	17	22	0.002	1413	18	17

3.3 Recommended retrofit strategies

The results from the detailed collapse study can be used to conceptualize the retrofit strategy for each building. In reference to Table 7, the following mitigation measures are outlined:

Near-term actions:

- During the course of this study, a few components that could potentially fail at much lower shaking levels (relative to 975 years return period shaking) were identified. These were deemed as “imminent risks” since relatively low levels of ground shaking (associated with more frequent return periods) could potentially cause failure. Retrofitting these components can significantly reduce the seismic risk associated with their failure. These imminent risk components are listed in detail in each building analysis report. For example, there is a long cantilever slab in the second floor of the west wing of the Macmillan building that shows failure at very early stage of nonlinear time history analysis (low shaking level). This failure could not be captured using simplified analysis in previous phase and the retrofit of this deficiency can reduce the life safety risk not only at the rare shaking level but also at lower shaking level such as 100 year return period.

- For some buildings, insufficient information was available from the structural drawings (or visual observation) to characterize some key components or connections in detail. These items, along with corresponding modeling assumptions, are listed in each building report. The actual details should be confirmed prior to determining a final conclusion on the building performance and associated mitigation strategy. The table below highlights these items.

Candidates for targeted retrofit:

- In some cases the analysis findings suggested that a targeted retrofit could be implemented to address a single type of vulnerability which could substantially reduce the collapse risk (and thus life safety risk). These buildings are identified in the table. It is unlikely that the targeted retrofit alone would satisfy comprehensive seismic retrofit standards (e.g. as outlined in the ASCE 41 guidelines from the United States) that intend to demonstrate equivalence (or a portion thereof) to the building code collapse risk acceptability targets, but these represent a potentially cost-effective strategy for mitigating a sizeable proportion of the risk.

Candidates for comprehensive retrofit:

- Once comprehensive retrofit is pursued for a building, it is likely to be inherently invasive due to the widespread deficiencies in older concrete buildings. From a structural engineering perspective, almost anything is achievable to bring a building up to a life-safety standard but the decision comes down to other impacts such as cost, architecture, and functionality. We have provided our opinion on the feasibility of comprehensive retrofits in the table below.

The retrofit strategies provided are based on judgment and represents Arup's opinion only. A retrofit design was not completed. Some deficiencies, particularly associated with the diaphragm chords and collectors may not have been identified. In addition, Canada has no standard retrofit code or guideline that provides performance objectives or retrofit design procedures, which could significantly alter the retrofit schemes provided by Arup. As part of the campus resilience strategy, Arup recommended that UBC develop retrofit guidelines to help guide its mitigation strategy.

Nonetheless, the retrofit options can be utilized by UBC to provide high-level cost estimates to aid in their decision-making and jumping off points for seismic retrofit consultants. In fact, the description of the comprehensive retrofit approach provided by Arup was utilized by UBC to influence the renewal costs for each building which were used in the cost-benefit analysis.

Table 7: Summary of findings from detailed nonlinear time history analysis

ID	Building	Probability of Collapse in 975 year shaking	Key Findings	Recommended Near Term Actions[1]	Potential Candidate for Targeted Retrofit[2]?	Opinion on Comprehensive Retrofit[3]
022	Lower Mall Research	Laboratory wing: 79%-97% Office wing: 4% - 21%	Laboratory wing: • Deep spandrel and extremely short columns result in a very brittle moment frame system • Extreme torsional irregularity due to expansion joint Office wing: • Performs well due to its relatively low inertial mass and the high density of lateral elements	• Check the heavy masonry/brick facades connection and remove or secure if necessary	No. Multiple major deficiencies in this building requires comprehensive retrofit to increase the safety of building.	Laboratory wing: Very costly and intrusive as it requires adding new lateral system and retrofit of the existing system in several locations and levels. Office wing: Comprehensive retrofit may not be a priority but could be accomplished with less impact.
048	Anthropology & Sociology	79%-97%	• Almost complete lack of lateral resistance in one direction of the second story • There is no connection between the roof slabs that currently act as three separate diaphragms • May be considered one of the more highly vulnerable buildings in this study		No. Multiple major deficiencies in this building requires comprehensive retrofit to increase the safety of building.	Very costly and intrusive as it requires adding a new lateral system in one direction and retrofitting the connections between existing beams and columns as well as addition of diaphragm.
148	Chemistry B Block	67%-84%	• Full collapse was observed 70% of the time; otherwise the collapse is partial in nature • The most critical deficiency in the structure is the deep long-span beams above the lecture theatres, which are supported by weaker columns	• Add lateral system for penthouse structure. • More detailed assessment of the connecting link.	Yes. Retrofit the columns supporting long span beams or add internal columns to support the beams.	Very costly and intrusive. Besides the new support for the long span beam a new lateral system in one direction may be required as well as retrofitting the connection between existing beams and columns in a few locations.

198	J B MacDonald	4% - 21%	• Significant damage in earthquake shaking but it does not appear to lead to progressive collapse. • The lateral system is well-distributed and columns are frequently spaced. • Concrete walls are thicker and better reinforced than other buildings in this study.	• Check the heavy precast concrete façade connections, and the internal masonry partitions, and remove or secure if necessary • Unknown diaphragm to wall connection should be confirmed	No. Multiple major deficiencies in this building requires comprehensive retrofit to increase the safety of building.	Comprehensive retrofit may not be a priority, pending further inspection of the diaphragm to wall connection. Could likely be accomplished with little impact.
306	Civil & Mechanical Engineering Building	79%-97%	• Irregular wall layout, which induces significant torsional demands on the walls • Precast pre-stressed T-beams, acting as the gravity system, do not appear to contain mild steel reinforcement, this can result in a brittle and abrupt failure of these elements.	• Secure the bridge connections to the building • More detailed assessment on the gangway connecting CEME Building to the CEME Labs Building • Check the heavy precast concrete façade connections and remove or secure if necessary	No. Multiple major deficiencies in this building requires comprehensive retrofit to increase the safety of building.	Very costly and intrusive as it requires adding new lateral system in both directions at multiple locations (wings) and levels and also retrofitting the existing precast floor joists which support the higher floor columns. One of the more challenging buildings to retrofit, particularly due to lack of reinforcement in gravity beams.
308	The Leonard S. Klinck	40%-56%	• The most significant vulnerabilities appear to be the corner shear walls, which exhibited failure that led to partial collapse in some of the analyses • Global collapse was observed in one simulated ground motion due to damage to the corner shear walls • Insufficient flexural deformation capacity of interior columns and several perimeter columns, overly-reinforced sections • Thin shear walls with single middle layer of reinforcement. This results in inadequate in-plane strength and low out-of-plane shear strength • The building appears to be vulnerable to long duration subduction-type earthquakes which induce many cycles of demand.	• More detailed assessment of the clay blocks between the concrete floor joists (protentional falling hazard)	Yes. Targeted retrofit of the corner walls can improve the performance of this building significantly. The clay blocks between the concrete floor joists might need some work pending on further detailed investigation.	It may require strengthening of the existing shear walls and also retrofitting the existing concrete columns to increase ductility.
312	Macleod	40%-56%	• The collapse is partial in nature and confined to the south corner of the building. • The building has generally high strength due to the length and number of concrete walls. • One critical deficiency is a wall that is offset between floors, causing a significant discontinuity in the load path.	• Confirm if bridges have adequate bearing support, and retrofit if required	Yes. Targeted retrofit of the south corner. This would include strengthening walls at the south and addressing non-continuous shear walls from second floor.	Comprehensive retrofit may not be a priority but may include strengthening of walls in other locations of the building.

386	Macmillan	79%-97%	• Highly vulnerable building with multiple severe deficiencies. • Lack of proper distribution of shear walls in each independent wing, with generally stiff walls on one side and flexible frames on the opposite, causing severe torsional issues. • Low lateral strength and ductility, due to low shear capacity of the shear-controlled spandrels among other deficiencies	• Mitigate the failure of the long span cantilever slab on the second floor of the west wing. • Remove or secure heavy interior partition walls • Check the heavy perimeter wall connections and remove or secure if necessary	No. Multiple major deficiencies in this building requires comprehensive retrofit to increase the safety of building.	Very costly and intrusive as it requires adding new lateral system in both directions and retrofitting the connection between existing deep spandrels and columns. One of the more challenging building to retrofit.
430	Osborne Unit 1	4%-21%	• Some of the major seismic deficiencies of the original structure were mitigated in an extensive seismic retrofit conducted in 1986 • The chief concern is the connection between the deep precast T-beams that form the gymnasiums' roof diaphragms and the building's shear walls. This connection is vulnerable and exhibited failure in our analysis.	• Verify internal steel reinforcement in precast T-beams	Yes. Surgical retrofit to a single connection type, easily accessed from the perimeter. Likely to be low-cost and non-invasive. Would greatly increase confidence in predicted collapse probability.	Comprehensive retrofit may not be a priority, pending further inspection of the diaphragm to wall connection. Retrofit of other areas may be accomplished with little impact.
431	Osborne Unit 2	79%-97%	• No direct connection between tilt up precast concrete walls and roof diaphragm. • Flexible roof diaphragm with heavy concrete walls.		No. Multiple major deficiencies in this building requires comprehensive retrofit to increase the safety of building.	Costly and intrusive as it requires adding new lateral system in couple of locations, strengthening the roof diaphragm, adding connection between roof diaphragm and precast panels.
447	Chemistry A Block	79%-97%	• The collapses observed were all of a partial nature. • Collapse was largely caused by the poor connection of the floor slabs to the exhaust shafts		Yes. Retrofit the floor slab to exhaust connection and/or provide supporting columns to the floors at this location.	Costly and intrusive as it requires adding new lateral system in one direction and retrofitting the connection between slab and exhaust shaft walls.
523-3	Medical & Science Block C	79%-97%	• Due to limited wall contribution in lateral system, very flexible and large lateral displacements are anticipated to occur under ground shaking • Brittle concrete columns due to overly reinforced section and no confinement are particularly susceptible due to large imposed displacements.	• Add lateral system for penthouse structure.	No. Multiple major deficiencies in this building requires comprehensive retrofit to increase the safety of building.	Very costly and intrusive as it requires adding new lateral system in both directions and retrofitting the existing over-reinforced concrete columns to increase ductility.
536	Woodward Library	67%-84%	• Relatively high strength but very low ductility due to overly high reinforcing ratio in the gravity columns, which support a flat slab floor system. • Columns exhibit failure at relatively low drift ratios	• Check the heavy perimeter wall connections and remove or secure if necessary.	No. Multiple major deficiencies in this building requires comprehensive	Very costly and intrusive as it requires adding new lateral system in both directions and retrofitting the

					retrofit to increase the safety of building.	existing over-reinforced concrete columns to increase ductility.
562	Frank Forward	79%-97%	• Highly vulnerable building with multiple severe deficiencies • Extremely low shear strength and ductility in the moment frame direction of each wing. • Deep spandrel and short column results in a very brittle moment frame system.	• Secure or remove the heavy concrete/masonry penthouse • Secure the entrance canopy • Structural observation to confirm whether cracking has occurred in some walls	No. Multiple major deficiencies in this building requires comprehensive retrofit to increase the safety of building.	Very costly and intrusive as it requires adding a new lateral system in one direction at multiple locations and levels and retrofitting the existing shear walls in the other direction. Due to irregular configuration could be one of the more challenging buildings to retrofit.
570	Museum of Anthropology	79%-97% Display area 44%-60% Office area	• The display area is the most vulnerable area and may potentially be deemed an imminent risk. • Some areas which were retrofit in 2009 also appear to be vulnerable due to some unaddressed deficiencies.	• Secure the display area glazing	No. Multiple major deficiencies in this building requires comprehensive retrofit to increase the safety of building.	Very costly and intrusive as it has a very complex geometry and adding new lateral system and retrofitting the deficiencies would be very challenging. Innovative approaches such as base isolation is likely the best option for the display area.
575	Music Building	54%-70%	• The collapse is confined to the upper story. • The entire upper portion of the building overhangs the bottom portion, causing vertical discontinuities • The connectivity between the steel upper portion and the concrete structure below is not robust	• Check the heavy perimeter wall connection and remove or secure if necessary • Retrofit the precast concrete columns at the covered terrace walk-way		Very costly and intrusive as it requires adding new lateral system in both directions for the upper portion of the building and addressing the offset between the upper and lower floor. May be able to salvage the lower flower if removing the top floor as it does not require significant retrofit.
732	Douglas Kenny	79%-97%	• Deep spandrel and extremely short columns result in a very brittle moment frame system that could be susceptible to failure in lower levels of ground shaking. • Wall locations create significant torsional irregularities and imposes additional drift demands on the perimeter frames.	• Check the heavy perimeter wall connection and remove or secure if necessary • Secure the atrium glass canopy	No. Multiple major deficiencies in this building requires comprehensive retrofit to increase the safety of building.	Very costly and intrusive as it requires adding new lateral system and retrofitting the existing shear walls at multiple locations and levels and retrofitting the existing deep spandrel to wall and column connections.

750	Jack Bell	4%-21%	• Pre Northridge moment frame connection in one direction. • The quality of the bolted flange plate connection between the MRFs columns and the beams has a significant effect on the global stability of building and should be checked on site.	• Perform a detailed inspection and appraisal of the quality of the MRF connections and panel zones.	• Pending on the MRF connection inspection, local targeted MRF connection retrofit might be required.	Comprehensive retrofit may not be a priority, pending further inspection of the MRF connection.

[1] Some components, identified through the analysis, may fail in much lower shaking levels. These were deemed “imminent risks”.

[2] Retrofits targeting specific portions or connection types in the building could substantially reduce the collapse risk

[3] The opinions provided on retrofit strategies and complexity is based on Arup’s judgment

4 Conclusions and Next Steps

The information from the detailed seismic analysis, in conjunction with cost estimates provided by UBC (based on Arup's retrofit strategies), was used to re-prioritize building mitigations (see section 3.2). The sophisticated analysis models have played a significant role in resilience planning as the outcomes have ultimately influenced the order in which buildings are renewed or replaced. In addition, the detailed analysis has shifted some buildings out of the highest vulnerability tiers, indicating that they may not be a priority for mitigation. This allows UBC to consolidate their resources with more confidence in those buildings deserving the most attention to address the highest seismic risks. The information from this study is being used to facilitate an exercise for capital investment prioritization.

The results of the detailed structural analysis are currently being utilized for the following purposes:

- To determine high level cost estimates for the identified retrofit strategies
- As jumping off points for structural consultants hired to determine retrofit design strategies
- To confirm approach for retrofit designs already underway

The detailed analysis models can play a significant role in future studies as well. As detailed retrofit design is pursued, the existing computer models generated in this study can be further utilized to test the various retrofit measures and to re-assess the probability of collapse. This can be used to explicitly confirm that retrofit performance objectives are satisfied as well as optimize the retrofit design from a cost and efficiency point of view. They could be utilized to compare, for example, the cost benefit of various discrete measures in reducing life safety for an individual building. In this manner, the best investment can be identified.

ATTACHMENT 2.

UBC Seismic Planning: Detailed Analysis of Priority Buildings

Priority buildings:

	Building Type	Bldg #	# Storeys	Area [m2]	FCI index	Age [Year]	Structural Vulnerability Tier [2017 study]	Collapse Risk % - 2475 yr return [2017 Study]	Probability of Collapse Tier - 975 yr Return [2018 Detailed Analysis]	Probability of Collapse % - 975 yr Return [2018 Detailed Analysis]	Strategy 2 Rank [2018 Analysis]	Candidate for Seismic Retrofit [Y/N]	Renewal feasible [Swing Space available] [Y/N]	Concept retrofit completed [Y/N]	Candidate for Near term measures for Risk mitigation [Y/N]	Est. Targetted retrofit cost [$M]	Est. Full renewal Cost [$M]	Est. Replacement Cost [$M]	Near Term Risk Mitigation Strategies to consider	Notes
Woodward Biomedical Library	Library	*536*	3	7,777	0.59	1964	III	20%-49%	V	70%+	1	Y	N	Y		$42	$45	$60		Vulnerability in column strength, lateral system and n shear. Brick veneer presents additional safety concern.
Museum of Anthropology	Museum / Office	*570*	2	11,487	0.46	1975	IV	50%-99%	IV	30-70%	2	Y	N	Y		$24	$86	$115	Great Hall mitigation design underway.	Replacement value for planning purposes only. Slope stability issues require further investigation.
Anthropology & Sociology	Academic / Office	*48*	2	3,282	0.48	1974	IV	50%-99%	V	70%+	3	Y	N		Y	$22	$24	$25	Address roof diaphragm issues and lateral strength capacity.	Wings B and C highly vulnerable to collapse. Lateral strength weakness very high, connections of roofs minimal. Mitigation would need to address adjacent ANSO buildings. Modelling includes assumtions about soil stability and foundation response.
Medical Science Block C	Lab / Office	*523-3*	4	4,017	0.69	1961	IV	50%-99%	V	70%+	4	N	Y	Y	Y		$34	$36	Penthouse collapse imminent risk at lower levels of shaking. Out of plane frame elements may require bracing.	Very high vulnerability, one of highest probability of collapse. Costly and invasive to retrofit.
Robert F. Osborne Center Unit 2	Gymnasium	*431*	2	4,589	0.61	1971	IV	50%-99%	V	70%+	5		N				$32	$36	Possible to consider reducing life risk but near term measures will not address need for comprehensive retrofit of lateral system.	Costly and invasive to achieve comprehensive retrofit. New lateral system required
Music	Offices,Halls, Practice rooms	*575*	4 + PH	6,919	0.64	1967	IV	50%-99%	V	70%+	6	N	N				$53	$59	Primary risk of collapse is in upper storeys.	New lateral system required. Weaknesses in shear, frameand column strength. Costly and invasive. Hazmat issues will significiantly complicate renewal or retrofit .
Civil & Mechanical Eng	Academic / Lab / Library	*306*	2 + PH	9,619	0.61	1974	IV	50%-99%	V	70%+	7	Y	N		Y		$78	$82	Near term measures would not address multiple major deficiencies of overall hazrd.	Difficult costly and invasive to retrofit. Precast floor joists and gravity beams represent collapse risk that is difficult to remediate. Possible to address wings in lateral stiffness.
Lower Mall Research Station	Lab / Office	*22*	3	6,629	0.58	1957	III	20%-49%	V	70%+	8	Y	Y	Y	Y		$48	$56	Non-structural masonry and glass could mitigate falling hazards. Unreinforced masonry and asymmetry present significant short term risks.	Lab wing 95% vulnerable - Office wing far less vulnerable at 5% collapse. New shear and frame ductility required. Non structural risk high. Retrofit possible but unlikely to be considered best use of site on campus.
H. R. MacMilllan	Lab / Office / Lecture	*386*	4	13,846	0.62	1967	IV	50%-99%	V	70%+	9	N	Y*	Y	Y	$100	$118	$118	critical weakness at lobby, unreinforced masonry in exit paths and parapets	Complex building form requires costly invasive retrofit. Non strutural masonry throughout presents significant hazard. * Large scale Swing space requires splitting of program groups.
Frank Forward	Lab / Office	*562*	5	7,937	0.75	1966	III	20%-49%	V	70%+	10	N	Y	Y	Y	$57	$64	$67	Soft storey at lower edge of slope presents significant hazard. External masonry presents falling hazard.	difficult costly and invasive. Irregular confirguration complicates retrofit potential. Multiple major deficiencies.
MacLeod	Lab / Office / Lecture	*312*	4 + PH	7,345	0.63	1962	IV	50%-99%	IV	30-70%	11	Y	Y	Y		$36	$48	$62	Address south corner to strengthen walls and improve shear connection.	Full renewal recommended. Deficienices include bridge and Kaiser connections, frame wekaness.
Chemistry Block A - Chemistry / Physics	Lab / Office	*447*	5	7,805	0.66	1989	III	20%-49%	V	70% +	12	Y	N	Y		$60	$67	$70	Partial retrofit of moment frames at shafts could significantly reduce life risk	Intensive systems within building limit possibilities for targetted retrofit. Constrained site conditions including topography.
Douglas Kenny	Classroom / Office	*732*	5	9,613	0.62	1981	III	20%-49%	V	70%+	13	Y	N	Y	Y	$62	$65	$77	Critical weakness at stair cores, external short columns. Possible external approach to reduce hazard.	Comprehensive retrofit recommended given multiple major deficiencies. Spandrel to wall connections throughout likely critical to collapse risk.
Chemistry B Block	Lab / Office	*148*	3 + PH	5,373	0.59	1958	IV	50%-99%	V	70%+	14	Y	Y	Y	Y		$41	$48	Retrofit of columns at long span beam or internal; supports	Costly and invasivce, new lateral system recommended in additiona to beam support issues.
Leonard S. Klinck	Classroom / Office	*308*	4	10,723	0.77	1946	IV	50%-99%	IV	30-70%	15	N	N		Y		$87	$91	Targeted retrofit of building corners.	Overall risk compounded by extent of hollow core block in non-structural elements. Corner shear elements most vulnerable.
Robert F. Osborne Center Unit 1	Gymnasium	*430*	2	5,098	0.72	1969	IV	50%-99%	III	11-30%	16	Y	N	Y	Y	$28	$30	$40	Possible perimeter upgrade to connection type to reduce collapse potential.	Comprehensive retrofit recommended , however short term connection retrofit may reduce collapse risk with low operational impact.
Jack Bell - School of Social Work	Classroom / Office	*750*	3	2,868	0.63	1994	IV	50%-99%	III	11-30%	17	Y	Y			$16	$17	$22	Targeted MRF connection improvements to reduce collapse risk.	Moment frame [MRF} issues require retrofit. Further detailed inspection required to focus retrofit strategy.
J. B. MacDonald	Lab / Academic	*198*	3	7,341	0.62	1967	III	20%-49%	III	11-30%	18	Y	Y*	Y		$47	$50	$62	Retrofit address multiple system deficiencies.	Comprehensive retrofit equired. Columan and slab density support retrofit potential. Swing space for teaching/ office spaces, no swing space for climics available.
Bookstore	Office	*81*	5	10,666	0.54	1981	III	20%-49%	III	0%		TBD	N							Bookstore not modelled in detailed analysis, as it is connected to adjacent structures. Would need to model the entire building complex to understand dynamic behavious during seismic events.

TOTALS:		Candidates for near-term risk mitigation	Candidates for targetted retrofit	Candidates for Full renewal	Candidates for Replacement	Recommended options: overall sum ($M)
#		9	3	5	10	18
est value $M		**$95**	**$108**	**$189**	**$664**	**$1,056**

Notes:
1. Probability of Collapse: Percentage collapse ratio represents number of collapse evidenced in 11 ground motions modelled at 975 yr interval
2. Retrofit / Renewal estimated order of magnitude costs relate to current codes/standards, no allowance for enhanced performance to achieve resilience standard.
3. Dollar estimates represent order of magnitude costs for planning purposes only.
3. All figures in 2018 $, no provision for escalation. Estimated order of magnitude project costs only, no allowance for swing space, complex phasing or related costs.
4. FCI index as at January 2019

= recommended mitigation option highlighted

ATTACHMENT 3.

UBC Seismic Planning: Notional Implementation Timeline for Mitigation of Priority Buildings (Dependent on funding, logisitics and consultation)

Priority buildings:

	Bldg #	Area [m2]	Age [Year]	Hazard Tier [2018 Detailed Analysis]	Probability of Collapse % - 975 yr Return [2018 Detailed Analysis]	Strategy 2 Rank [2018 Analysis]	2019-2025					2025-2030					2030-2035					2035-2040				
Woodward Biomedical Library	*536*	7,777	1964	V	70%+	1				$51																
Museum of Anthropology	*570*	11,487	1975	IV	30-70%	2	$24																			
Anthropology & Sociology	*48*	3,282	1974	V	70%+	3						$31														
Medical Science Block C	*523-3*	4,017	1961	V	70%+	4		$10						$49												
Robert F. Osborne Center Unit 2	*431*	4,589	1971	V	70%+	5				$10												$61				
Music	*575*	6,919	1967	V	70%+	6							$81													
Civil & Mechanical Eng	*306*	9,619	1974	V	70%+	7		$15								$123										
Lower Mall Research Station	*22*	6,629	1957	V	70%+	8			$10								$77									
H. R. MacMilllan	*386*	13,846	1967	V	70%+	9								$20				$184								
Frank Forward	*562*	7,937	1966	V	70%+	10				$78																
MacLeod	*312*	7,345	1962	IV	30-70%	11	$48																			
Chemistry Block A - Chemistry / Physics	*447*	7,805	1989	V	70% +	12								$89												
Douglas Kenny	*732*	9,613	1981	V	70%+	13				$32									$123							
Chemistry B Block	*148*	5,373	1958	V	70%+	14		$10				$62														
Leonard S. Klinck	*308*	10,723	1946	IV	30-70%	15							$20								$141					
Robert F. Osborne Center Unit 1	*430*	5,098	1969	III	11-30%	16																$51				
Jack Bell - School of Social Work	*750*	2,868	1994	III	11-30%	17						$20														
J. B. MacDonald	*198*	7,341	1967	III	11-30%	18								$70												

Swing Space:

			2019-2025					2025-2030					2030-2035					2035-2040				
1 - UBC Life - Level 2	*790*	6,593	Macleod			Woodward		ANSO		Macmillan South												
2 - Wesbrook/Cunningham						Forward																
3 - Pond Annexes						Kenny		Jack Bell									Klinck					
4 - Chem A										JBM												

	2019-2025					2025-2030					2030-2035					2035-2040					
est. Capital spend by Period: [$M]	$72	$35	$10	$171	$0	$114	$101	$228	$0	$123	$77	$184	$123	$0	$141	$112	$0	$0	$0	$0	*est. Overall Capital expenditure [$M]*
					$288					**$566**					**$525**					**$112**	**$1,491**

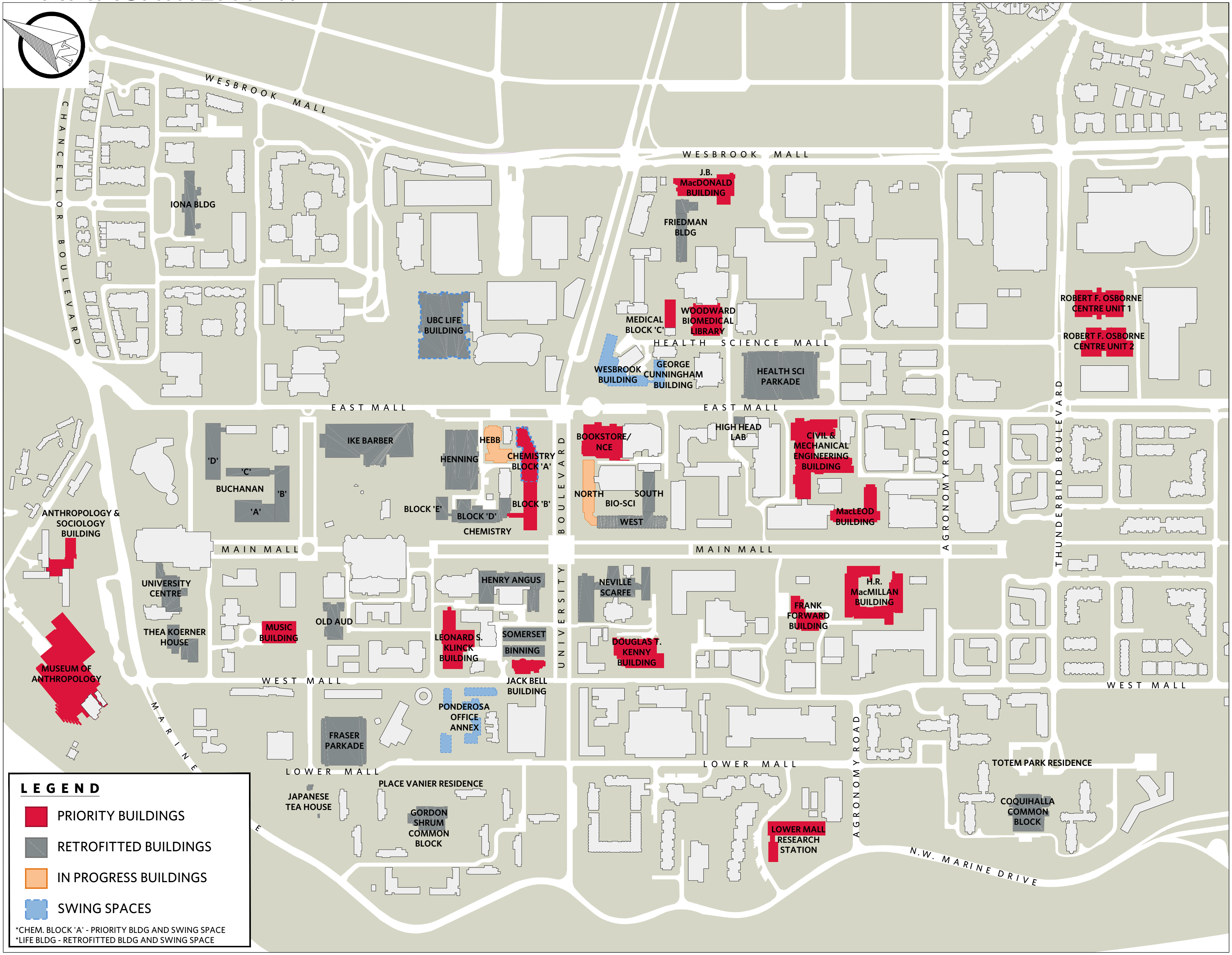
legend:

- $80 — Replacement
- $60 — Full Renewal
- $50 — Targetted retrofit
- $20 — Mitigation measures
- bldg — Swing Space

Notes:

1. Order of magnitude costs from Table 1: Summary of high priority buildings are shown for indicative planning purposes.
2. Costs shown in implementation timeline include provision for annual escalation over 2018$ amounts. 6% p.a. annualized assumed.
3. Costs assume like-like for like replacement / renewal, do not include provision for space additions expansion or program adaptation.
4. Near term mitigation measures are indicative costs and require detailed investigation.

ATTACHMENT 4.



ATTACHMENT 5

Table showing Previously Retrofitted Buildings

Building ID	Building name
23	HENRY ANGUS BUILDING
26	HENRY ANGUS BUILDING ADDITION
44	OLD AUDITORIUM
52	FRASER RIVER PARKADE
65	BIOLOGICAL SCIENCES BUILDING - WEST WING
66	BIOLOGICAL SCIENCES BUILDING - NORTH WING
68	BIOLOGICAL SCIENCES BUILDING - SOUTH WING
91	BOTANICAL GARDEN - GARDEN PAVILION
121-1	BUCHANAN BUILDING BLOCK A
121-2	BUCHANAN BUILDING BLOCK B
121-3	BUCHANAN BUILDING BLOCK C
122-1	BUCHANAN BUILDING BLOCK D
132	CHEMISTRY D BLOCK, CENTRE WING
136	CHEMISTRY E BLOCK, NORTH WING
232	NEVILLE SCARFE BUILDING - LECTURE BLOCK
240-1	NEVILLE SCARFE BUILDING - CLASSROOM BLOCK
240-2	NEVILLE SCARFE BUILDING - OFFICE BLOCK
320	DOROTHY SOMERSET STUDIOS
324	B.C. BINNING STUDIOS
344	LEON AND THEA KOERNER UNIVERSITY CENTRE
345	PETER WALL INSTITUTE FOR ADVANCED STUDIES
408	THEA KOERNER HOUSE
409	THEA KOERNER HOUSE ADDITION
467	HEALTH SCIENCES PARKADE
476	JAPANESE TEA HOUSE - NITOBE GARDENS
511	ENGINEERING HIGH HEAD ROOM LABORATORY
516	IRVING K. BARBER LEARNING CENTRE
523-2	FRIEDMAN BUILDING
525-2	FRIEDMAN BUILDING ADDITION
540-1	TOTEM PARK RESIDENCE - COQUIHALA COMMON BLOCK/MAGDA's CONVENIENCE STORE
544	PLACE VANIER RESIDENCE - GORDON SHRUM COMMON BLOCK
652	HENNINGS BUILDING
656	HEBB BUILDING - AUDITORIUM
790	STUDENT UNION BUILDING (SUB)
836	IONA BUILDING

Retrofits currently underway:

Building ID	Building name
66	BIOLOGICAL SCIENCES BUILDING - NORTH WING [ULTL]
656	HEBB BUILDING - TOWER