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THE BC SCHOOL SEISMIC RETROFIT PROGRAM - LESSON LEARNT AND APPLICATION OF INNOVATIONS

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ABSTRACT

The British Columbia Province started a seismic mitigation program for the province's school buildings in 2004. The aim of the program is to reduce overall seismic risk of public schools through several mitigation measures including retrofitting intervention in school buildings. The program incorporates development of technical guidelines for performance–based seismic assessment and retrofitting. Development of innovative retrofitting technologies is also a part of the program. It offers many lessons to be learned in terms of strategies to adopt when initiating a major infrastructure rehabilitation project. The lessons learnt are applicable in a great extent to rehabilitation of other infrastructures and cross the boundary of British Columbia within and beyond Canada. This paper gives a brief account of seismic vulnerabilities of school buildings in British Columbia based on preliminary assessment survey conducted in 2004 followed by some important features in development of performance-based seismic retrofitting guidelines, which are based on Incremental Probabilistic Nonlinear Dynamic Analysis. The paper presents a case of establishment and development of the seismic retrofitting program which can be extended to other infrastructures and to other regions which may have different seismic hazard levels. This program can be a model for seismic rehabilitation of school and other similar public infrastructures in other countries as well.

Introduction

The south-west British Columbia lies in the most seismically active region in Canada. The region is subjected to crustal, sub-crustal and subduction earthquakes of moderate to high intensity in the past (Rogers 1994). When earthquakes strike communities, the hardest hits are weak infrastructures and vulnerable group of societies. It is revealed in the recent earthquakes that school buildings are disproportionately vulnerable to earthquakes resulting into very high proportions of death of school-going children. It's not only the cases of Pakistan and China in the developing world where recent earthquakes exposed the vulnerabilities of school buildings, schools have been disproportionately damaged, often to levels of life-threatening severity, repeatedly in North

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American history too (Monk 2007). Unlike other buildings, the collapse of a school building in an earthquake can potentially kill hundreds of school children in the matter of a few seconds.

While several measures like disaster education, safety drills in classrooms etc are also considered important for safety of school children from earthquakes, the most critical element of seismic risk mitigation for their safety is making school buildings safe from earthquakes. In a recent colloquium of seismic experts in the aftermath of Sichuan Earthquake of 12th May 2008, Bendimerad (2008) claimed, "Including disaster risk management in the curriculum of schools is important, but it does not help this generation or the next one, or may not even be the one after. If we want to protect children, we must address the structural issue of thousands and thousands of schools that are unsafe, not only in China but in most countries of the world. For the millions of children who are at risk every day in their schools, being in a safe building is only one parameter that will save their lives."

In order to address the risk to the lives of school children in British Columbia (BC) from earthquakes, the Ministry of Education of BC has made a 15-year, $1.5-billion commitment to make all public elementary and secondary school buildings safe. The commitment brought a comprehensive school seismic upgrading program. The program, started in 2004, is now under implementation in the collaboration of government, private sectors and academia. All high priority schools are either complete, under construction or in the planning stage, and have received funding from the ministry for rehabilitation. Until 15th October 2009, 60 school seismic projects are complete, 30 projects are under construction and 28 projects are proceeding to construction.

A part of the program is the development of guidelines for innovative, cost effective assessment and mitigation design. This is carried out through a cooperative agreement between the Association of Professional Engineers and Geoscientists of British Columbia (APEGBC) and the Department of Civil Engineering of the University of British Columbia (UBC). In the undertaking of development of these technical guidelines, APEGBC and UBC prepared a document entitled "Performance-based Seismic Assessment and Retrofit Design Concepts (second edition) in November 2006. The document is referred to as the Bridging Guidelines which reflects the interim nature of the document. In a course of further refinement of the guidelines and making it full-fledged document, APEGBC and UBC continued a research program to develop a set of Technical Guidelines (first edition) to be published by the mid of 2010. These documents are developed through an extensive research study passed through peer-review by BC Peer Review Committee of experienced local consulting engineers and by External Peer Review Committee comprised of consulting engineers and researchers from California, USA. This paper describes the development and important features of the school retrofitting program and more specifically the lessons learnt in this course that can be applied to other infrastructure rehabilitation projects in other parts of Canada and beyond its border.

Evolution of Seismic Mitigation Program

The school seismic mitigation program of BC is a result of several initiatives, built on experiences from pilot projects and follow-ups. In late 1980s, the BC Ministry of Education initiated seismic assessments of public schools and started some structural seismic upgrading projects in Vancouver and Victoria in early 1990's. Later, the issue of seismic risk of BC province has been entered into legislature. In 1997 the Office of the Auditor General reported on the state of earthquake preparedness in the province and, later, in 1999 the Public Accounts Committee of the Legislature tabled a report on earthquake risk. The province then started a seismic mitigation program as pilot project which included seismic assessment and upgrading of some school buildings. Civil society groups in BC had been very active to advocate for complete and full-fledged school seismic rehabilitation of all vulnerable schools in the province. An advocacy campaign led by a group of school parents called "Families for School Seismic Safety (FSSS)" was particularly instrumental to raise awareness of seismic risk of BC schools and to advocate for a major rehabilitation program.

Launching of Major Seismic Upgrading Program

In 2004, the Ministry of Education provided funding for structural seismic risk assessments of schools located in the high-risk seismic zones of the province. The assessment of 850 schools revealed that 311 of them are at high risk of sustaining severe damages to structural elements in the event of a moderate to strong earthquake. In November 2004 the Premier of BC announced that the province would make a C$1.5 billion investment over 15 years to ensure that the schools in BC will meet acceptable seismic life safety standards. The ministry formally launched the Seismic Mitigation Program in March, 2005 (Auditor General of British Columbia 2008). In launching the program, the ministry has budgeted C$254 million in the first phase of the program for improvements of 80 schools to be upgraded over the next three years. The budget was based on the assessment in 2004 and on cost and scope assumptions at that time. Later in 2008, the first phase project agreements had been signed for only 53 schools with the budget amounting to C$234 million. The Auditor General's report stated that the change in projected cost arises because of two significant factors: (1) the significant increase in construction costs since the original cost estimates for the program were prepared; and (2) the changes to the project scope resulting from more accurate risk assessments and a more detailed consideration of other remediation needs identified later.

Seismic Vulnerability of BC Schools

In 2004, over 850 schools located in 37 school districts (Fig. 1) were assessed for seismic safety. About 750 of the schools were found to have one or more building components rated as moderate to high seismic risk. School buildings were rated as high-risk if the structures have major seismic deficiencies. The moderate risk buildings were those which did not meet the criteria of code but would likely to withstand in moderate earthquakes. In the assessment, new schools, or any schools retrofitted since 1990, were not considered to be at-risk as those schools were designed in accordance with the 1990 National Building Code of Canada (NBCC), which included design provisions for buildings in seismic regions. The high-risk buildings comprise mostly clay brick unreinforced masonry buildings, unreinforced concrete masonry buildings, non-ductile concrete frames and buildings with heavy partition walls. Recent earthquakes in other countries including L'Aquila Earthquake 2009 in Italy revealed the high vulnerability of unreinforced the clay brick masonry buildings (EERI, 2009). This category of school buildings features in the most of the school buildings with heritage values. Those schools need some special considerations as regular retrofitting options may not be available for seismic upgrading.

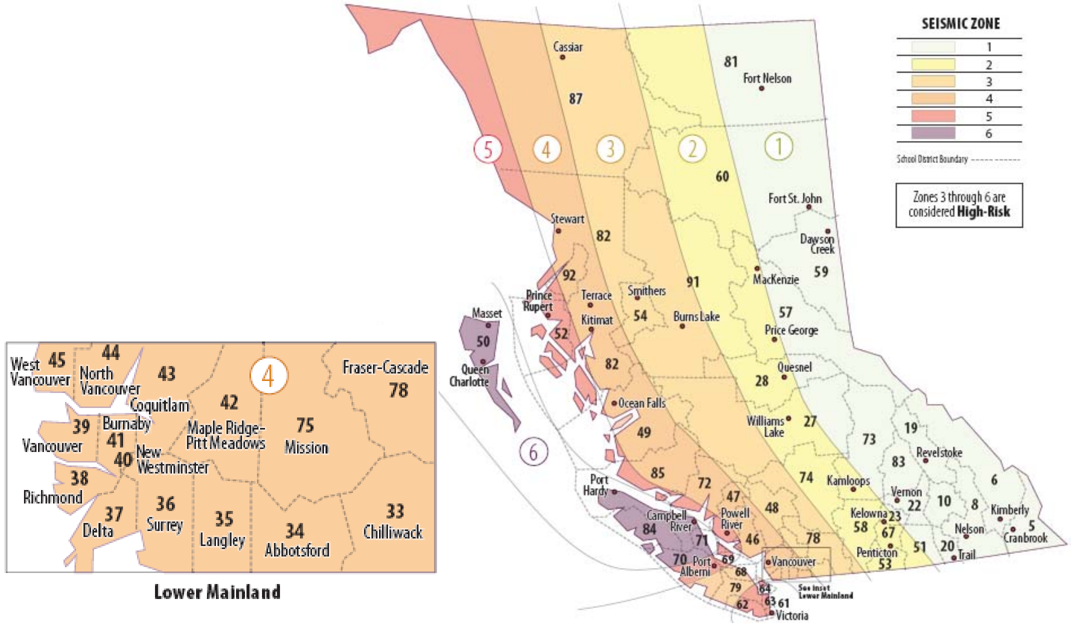

Figure 1. BC school district seismic zones. (Ministry of Education, 2009)

Development of Guidelines

One crucial component to the retrofit design process of BC schools is a multi-year development of policy and technical guidelines that are to guide the mitigation program (White 2007). In 2004, the ministry has contracted with the APEGBC to develop seismic assessment tools and retrofit guidelines for school buildings. The development of these standards commenced in 2004. The first project was the Performance-based Seismic Risk Assessment Tool UBC-100, completed in 2004. The UBC-100 was successfully used to rank 125 high risk schools in priority, which aided the Ministry of Education in deciding where the initial funds would be spent. The first edition of the Bridging Guidelines (EERF, 2005) was completed in 2005, and was used by local practitioners until October 2006, when the Second Edition Bridging Guidelines (APEGBC 2006) were released. These bridging guidelines, which are interim in nature, were developed based on need to commence retrofit construction prior to the completion of complete technical guidelines that requires several years in development. These guidelines provide tools for assessment of school buildings and performance-based cost effective strategies that reflect community-based life safety standards. The APEGBC has been holding training workshops for professional engineers and geoscientists on the use of the assessment tools and the guidelines.

In March 2008, APEGBC, with support of UBC, started the development of the Technical Guidelines. The development of the guideline uses an advanced methodology employing the Incremental Probabilistic Nonlinear Dynamic Analysis (IPNLDA) method for assessment and retrofitting decisions. The details of the methodology are presented in a companion paper at this conference (Ventura 2010). This is to refine the methodology of Bridging Guidelines and to develop a complete set of state-of-art performance-based guideline for assessment and retrofitting of low-rise school building in BC. APEGBC has established a Technical Review Board (TRB), consisting of structural engineers, which responds to questions and comments regarding the application of the guidelines and advises on innovative seismic retrofit techniques which should proceed to formal testing.

The approach of guidelines is novel as it provides result of extensive nonlinear analysis of large range of prototypes in simple guidelines that every engineer can use easily. This offers opportunities to wide application and extension of performance based earthquake engineering to the doorstep of all engineers who are engaged in building assessment and design in seismic countries. The prototypes represented in the guidelines represent the wide array of building types and lateral resisting systems found in low-rise construction. Because of this feature, its applicability is wide. This method of seismic risk assessment can be easily applied to other infrastructures and residential buildings in which similar structural elements are used. Those structural elements can be represented by the prototypes in the guidelines.

Review of Project Implementation Framework

The seismic mitigation program has been established under capital funding at the Ministry of Education. The ministry manages the fund with long-term capital planning and makes fund available for implementation of seismic mitigation projects. There are three key components of program; (1) Development of seismic technology, (2) Development of human resources for application of the technology, and (3) Implementation of seismic mitigation projects. The overall resource flow in the program and the relation of key players in the program can be illustrated as in Fig. 2.

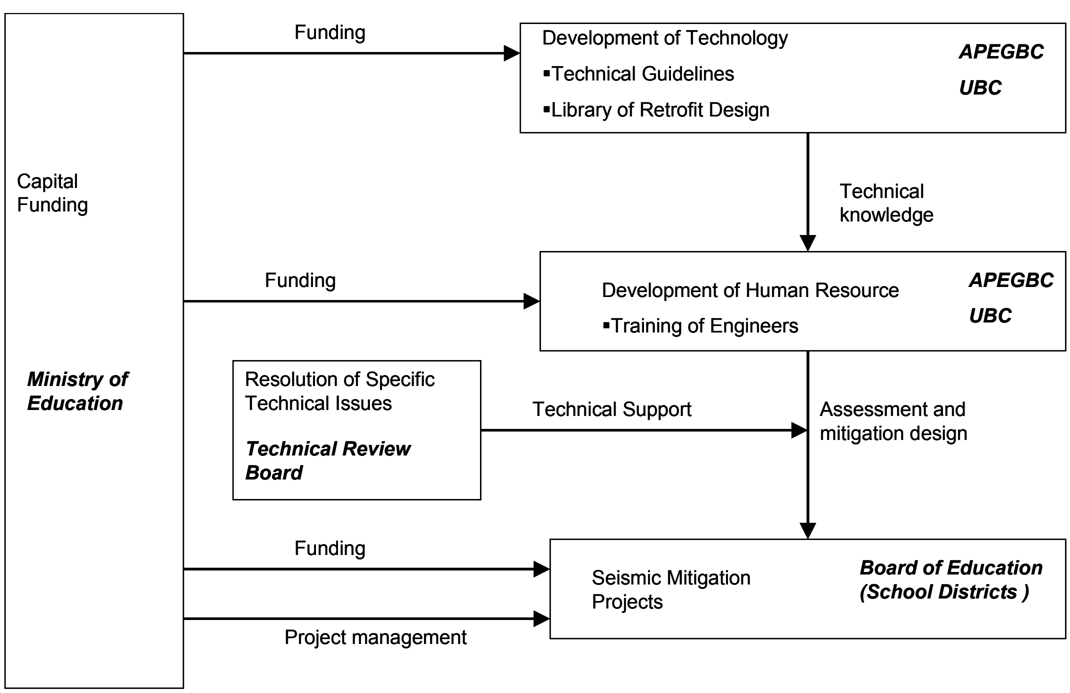

Figure 2. Resource flow in the seismic mitigation program

The APEGBC and UBC, as the engineering professional organization and the academia, provide the technical support for the program and guideline developments. They also provide training for capacity enhancement of local engineers in implementing these guidelines. The APEGBC will also develop a library of retrofit designs as examples of innovative seismic mitigation. The ministry provides fund for seismic mitigation projects through the school district Education Boards. In some cases the ministry also provides project management supports to the Education Boards. Project monitoring and evaluation has been carried out through status and progress reports delivered by school districts to the ministry. The Technical Review Board (TRB) of APEGBC provides necessary input to the local construction industry and design consulting team in case they face some specific technical problems in implementation of guidelines in assessment and design.

Program Implementation Issues

The Auditor General's Report (2008) reported that in implementing the program, the ministry and its partners have worked well on developing technical capacity and have established good evaluation and monitoring process. However, it laid out some area of improvements in accountability relationship with stakeholders and public.

The issue is related to informing public about decision making process and engaging them in resolving the issues arisen in seismic mitigation projects. A need is realized that program has a formal process to seek public input periodically and a tool to get them informed on the factors affecting decisions on priority and project scope. A model for communication flow that could be effective in active engagement of public in infrastructure risk management program is proposed as illustrated in Fig. 3.

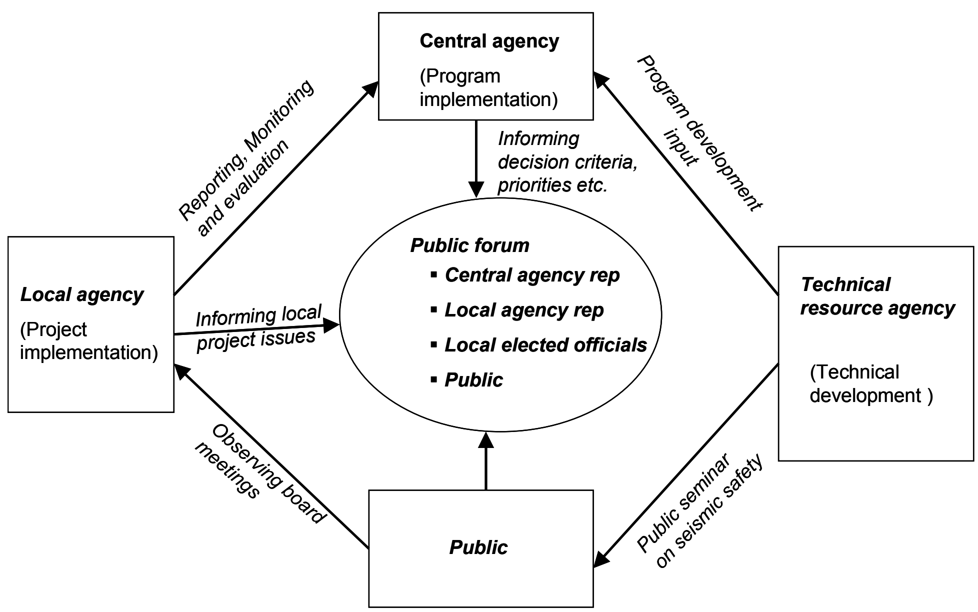

Figure 3. Information flow model for public engagement in seismic mitigation program

Another element of program implementation that could have significant impact in carrying out mitigation projects is budget estimation for mitigation action. The discrepancy in original budget estimation, which was based on preliminary assessment and on cost and scope assumptions at the time of project formulation, is a matter of concern for general seismic mitigation program. There are two caveats: (1) The large infrastructure mitigation programs span over many years that risk having uncertainties in analysis of market trend and cost projection and (2) The budget is based on the results of preliminary assessment, which may differ significantly with the detail assessment carried out at later stage. Strategies need to be developed to address such risks taking comprehensive risk management approach for the program.

Lessons on Program Establishment and Development

It is itself a matter of pride and success in getting an unprecedented commitment for seismic mitigation of schools in terms of its scope and size. A key to the success in getting C$1.5 billion program for seismic safety of school is an alliance of parents and community organizations with the scientific community in educating government and the population about the risks and the solutions.

Role of Engineering Community

The program was created due to the public concern of the school safety. Here, the role of scientific and engineering communities can't be overemphasized as they are the one who provided key information about risk of schools and measures to contain the risk to public in British Columbia. In the road to success to have major capital funding for this program, the structural engineers from APEGBC and civil engineering professors from UBC participated in public and government meetings offering the advice and expertise (Monk 2007).

The engineering community can provide information and education to the public on seismic risk and the solutions effectively. The key here is that the knowledge should be constructively formulated, transmitted, and received so that they result in meaningful actions to reduce the risk. As the earthquake technology has complex concepts and demands scientific analysis, the task of translating these concepts into language of common people is vital aspect to be considered in educating public and government as well.

Life Safety is Major Concern

Safety of school children can't be compromised in the pretext of economic analysis. The concept has been well established in BC that there is nothing more important than lives of children. The government commitment of large scale mitigation program reinforces the community value that children, future of the nation, are the most important and precious which can't be lost in seismic events. The government is convinced on policy framework that sending children to schools implies that it is the government's responsibility to provide them safe shelter while they are studying. It is in line with OECD's standpoint (OECD 2004), "Most nations make education compulsory. However, a state requirement for compulsory education, while allowing the continued use of seismically unsafe buildings, is an inconsistent and unjustifiable practice." The program took life safety performance objective in addressing the concern.

Public Awareness as Driving Force

Disaster awareness of community is vital to initiate and implement seismic risk mitigation program of infrastructure. The political will of British Columbia government for announcing the capital budget for large scale seismic mitigation of schools in the province was largely developed by the awareness of communities on seismic risk of their schools. The role of community originations, media and advocacy group like FSSS is vital to the success of launching this program.

Buy-in of Concepts by Stakeholders is Important

In the program development and implementation phase, the approach of consensus, peer-review and keeping informed is fundamental and unwavering. The collaboration of industry, academia and government is very successful in delivering solution to the seismic risk. The APEGBC entrusted UBC in carrying out extensive research program for guideline development. Research outcome and analysis result has been peer reviewed by local engineers and geoscientist through APEGBC. Nothing goes to final unless the engineering community represented by the Peer Review Committee agrees on the proposal. For the problems of specific nature in implementation of the guidelines, the TRB facilitates the consensus among engineers. The ministry is kept informed about the new tools and methods once finalized and ready for use by the engineering community. This dynamics of inter-sectoral relation and partnership has ensured effective implementation of technology development for seismic mitigation.

Vulnerability Assessment Opens Door for Mitigation

Seismic vulnerability assessment is important and prerequisite for development of mitigation program. Developing as well as developed countries may possess large stock of seismically vulnerable school buildings threatening the life of children. The seismic risk assessment of schools conducted in 2004 revealed the weakness of school system in BC in regards to seismic adequacy. While there are few cases of earthquake occurrences during school operation times in North America, it used to be believed that children are vulnerable only in developing countries of Asia region. The assessment showed the real pictures of school and led to the mitigation program.

Lessons on Program Implementation and Tools

The BC school retrofitting program took some unique approaches in solving the technical problems of seismic risk assessment and mitigation design. Some of the lessons on application of unique strategies are discussed below:

- State-of-art methods of seismic analysis should be accessible to every engineer for effective mitigation of seismic risk of large scale distributed infrastructure. In many cases, the technological advancement in seismic analysis could not be used by regular engineer because of the complexity in analysis process. The guidelines in school seismic retrofitting program provide database of readymade solutions derived from state-of-art methods. The tool box method simplifies the complex seismic problems into simple analysis.

- Engineering solution for assessment and rehabilitation may be found beyond the realm of national building codes. The performance based analysis of the guidelines is conceived as looking into the broader approach than the code-based prescriptive approach.

Lesson on Extension and Application of Guidelines

The universality of tools developed in this program offers possibilities of extension and application of guideline to other infrastructures and in other regions:

- Guideline for seismic assessment and mitigation design of school buildings can be applied to other infrastructures and houses. Since any low rise building system has structural components that can be treated as Lateral Load Deformation Systems (LDRSs) as represented in the guidelines (APEGBC 2006), this method can be applied to hospitals and other similar building infrastructures with little modifications and adaptation.
- The methodology can be easily implemented in other regions of Canada and beyond its boarder. As the methodology is universal, it can be brought into developed as well as developing countries for application. The important adaption would be in assigning specific seismic hazard of the region of interest and incorporating of new elements of building structures in prototype database.
- The methodology offers an opportunity to establish single seismic risk index of schools and other similar infrastructures globally. The methodology is based on risk in probabilistic term, which can be calculated for any given seismicity and structural system. For an international accepted risk value for school system, this method can provide a consistent measure for the capacity. This allows adapting a global seismic risk index for schools.

Model Application of Process and Development in Other Regions

From the experience of program establishment and its process of implementation, it is concluded that following approaches and steps are necessary for a successful infrastructure seismic rehabilitation project:

1. Initiate public awareness campaign involving engineering community, civil society groups, and media and pass the message of seismic safety solution to the government.
2. Make a case for capital funding for infrastructure mitigation avoiding the budget-cut to already stressed sectoral budget.
3. Utilize the pilot assessment opportunity to press for mitigation action. Take consideration in using the data in deriving the program budget.
4. Build partnership of stakeholders in program development and implementation. Keep public engaging in the mitigation project informing them decision and priority criteria.
5. Derive simple method that every engineer can participate in the task of assessment and mitigation of large scale infrastructures.

Conclusion

The BC school seismic retrofitting program has been initiated after the realization of seismic risk of schools. The establishment and development of program evolved over several years. It has not only benefited in reducing the seismic risk of the school system of BC but also offers a innovative tool for risk analysis and mitigation design for similar infrastructures applicable outside the BC province. The innovative approach of this program in development and implementation of infrastructure seismic mitigation will transcend beyond the boarder of British Columbia.

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