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Canadian Consulting Engineering Awards 2013

ASSOCIATION OF CONSULTING ENGINEERING COMPANIES | CANADA
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Category F: Special Projects

Seismic Retrofit Guidelines

For the Performance-based Seismic Risk Assessment and Seismic Retrofit Design of BC School Buildings

Unprecedented collaboration between Government, Academia, and the Structural Engineering Community with Peer Review and Acclaim by International Experts

Submitted by:

Ausenco

on behalf of the entire team:

Ausenco Engineering Canada Inc.
Bush Bohlman & Partners
Read Jones Christoffersen Ltd.
Genivar

David Nairne & Associates Ltd.
John A. Wallace Engineering

University of British Columbia
with key subconsultant TBG Seismic

Robert Hanson, PE, PhD
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Michael Mehrain, PE, SE

Owner: BRITISH COLUMBIA Ministry of Education

Client: APEG Professional Engineers and Geoscientists of BC

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Attachment to Entry Consent Form
Canadian Consulting Engineering Awards 2013

Ausenco Engineering Canada Inc. (Ausenco) is making this submission on behalf of the entire team, consisting of:

ACEC-BC Companies (Peer Review Committee)	Ausenco Engineering Canada Inc. Bush Bohlman & Partners Read Jones Christoffersen Ltd. Genivar
Non-ACEC-BC Consulting Firms (Peer Review Committee)	David Nairne & Associates Ltd. John A. Wallace Engineering
Guidelines Lead Developer	University of British Columbia with key subconsultant TBG Seismic
U.S. Consultants (External Peer Reviewers)	Robert Hanson, PE, PhD Farzad Naiem, PE, SE, Esq. PhD Michael Mehrain, PE, SE

Key staff of the Canadian team members include:

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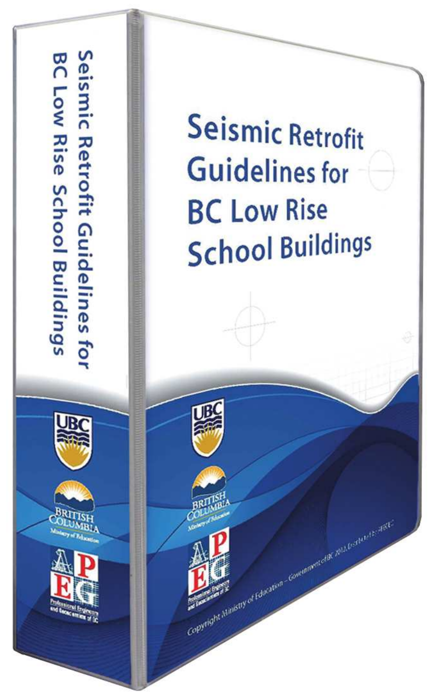
TBG Seismic	Graham Taylor, P.Eng. PhD
Ausenco	John Sherstobitoff, P.Eng.
Bush Bohlman & Partners	Clint Low, P.Eng. Struct. Eng. Tim White
Read Jones Christoffersen Ltd.	Ron Devall, P.Eng., PhD
Genivar	John Wallace, P.Eng. Struct. Eng. (formerly with Genivar, now with John A. Wallace Engineering)
David Nairne & Associates Ltd.	Andy Mill, P.Eng., Struct. Eng.
Association of Professional Engineers and Geoscientists of BC	Peter Mitchell, P.Eng.

The Ministry of Education is implementing a billion-dollar-plus seismic mitigation program for school buildings. New, developed-in-BC performance-based Seismic Retrofit Guidelines and a unique state-of-the-art web-based Seismic Performance Analyzer enable structural engineers to rapidly and consistently determine the seismic risk of existing buildings and optimize retrofits to achieve "life-safety" seismic performance. This ground-breaking work, a unique collaboration between government, academia and the engineering community, with key involvement by ACEC-BC firms, has been recognized nationally and internationally.



Project Highlights

Innovation

Innovation and complexity is incorporated in this section (400 words) and the next section (250 words) to be read together.

Starting with “a blank piece of paper” the all new, made-in-BC Seismic Retrofit Guidelines consist of a nine-volume, 300+ page manual, including a companion tool: a unique state-of-the-art web-based Seismic Performance Analyzer. The Analyzer accesses the program-developed database containing millions of non-linear incremental dynamic analyses for different structural systems and types of high-risk partition walls, for buildings located in seismic prone locations in BC, for different soil conditions, evaluated for 3 different types of earthquakes expected to occur in BC. Users can rapidly and with province-wide consistency determine the seismic risk of an existing building, and optimize the extent and cost of new structural components required to achieve a life-safety seismic performance.

The overall methodology is considered ground-breaking and state-of-the art, and is outlined below:

- Extensive literature search, and physical testing of structural components to determine their non-linear inelastic behavior; this includes data on strength and degradation as a function of interstorey drift, when subjected to dynamic cyclic loading. (Note: drift is the relative horizontal displacement of adjacent floors, divided by the floor-to-floor height, expressed as percentage).
- The above noted work produced ‘Backbone Curves’ and ‘Hysteretic Rules’ for use in the computer analyses; this was prepared for 27 different structural ‘prototypes’ typically found in existing BC schools, as well as 6 different timber or metal deck floor and roof systems, and 4 types of heavy brittle partition walls that have a high risk of collapsing out-of-plane into occupied areas.
- A key aspect is that the approach allows for archaic materials commonly found in existing buildings, but not addressed by current standards; and allows a similar approach for novel materials and innovative retrofit methods as the Guidelines evolve and further research and testing is done.
- The ‘performance-based’ aspect considers and accepts inelastic behavior of the structural components (damage), as long as the components remain within a prescribed maximum allowable drift limit. Adhering to the drift limits, determined from research/testing and analysis, will provide the desired “life-safety” seismic performance which will enable all occupants to safely exit the building after an earthquake.
- The combined experience of over 150 years of seismic upgrading in BC was used in two volumes containing a ‘library’ of 35 proven retrofit details and 14 seismic retrofit strategies; a collaborative sharing of information from the consulting firms involved.

Complexity

- The analyses considered three different types of earthquakes expected in BC: 'crustal' (shallow); 'subcrustal' (deeper); and 'subduction' (large, long duration, offshore interplate). Ten unique records of each type of earthquake were used; the 'incremental dynamic' analyses evaluated the effect of smaller and larger than code level earthquakes ranging from 30% to 250% of the code level earthquake in 10% increments, for all 30 earthquake records.
- The non-linear analyses produced results to determine the required lateral capacity of the structural components, existing, new, or a combination of both, such that the prescribed drift limit has a probability of exceedence of 2% over a 50 year life of a building (98% probability that a drift less than or equal to the prescribed drift limit will be achieved if the required lateral capacity is provided).
- The analyses considered variations in: site location; soil conditions; floor-to-floor heights; partition wall thickness and surcharge; floor/roof spans; drifts less than but not exceeding prescribed limits; component strengths or resistance levels; tolerance of vertical load carrying elements to drifts.
- Results of more than nine million analyses are incorporated into a peer-reviewed database, with fast user-friendly access via the Analyzer, which can be used for: seismic risk assessment of existing structural and partition wall components, to assign a risk level of High, Medium, or Low risk; retrofit of High or Medium risk buildings, to determine the required lateral capacity of new structural components in combination with existing components - for the lateral deformation resisting system and floor/roof diaphragms.

Social and Economic Benefits

Social and Economic Benefits, and Environmental Impact are incorporated in this section (max 250 words) and the next section (250 words), intended to be read together.

The use of the Guidelines by the structural community has proven to:

- Relieve structural engineers from selecting earthquake ground motion records or carrying out non-linear analyses; this is already done with results accessible in the Analyzer. It allows engineers to focus on determining the capacity of the existing building to better determine risk, and consider a variety of retrofit options that address issues such as disruption, schedule, phasing, cost, implementation, constructability.
- Offer the capability of mixing different new structural systems, in combination with existing systems.
- Be an effective way to utilize all available information on an existing building in the risk assessment.
- Be effective in selecting a very efficient, cost-effective retrofit scheme for a building; it is noted that the required lateral capacity for the new structural components can be as low as 50% of current code force levels for new buildings (the old 'force based approach') – directly contributing to the cost savings.

Various members of the team have made presentations on various aspects of the Guidelines and their use; over 100 presentations at local and international conferences/seminars/workshops since the development started, with about 40 presentations in the last 15 months.

Environmental Impact

The use of the Guidelines affects the noted aspects as follows:

- Reduced cost of seismic retrofits compared to previous approaches; enables more school buildings to be upgraded, and made safer, within the available Ministry budget.
- By effectively assessing the building's existing components, less buildings are ranked "High Risk", leading to less demolition/replacement (less landfill material, less energy for new materials) and contributing to the retention of more heritage buildings.
- The ability to assess a variety of retrofit options ranging from "hiding" the new structural components within the existing fabric and not affecting existing aesthetics, to expressing the new structural components either externally or internally, either as stand-alone seismic elements or as part of new architectural/functional modifications, to enhance existing aesthetics.

APEGBC Council endorsed the Guidelines as applicable for use on *all* low-rise buildings in BC. This has resulted in private entities, with large inventories of buildings, commencing seismic risk assessments using the Guidelines and developing seismic mitigation programs.

The Ministry of Advanced Education has retained APEGBC and the development team to adapt the Guidelines for their inventory of buildings, including mid-rise buildings up to 8 stories high.

US and China have expressed interest in using the Guidelines methodology to assess the seismic performance of their buildings. The US-based Applied Technology Council (ATC) is using the Guidelines approach for their recently initiated ATC-99 project to develop an alternative seismic design approach of low-rise US construction, and to develop a case study of a new effective retrofit program for US schools.

Meeting the Owner Needs

In 2004 the Ministry of Education (Ministry) announced a $1.5B seismic mitigation program for BC school buildings.

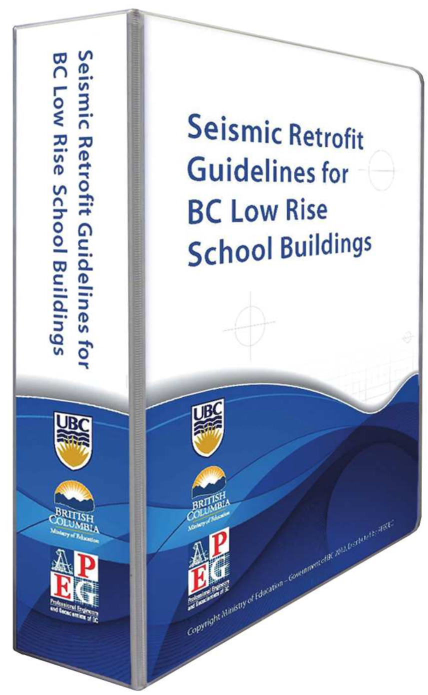
Prior to 2004 seismic mitigation programs generally used a 'force based approach' as outlined in building code provisions for new buildings. The seismic assessment consisted of determining a building's seismic capacity and comparing it to the capacity required for a similar but *new* building. If the capacity was less than some threshold capacity then a retrofit was required, and designed to meet "100% of code" force levels for a *new* building. This approach was simple and easy, but had significant drawbacks:

- contribution of archaic materials, non-compliant with current standards, was rarely included;
- a threshold such as "60% of code" did not enable engineers to understand the performance of the building;
- retrofitting for force levels compliant with 100% of code proved costly, exacerbated when contribution of existing archaic materials was ignored; and
- the seismic assessment and retrofit approaches varied widely, thus did not provide a uniform level of risk assessment nor of seismic performance and safety of the retrofitted buildings.

The Ministry wanted a new, innovative approach for the program, with a comprehensive, technical manual that included a customized set of guidelines. Key project objectives included:

- a common engineering approach to provide uniformity to seismic assessments and retrofit designs;
- seismic retrofits that achieve a "life-safety" performance level, in a cost effective manner.

The new guidelines developed in this project addressed the drawbacks of the pre-2004 approach, and fully met the owner needs and objectives.



Project Description

Introduction and Background

In 2004 the Ministry of Education (Ministry) announced a $1.5B seismic mitigation program for BC school buildings.

Prior to 2004 seismic mitigation programs generally used a 'force based approach' relating to seismic forces as outlined in building code provisions for *new* buildings. The seismic assessment consisted of determining a building's seismic capacity and comparing it to the seismic capacity required for a similar but *new* building designed to the current code; if the capacity was less than some threshold capacity such as "60% of code" then a retrofit was required. The seismic retrofit was then designed typically to meet "100% of code" force levels for a *new* building. This approach was simple and easy, and structural engineers could relate to provisions commonly used for the design of new buildings. However, there were significant drawbacks to this approach:

- the contribution of archaic materials, non-compliant with current codes/standards, were difficult to relate to current standards and thus rarely included;
- the threshold of "60% of code" did not enable the engineer to understand the performance of the building at that force level: would it collapse? How badly damaged would it be? How do buildings constructed of many different materials really perform?;
- retrofitting buildings for force levels compliant with 100% of code force levels proved costly, exacerbated when the contribution of existing archaic materials were ignored; and
- the seismic assessment and seismic retrofit approaches varied widely throughout the engineering community, thus did not provide a uniform level of risk assessment nor of seismic performance and safety of the retrofitted buildings.

Project Objectives

The Ministry wanted a new, innovative approach for the program, with a comprehensive, state-of-the-art technical manual that included a customized set of guidelines. The key project objectives included:

- a common engineering approach to provide uniformity to the seismic assessments and retrofit designs
- seismic retrofits that achieve a "life-safety" performance level, in a cost effective manner

Furthermore, the new guidelines were to address the drawbacks of the pre-2004 approach, discussed above.

The Team and the Solution

The Ministry retained the Association of Professional Engineers and Geoscientists (APEGBC) to manage a team to develop the new Seismic Retrofit Guidelines. The team consisted of the University of British Columbia (UBC), a Seismic Peer Review Committee (SPRC) consisting primarily of structural engineers from ACEC-BC firms, and an External Peer Review Committee consisting of seismic specialists from the US.

Starting with "a blank piece of paper" the all new, made-in-BC Seismic Retrofit Guidelines now consist of a nine-volume, 300+ page manual, including a companion tool: a unique state-of-the-art web-based Seismic Performance Analyzer. The Analyzer accesses the program-developed database containing millions of non-linear incremental dynamic analyses for different structural systems and types of high-risk partition walls, for buildings located at all seismic prone locations in BC, for different soil conditions, evaluated for the 3 different types of earthquakes expected to occur in BC. Users can rapidly and with province-wide consistency determine the seismic risk of an existing building, and optimize the extent and cost of new structural components required to achieve a life-safety seismic performance.

The Roles of the Team Members

The members on the team and their roles are as follows:

- The University of British Columbia (UBC) carried out the research, testing and analytical aspects of the development. The group includes: UBC structural and geotechnical professors; UBC researchers that carried out the bulk of the literature searches and non-linear analyses; the UBC Earthquake Engineering Research Facility, where the testing was carried out; TBG Seismic, that developed the performance based approach and initiated development of the Analyzer.
- The Seismic Peer Review Committee (SPRC) provided overview and critiqued all UBC work. The group consists of seven structural engineers with extensive experience in seismic retrofits and assessments, code and guideline development, and analysis. Five engineers are from the ACEC-BC firms noted as submitter or joint submitters; one engineer is from a local non-ACEC-BC firm, and one engineer is a US specialist in seismic engineering and an advisor to the US Federal Emergency Management Agency (FEMA). The SPRC scope evolved significantly to include writing large portions of the manual, developing a library of retrofit details, outlining retrofit strategies, and ultimately ensuring the consultant 'usability' of both the manual and the Analyzer.
- The External Peer Review Committee provided peer review of the analyses and brought to the project the expertise of two prominent US structural engineers specializing in seismic engineering.

All members of the team were involved in presentations at the training sessions for the structural community, delivered during one-day seminars and workshops shortly after each release of the Guidelines.

The Scope

The overall methodology incorporated into the Guidelines is considered ground-breaking and state-of-the art, and is outlined below:

- Extensive literature search, and physical testing of structural components to determine their non-linear inelastic behavior; this includes data on strength and degradation as a function of interstorey drift, when subjected to dynamic cyclic loading. (Note: drift is the relative horizontal displacement of adjacent floors, divided by the floor-to-floor height, typically expressed as a percentage).
- The above noted work produced 'Backbone Curves' and 'Hysteretic Rules' for use in the computer analyses; this was prepared for 27 different structural systems or 'prototypes' most typically found in existing BC schools, as well as 6 different timber or metal deck floor and roof systems, and 4 types of heavy brittle partition walls that have a high risk of collapsing out-of-plane into classroom or corridor areas.
- A key aspect is that the approach allows for archaic materials commonly found in existing buildings, but not addressed by current codes and standards; and allows a similar approach for novel materials and innovative retrofit methods as the Guidelines evolve and further research and testing is carried out.
- The 'performance-based' aspect of the guidelines considers and accepts inelastic behavior of the structural components (damage), as long as the components remain within a prescribed maximum allowable drift limit. Adhering to the drift limits, determined from the research/testing and analysis, will provide the desired "life-safety" seismic performance which will enable all occupants to safely exit the building after an earthquake.
- The input to the analyses considered the three different types of earthquake expected in BC: 'crustal' (shallow) earthquakes; 'subcrustal' (deeper) earthquakes; and 'subduction' (the very large, long duration offshore interplate earthquakes). Ten unique records of each type of earthquake were used; the 'incremental dynamic' analyses evaluated the effect of smaller and larger than code level earthquakes ranging from 30% to 250% of the code level earthquake in 10% increments, for all 30 earthquake records considered.

- The non-linear analyses produced results to determine the required lateral capacity of the structural components, existing, new, or a combination of both, such that the prescribed drift limit has a probability of exceedence of 2% over a 50 year life of a building (or conversely a 98% probability that a drift less than or equal to the prescribed drift limit will be achieved if the required lateral capacity is provided)
- The analyses considered variations in: site location in BC; soil conditions; floor to floor heights; partition wall thickness and surcharge; floor/roof spans; drifts less than but not exceeding the prescribed limits; component strengths or resistance levels; tolerance of the vertical load carrying elements to drifts
- The results of more than nine million analyses are incorporated into a peer-reviewed database, with fast user-friendly access via the Analyzer, which can be used for: seismic risk assessment of existing structural and partition wall components, to assign a risk level of High, Medium, or Low risk; for retrofit of High or Medium risk buildings, to determine the required lateral capacity of new structural components in combination with existing components - for the lateral deformation resisting system and floor/roof diaphragms.
- The combined experience of over 150 years of seismic upgrading in BC, within the SPRC, was used to include in the Guidelines two volumes containing a 'library' of 35 proven retrofit details and 14 seismic retrofit strategies; a collaborative sharing of information from the many different consulting firms involved.
- All aspects of the methodology, analyses, use of results, Analyzer, manual text and contents was debated and discussed amongst all team members, at regular workshops that varied from ½ day to 2 days in length.

Use of the Guidelines

The use of the guidelines by the structural community has proven to:

- Relieve structural engineers from selecting earthquake ground motion records or carrying out non-linear analyses; this is already done with results accessible in the Analyzer. It allows engineers to focus on determining the capacity of the existing building to better determine risk, and consider a variety of retrofit options that address issues such as disruption, schedule, phasing, cost, implementation, constructability.
- Offer the capability of mixing different new structural systems, in combination with existing systems
- Be an effective way to utilize all available information on an existing building in the risk assessment
- Be effective in selecting a very efficient, cost-effective retrofit scheme for a building; it is noted that the required lateral capacity for the new structural components can be as low as 50% of current code force levels for new buildings (the old 'force based approach') – directly contributing to the cost savings

Various members of the team have made presentations on various aspects of the Guidelines and their use; over 100 presentations at local and international conferences/seminars/workshops since the development started, with about 40 presentations in the last 15 months.

Environmental, Economic, Social Sustainability, Aesthetic Aspects

The use of the Guidelines affects the noted aspects as follows:

- Reduced cost of seismic retrofits compared to previous approaches; enables more school buildings to be upgraded, and made safer , within the available Ministry budget
- By effectively assessing the building's existing components, less buildings are ranked "High Risk", leading to less demolition/replacement (less landfill material, less energy for new materials) and contributing to the retention of more heritage buildings
- The ability to assess a variety of retrofit options ranging from "hiding" the new structural components within the existing fabric and not affecting existing aesthetics, to expressing the new structural components either externally or internally, either as stand-alone seismic elements or as part of new architectural/functional modifications, to enhance existing aesthetics.

Acknowledgements

"We believe that the continuation and successful implementation of this approach in BC will have long lasting positive effects on seismic rehabilitation that transcends BC and can have profound influences on such practise in the US and elsewhere in the world." – Dr. Farzad Naiem, prominent US structural/seismic engineer, recent President of the US-based Earthquake Engineering Research Institute

"It presents to Canada the opportunity to address a severe BC concern while providing a significant contribution to the tools of the international community in reducing life loss from earthquakes." – Dr. Robert Hanson, advisor to the US Federal Emergency Management Agency (FEMA) Mitigation Directorate

Achievements

The Seismic Retrofit Guidelines are being used by all BC School Districts and their structural engineering consultants for the seismic assessment and seismic retrofit design of school buildings.

The Seismic Peer Review Committee was awarded the APEGBC Meritorious Service Award in 2007.

The Guidelines received the 2010 Award for Excellence in Innovation in Civil Engineering from the Canadian Society for Civil Engineering; accepted by APEGBC, UBC/TBG Seismic, and the Seismic Peer Review Committee.

APEGBC Council endorsed the Guidelines as applicable for use on all low-rise buildings in BC (not just school buildings). This has resulted in private entities, with large inventories of buildings, commencing seismic risk assessments using the Guidelines and developing their own seismic mitigation programs.

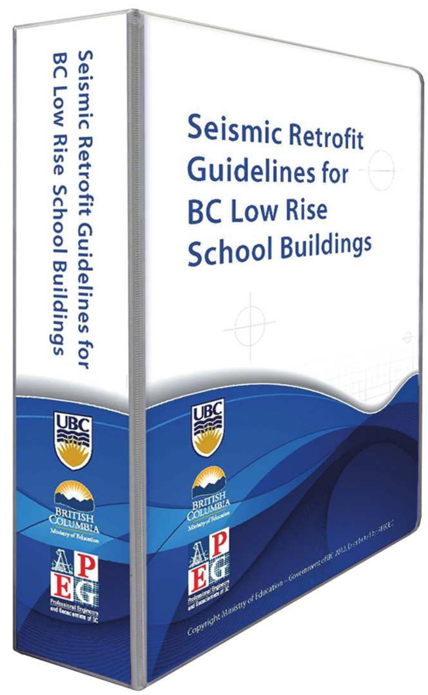
The Ministry of Advanced Education has retained APEGBC and the development team to adapt the Guidelines for use for their inventory of buildings, including mid-rise buildings up to 8 stories high.

US and China have expressed strong interest in using the methodology of these Guidelines to assess the seismic performance of their buildings. Furthermore, the US-based Applied Technology Council (ATC) is using the approach outlined in the Guidelines for their recently initiated ATC-99 project to develop an alternative seismic design approach of low-rise US construction, and to develop a case study of a new effective retrofit program for US schools.

Ongoing Work

The development team continues to be actively involved with the Ministry and APEGBC on new, related initiatives related to the Guidelines:

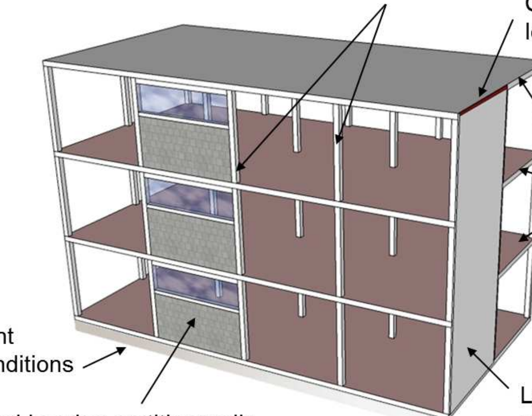
- Technical Review Board: for review of risk assessments and retrofit designs to maximize uniformity of the application of the Guidelines; to provide technical guidance and support as requested; to consider new laboratory testing or innovative retrofits to augment the provisions in the Guidelines.
- Database; of all assessments and retrofit designs, for all school buildings in BC; including rapid access to understand risk ranking of a particular building, and status of its retrofit in the overall mitigation program
- Post-Earthquake Evaluation guidelines; to enable enhanced post-earthquake assessments of both damaged and undamaged buildings, using information from the Guideline's research, testing, and analyses
- Seismic Instrumentation; being considered for all retrofitted buildings, to provide immediate information to the Ministry and the structural engineering community to enhance post-earthquake evaluations, and hopefully reduce the time before students and staff can return to an earthquake-affected building
- Liquefaction Guidelines; to clarify liquefaction impacts and provide guidance on geotechnical investigations and required; outline soil remediation options, combined with structural options to address liquefaction effects
- 2nd Edition Guidelines: addition of more structural prototypes; additional performance levels such as 'Damage Mitigation' and 'Post-Earthquake Occupancy' (other than 'Life-Safety'); all included in updated Analyzer



Drawings & Photos

Seismic Retrofit Guidelines

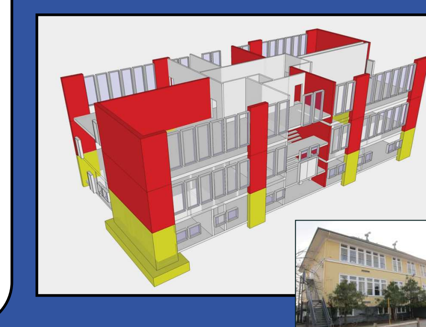
The development of the all new and made-in-BC Seismic Retrofit Guidelines, was an unprecedented collaborative effort between Government, Academia and the Structural Engineering Community to deliver a comprehensive manual and a unique state-of-the-art seismic performance analyser used to determine seismic risk of existing buildings and optimise the extent of retrofit necessary to achieve life-safety seismic performance.



- Utilizes all available information on an existing building in the risk assessment
- Offers the capability of mixing different structural systems, and new in combination with existing
- Relieves structural engineers from carrying out non-linear analyses
- Engineers can focus on determining the capacity of the existing building to better determine risk
- Engineers can be more effective in evaluating options and selecting efficient, cost-effective retrofit schemes

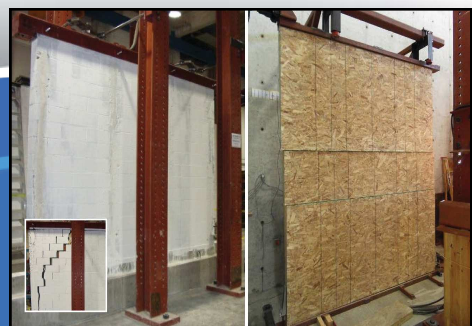
Various members of the team have made over 100 presentations on various aspects of the Guidelines at local and international conferences/seminars/workshops since the development started.

Cost effective retrofits based on Guidelines/Analyzer effectively use existing components to minimize the extent of new structural components



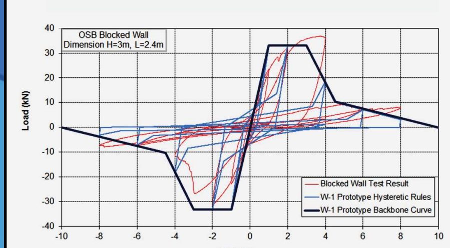
A variety of options, different new systems combined with existing, can be rapidly evaluated, to optimize cost, minimize school disruption.

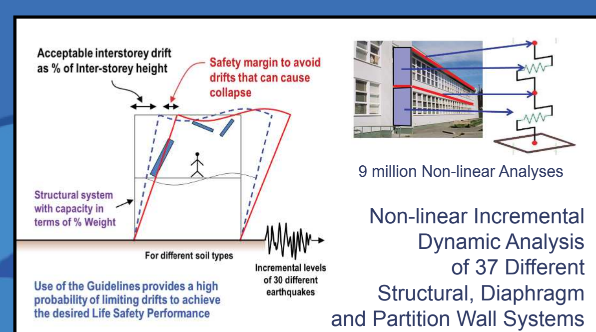
SEISMIC RETROFIT GUIDELINES DEVELOPMENT



Research and testing to determine strength and degradation, relative to drift, for cyclic loading (Backbone Curves / Hysteric Rules) of different structural components; archaic, retrofitted, and new.

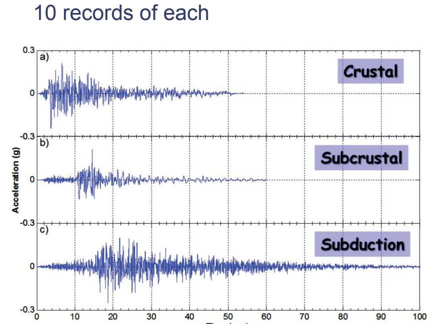
Backbone Curves / Hysteric Rules
- from the Research and Test Results





Non-linear Incremental Dynamic Analysis of 37 Different Structural, Diaphragm and Partition Wall Systems

Analysis Using 3 Different Types of Earthquakes in BC, 10 records of each

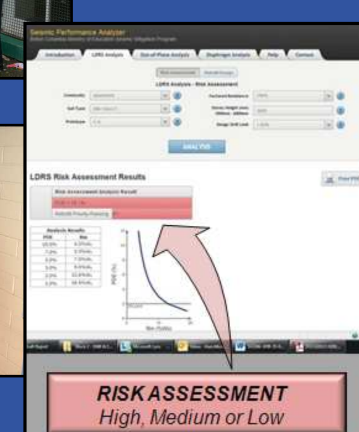


All aspects of the research, testing, analysis, manual text guidelines, and Analyzer interface were discussed and reviewed in detail by the team in regular 1/2 day to 2-day workshops.

SEISMIC RISK ASSESSMENT

Site inspections coupled with review of existing drawings to determine existing structural components and enable calculation of their seismic capacity

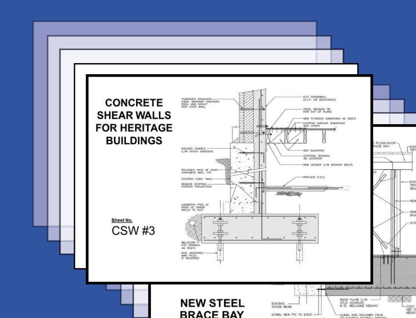
Destructive inspection and material testing to reduce uncertainties regarding original construction.



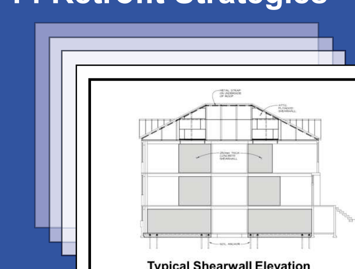
Use of Seismic Performance Analyzer to assess risk

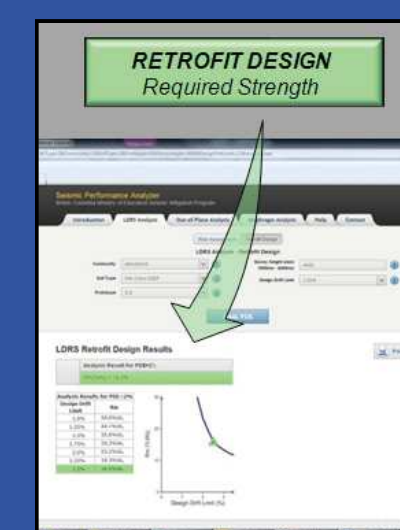
RETROFIT DESIGN

Library of 35 Retrofit Details



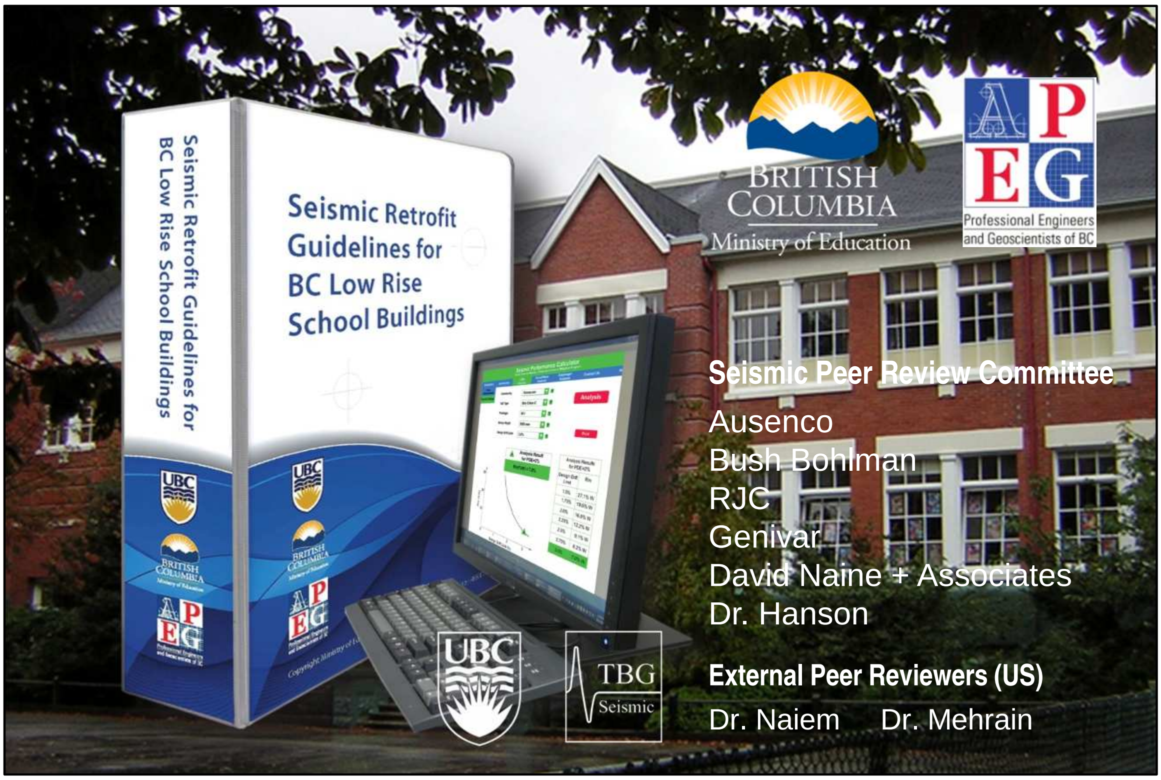
14 Retrofit Strategies





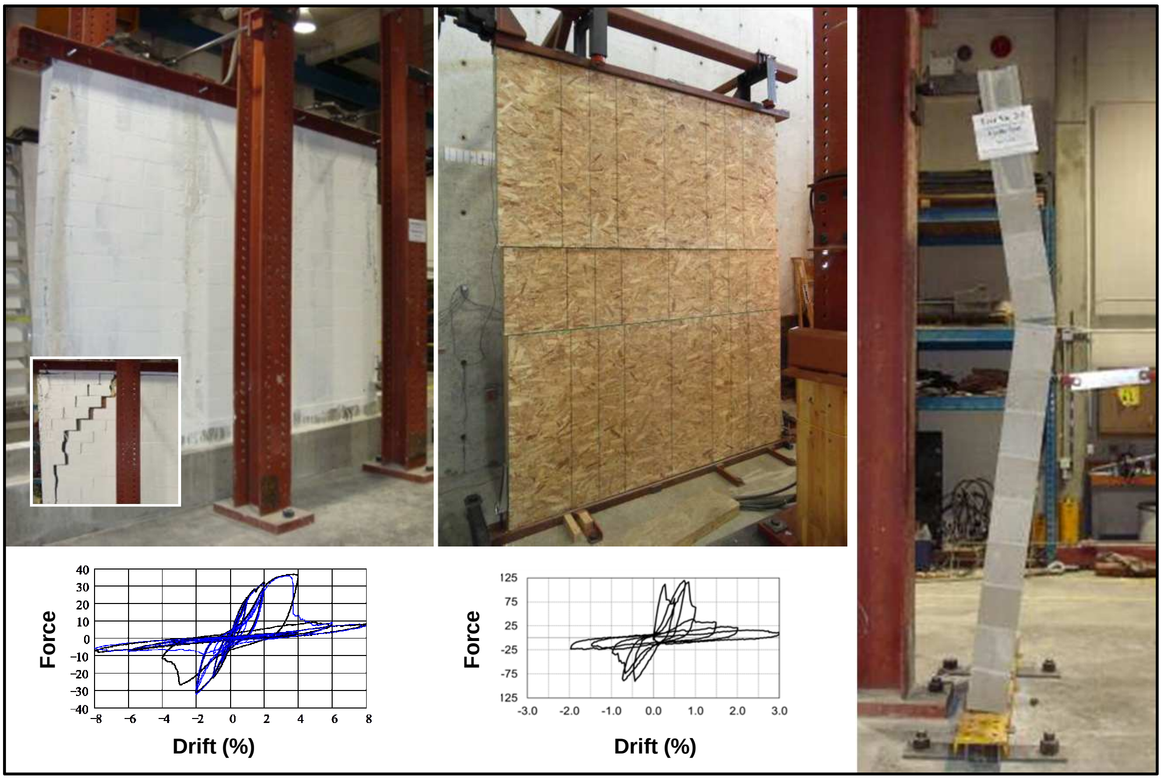
Use of Seismic Performance Analyzer to determine required strength

Ausenco

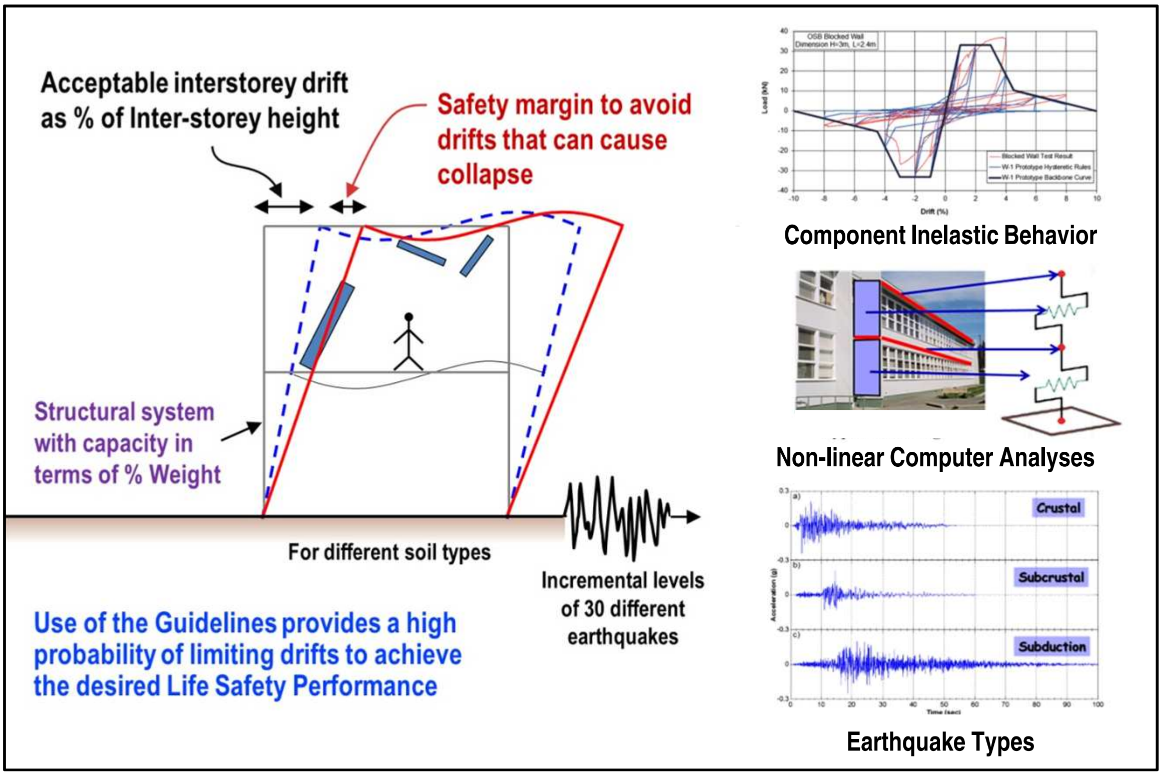


All new, made-in-BC Seismic Retrofit Guidelines include a 300 + page manual and a web-based Seismic Performance Analyzer.

Bob Hanson, representative of FEMA, (on right) accepting a copy of Guidelines from Minister of Education George Abbott (on left), May 2012.



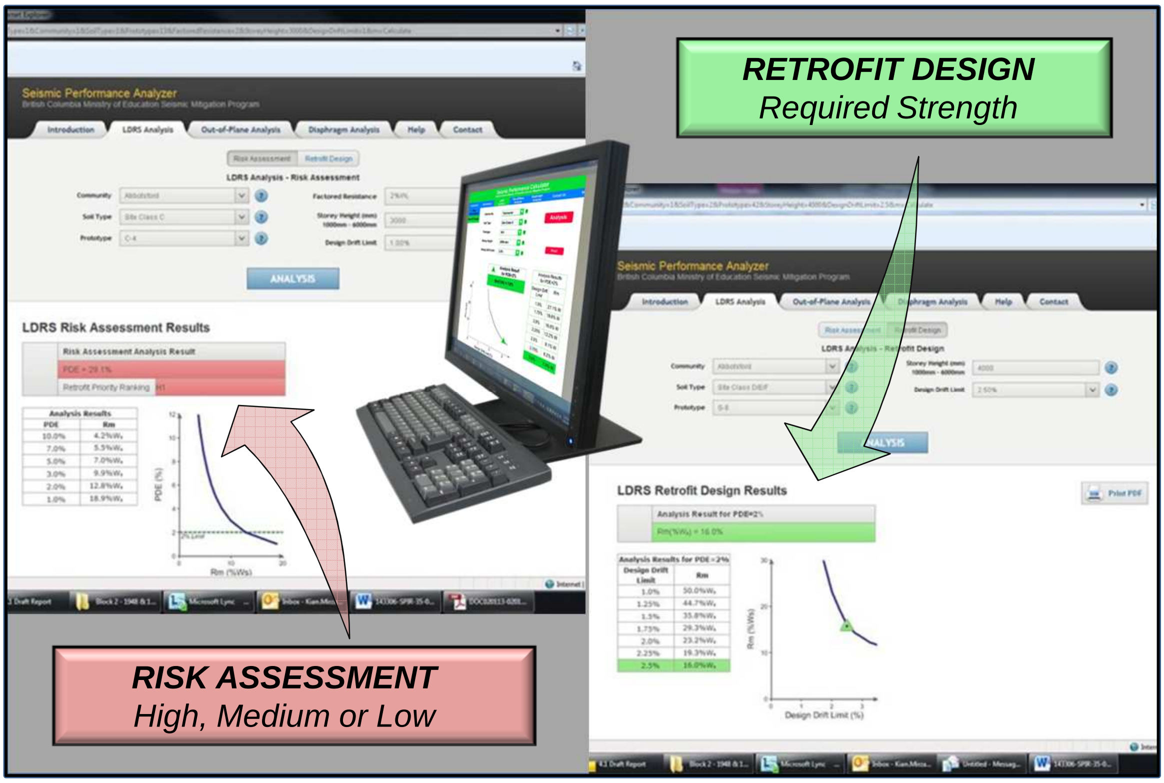
Research and testing to determine strength and degradation, relative to drift, of different structural components; archaic, retrofitted, and new.



Incremental Dynamic Non-Linear Analyses to determine maximum drift limits to achieve Life Safety Performance; results accessible via Analyzer database.

Ausenco

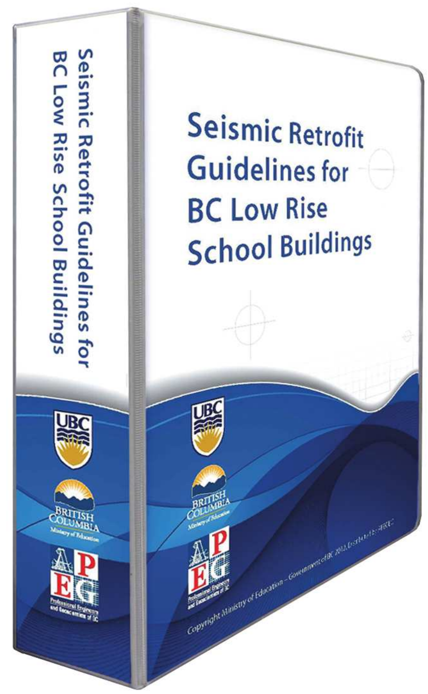
All aspects of the guidelines and analyzer were discussed and reviewed in detail by all team members in regular ½ day to 2-day workshops.



Web-based Seismic Performance Analyzer – seismic risk assessment and component strength requirements for retrofit design.

Site inspection and review of drawings to determine existing structural "prototypes", coupled with material testing to enable calculation of their seismic capacity.

Cost effective seismic retrofits based on use of Guidelines/Analyzer; including effective use of existing components to minimize extent of new work.



Display Board

as submitted to ACEC-BC

ASSOCIATION OF CONSULTING ENGINEERING COMPANIES BRITISH COLUMBIA

Submitted by: Ausenco

Category 5: Soft Engineering

Seismic Retrofit Guidelines

For the Performance-based Seismic Risk Assessment and Seismic Retrofit Design of BC School Buildings

Owner: British Columbia Ministry of Education

Client: APEG Professional Engineers and Geoscientists of BC

Joint Submitters: Bush, Bohlman & Partners consulting structural engineers; rjc Read Jones Christoffersen Consulting Engineers; GENIVAR

Other Consultants: UBC; TBG Seismic; Farzad Naeim; Mike Mehrain; Bob Hanson; John A. Wallace Engineering Ltd.; David Nairne + Associates

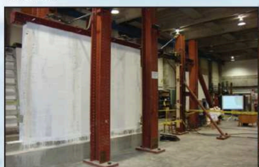
In 2004 the Ministry of Education (MEd) initiated a $1.5B seismic mitigation program for public school buildings. MEd retained the Association of Professional Engineers and Geoscientists of BC (APEGBC) to manage the development of new, innovative, performance-based technical guidelines for structural engineers to use in seismic risk assessments and to produce cost-effective retrofit designs. This unique collaboration between government, academia and the engineering community involved research, testing and analysis (University of British Columbia); provided ongoing review, guideline development, typical retrofit details and strategies, and confirmation of consultant "usability" of the final product (Seismic Peer Review Committee, comprised of structural engineers and members of ACEC-BC); and benefited from the input and participation of prominent US structural/seismic engineers for External Peer Review.

Interim guidelines were released in 2005 and 2006, followed by the 1st Edition in 2011. The 2nd Edition (draft) was issued in 2012 with full release scheduled for 2013. The Seismic Peer Review Committee had direct involvement in all releases, including training of the structural engineering community.

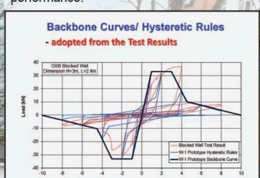
The 300+ page manual includes a companion tool - a unique state-of-the-art web-based Seismic Performance Analyzer. This Analyzer uses a database containing millions of non-linear incremental dynamic analyses for different structural systems and high-risk partition walls, evaluated for earthquakes expected to occur in BC. Users can rapidly and with province-wide consistency determine the seismic risk of an existing building, and optimize the extent of new structural components required to achieve a life-safety seismic performance.

This groundbreaking work has been recognized both nationally and internationally by leaders in the seismic engineering field.

Research and testing to determine strength and degradation, relative to drift, of different structural components; archaic, retrofitted, and new.



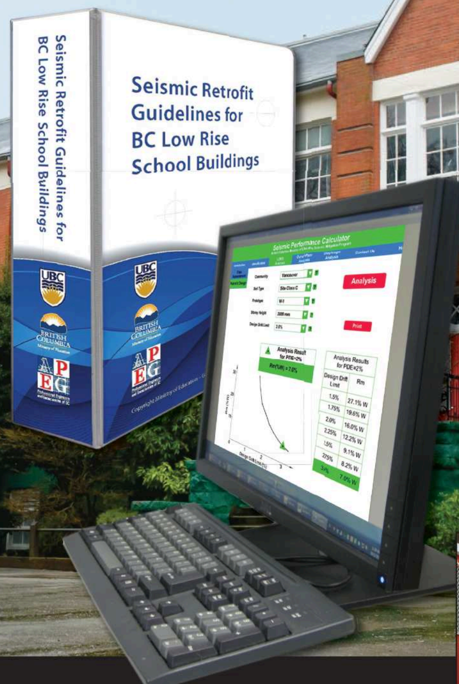
Non-linear incremental dynamic analysis of each structural component to determine maximum drift limits that ensures life-safety performance.



All aspects of the guidelines and analyzer were discussed and reviewed in detail by all team members in regular ½ day to 2-day workshops.

Guidelines Manual and Performance Analyzer

- All new made-in-BC 300+ page manual
- Analyzer's peer-reviewed data base accesses over 9 million non-linear analyses
- Fast, user friendly
- 27 different structural systems
- 6 floor / roof types
- 4 types high-risk partition walls
- 30 different earthquakes
- Seismic risk assessment
- Seismic retrofit design



ACEC-BC Award of Excellence

ACEC-BC Lieutenant Govenor's Award

Use of Guidelines to Design and Deliver Cost Effective Seismic Retrofits

Site inspections coupled with review of existing drawings, to determine existing structural components and enable calculation of their seismic capacity

Destructive inspection and material testing to reduce uncertainties regarding original construction

Retrofits based on Guidelines/Analyzer effectively use existing components to minimize the extent of new structural components

Unprecedented collaboration between Government, Academia, and the Structural Engineering Community with Peer Review and Acclaim by International Experts

Award of Excellence

SEISMIC RETROFIT GUIDELINES

AUSENCO with BUSH, BOHLMAN & PARTNERS LTD.; GENIVAR;
and READ JONES CHRISTOFFERSEN LTD.

BC MINISTRY OF EDUCATION

THE ASSOCIATION OF PROFESSIONAL ENGINEERS
& GEOSCIENTISTS OF BRITISH COLUMBIA

ASSOCIATION OF CONSULTING
ENGINEERING COMPANIES
BRITISH COLUMBIA

2013 AWARDS FOR
ENGINEERING EXCELLENCE

Lieutenant Governor's Award
for Engineering Excellence

SEISMIC RETROFIT GUIDELINES

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