SEISMIC RETROFIT OF FEDERAL BUILDINGS IN CANADA

Gerald H DAVY[1] And Jacques GRANADINO[2]

SUMMARY

As the federal agency responsible for assisting all federal departments to minimize the impact of an earthquake, Public Works and Government Services Canada (PWGSC) recently developed a series of earthquake retrofit strategies and implementation plans for the necessary strengthening of the existing inventory of federal buildings. PWGSC's earthquake retrofit strategy encompasses a three-phase risk reduction program that includes the screening (assessing potential seismic hazard), performance evaluation (through simplified methods and/or advanced dynamic analyses) and structural upgrading (via cost effective conventional or innovative technologies) of buildings. In addition, PWGSC evaluates and upgrades in a systematic way Functional and Operational Components in its buildings after rating their vulnerability, consequences of failure and priority for mitigation. Total seismic upgrading costs are comprised of direct construction costs and indirect costs related to occupants relocation and reduced productivity and revenue. To achieve cost savings while meeting equivalent seismic safety requirements, PWGSC decided to use passive damping and advanced composite materials such as carbon fibre reinforced plastic (CFRP) sheets and fibre reinforced cements (FRC) in seismic upgrading projects of federal buildings. The use of passive damping and CFRP and FRC sheets have dual beneficial effect on the reduction of seismic risk. Passive damping reduces the lateral forces induced to the building structure, while wrapping structural components with composite sheets increases their strength and ductility. It has been demonstrated that the use of new technologies in structural seismic upgrading is far less intrusive to building occupants and can offer significant savings in direct and indirect construction costs. This paper gives an overview of the Canadian federal government's seismic risk reduction program, its research work, its status in the structural and nonstructural risk reduction for conventional and heritage buildings in British Columbia, and the experience gained through the use of new technologies.

INTRODUCTION

For the Canadian federal government, there has been an increasing awareness in the well being of all Crown owned buildings, specially in areas of moderate to high seismic activity such as the West Coast and the regions along the St. Lawrence River in eastern Canada. Recent earthquakes along the Pacific Rim exposed the vulnerability of older federal buildings to earthquakes and revealed the need for seismic strengthening of such buildings. In Canada, building code requirements for lateral force reinforcing have increased by as much as 50 per cent since the early 1970's. In light of these concerns, and to be able to continue providing a safe work environment for occupants and public seeking government services, there is a national recognition of the need to evaluate and to improve the seismic performance of older buildings to ensure that these buildings meet closely or fully the requirements of current building codes that would provide adequate resistance to the destructive effects of ground vibration induced by seismic waves.

Public Works and Government Services Canada (PWGSC) provides productive working environments for public servants on behalf of the Government of Canada, manages a diverse portfolio of office space and other general purpose property, and provides professional and technical services to federal departments and other general

[1] *Public Works and Government Services Canada, Vancouver, British Columbia, Canada Email: gerry.davy@pwgsc.gc.ca*

[2] *Public Works and Government Services Canada, Vancouver, British Columbia, Canada*

purpose property, and provides professional and technical services to federal departments and agencies for the acquisition, management, operation, maintenance, construction, repair and disposal of real property. PWGSC has over the years displayed significant effort in ensuring the safety of human lives and buildings so that federal programs and services can be delivered efficiently and effectively. One of the results of this effort is specific earthquake risk reduction strategies and implementation plans for all federal buildings with which the following objectives can be accomplished:

(1) safety of all federal buildings in terms of life and economic losses during an earthquake;
(2) minimization of reconstruction costs; and
(3) earthquake relief and business resumption with minimal disruption.

The geophysical characteristics of southwestern British Columbia, located near the active juncture of the Pacific and Juan de Fuca tectonic plates, and the latter under thrusting the North American continent at the Cascadia subduction zone, distinguish it as the most seismically active region in Canada. Geological and geophysical evidence of several major earthquakes in British Columbia's past are an indication that the next event could be imminent. As such, most of the federal government's current seismic hazard reduction activities have been carried out in British Columbia.

SEISMIC RISK REDUCTION PROGRAM FOR FEDERAL BUILDINGS

The primary consideration of a seismic upgrading program is to prevent the partial or total structural collapse of a building, thus ensuring public safety. Life can be saved by virtue of a building's capability to withstand seismic ground motions. Seismic upgrading is not restricted to structural components, however. Nonstructural components such as stairs, rigid partition walls, ceilings, mechanical equipment, filing cabinets, etc., also are part of the risk reduction program.

PWGSC recently developed specific earthquake risk reduction strategies and implementation plans to bring older federal buildings to a standard consistent with or close to current Canadian building code requirements. This seismic risk reduction strategy is a three-phase Seismic Risk Reduction Program that encompasses screening, evaluation and upgrading. The screening process defines basic criteria for potential structural and nonstructural hazards and involves the screening of buildings to eliminate those of low seismic risk. In the evaluation process, a detailed study of moderate to high risk buildings is performed. Results of the evaluation are to be used for establishing a strategy for seismic risk reduction and control relative to the extent of upgrading required. It can be decided to take upgrading measures at different levels. At the basic level provide low cost measures that enhance basic life safety levels in the building (such as eliminating short columns and brick tile partitions, securing access/exit points, securing roof parapets and canopies, upgrading nonstructural components); at the intermediate level bring the structure to a level of at least 60% of the current code requirements for new construction; or bring the building up to the full current code requirement for new construction.

Finally, on the basis of a risk-cost analysis, cost-effective retrofit methods are developed corresponding to life safety, financial conditions and specific project requirements.

Preliminary Screenings

This is the first stage of the 3-phase risk reduction program. Screening entails assessing buildings to ascertain their level of seismic risk (low, moderate or high), and to assess whether they should or should not be subject to more detailed investigation. Using the method developed by the National Research Council's Institute for Research in Construction [NRC/IRC 1993a], both structural and nonstructural components of a building are assessed to determine their seismic priority index, or SPI, as follows:

$$SPI = SI + NSI$$

where SI = Structural Index = A*B*C*D*E

A: seismicity factor (1.0 to 4.0)
B: soil conditions factor (1.0 to 2.0)
C: type of structure factor (1.0 to 3.5)
D: building irregularities factor (1.0 to 4.0)

E: building importance factor (1.0 to 3.0)

and NSI = Non-Structural Index = B*E*F

F: hazards to life or vital operations factor (1.0 to 6.0)

The bench mark for the screening is the 1990 edition of the National Building Code of Canada [NRC/IRC 1990], i.e. for a building built in full compliance with NBC 1990 on firm soil, SPI = 2.0.

The purpose of the screening process is to identify and prioritize which buildings pose a potential seismic hazard. The cut-off score, below which a building is deemed acceptable is rather arbitrary and is to be selected by the owner or competent authority. The following rating system may be used as a guide to make decisions with respect to potential building vulnerability and the need for a more detailed evaluation:

SPI < 10	Low Priority
10 < SPI < 20	Medium Priority
SPI > 20	High Priority

Although no rapid examination can provide highly reliable estimates of seismic performance, the screening is used to assist in identifying those buildings where reasonable doubts may exist, or used as a management planning tool for authorities with large inventories of buildings. This is a rapid procedure for ranking buildings for further evaluation and, in essence, creates a seismic inventory which can be used for future planning purposes. In the case of British Columbia, PWGSC has applied the seismic screening methodology only to buildings situated in areas of low seismicity within British Columbia in the interior of the province. A cut-off value of 12.0 for SPI is used to propose a more detailed evaluation.

Performance Evaluation

This the second stage of the of the 3-phase risk reduction program. The objective of a performance evaluation is to identify the vulnerability of the structural system and its components to seismic loads. PWGSC has developed such a procedure [PWGSC 1999]. Highlights of the procedure are as follows:
(1) Conduct site visit, collect building design and construction data, establish site and soil parameters, and assess the building condition,
(2) Carry out in-situ evaluation tests if required,
(3) Determine the structural system to be investigated for seismic adequacy and perform analysis,
(4) Define desired performance level for structural hazards (collapse prevention, life safety, immediate occupancy or operational requirements), and establish corresponding seismic resistance level from 60% of NBC 1995 to full code conformity,
(5) Follow the guideline [NRC/IRC 1993b] for applicable evaluation statements and calculations to to identify potential structural and configuration deficiencies for the 60% level of NBC 1995 [NRC/IRC 1995a]. Adjust the results for the desired performance level,
(6) Identify significant nonstructural hazards following the criteria established in evaluation guidelines [PWGSC 1995 or CSA 1999]

The level of analysis required depends on the type and level of complexity of the structure and can be based on the equivalent lateral force procedure defined in the current code or more refined linear or nonlinear dynamic analysis, including the use of a suitably modified earthquake time-histories in the linear or nonlinear range. The seismic evaluations performed by PWGSC have always included not only a list of seismic deficiencies and their relative importance, but also risk assessment, upgrading schemes, a mitigation and implementation plan, and cost estimates of the work for the benefit of our clients.

Of the twenty-two PWGSC buildings in British Columbia that have undergone a performance seismic evaluation, two belong to low risk, four belong from low to moderate risk, seven belong to moderate risk, six belong from moderate to high risk, and three belong to high risk. Action priority is greatly influenced by the risk level associated with the building, i.e. buildings with a higher risk level would likely be upgraded before those with a lower risk level.

Seismic Upgrading

This is the third phase of the 3-phase seismic risk reduction program. The purpose of seismic upgrading is to enhance the overall resistance of the building and individual structural and nonstructural components within the building to achieve the following objectives: life-safety, damage control, minimum disruption during upgrading, attain a proper function of the building, acceptable appearance, maintain heritage value (if applicable) and minimum cost for the intervention.

Conventional structural upgrading (addition of shear walls and/or steel bracing, enlarging columns, in-fill walls, strengthening foundations) often leads to heavy demolition, lengthy construction time, tenants' relocation with all the associated direct and indirect costs. Total seismic upgrading costs are comprised of direct construction costs, and indirect costs related to occupants' relocation and reduced productivity and revenue. It is often the indirect costs and the inconvenience associated with conventional techniques, that deter building owners and custodians from committing to seismic upgrades, as the overall increase in property value is usually less than the cost of the upgrade. As a result of this, PWGSC found it necessary to investigate an alternative approach to be implemented to carryout cost-effective seismic upgrading projects. The objective is to provide the buildings with an equivalent seismic safety, as specified in the intent of the National Building Code and existing guidelines [NRC/IRC 1995b].

Use of two innovative technologies, namely passive damping and the use of advanced composite materials such as carbon fibre reinforced plastics (CFRP) have been implemented and are being considered for upcoming upgrading projects in situations that the structural characteristics of the existing building allow for their use. While passive damping reduces the level of lateral seismic forces induced in the building as long as the structure remains elastic, wrapping structural components with CFRP sheets increase the strength and ductility of individual components such as concrete and masonry walls, beams and columns without adding stiffness. Friction dampers (a common type of passive damping devices), CFRP and FRC (fibre reinforced cement) have been recently applied to three federal buildings in the province of British Columbia.

TECHNOLOGY INNOVATION AND SEISMIC SAFETY

During the past four years, PWGSC has implemented its Seismic Risk Reduction Program in the province of British Columbia through the screening of twelve of its buildings, the evaluation of seismic performance of another twenty-two, and the upgrading of four federal buildings to meet its objectives of life-safety and damage control: The Harry Stevens Building in Vancouver (built 1963, area 6,243m2, reinforced concrete, retrofitted 1997), the Revenue Canada Building in Victoria (built 1965, area 4,785m2, reinforced concrete, retrofitted 1997), the Federal Building in Port Alberni (built 1960, area 2,400m2, reinforced concrete, start of retrofit 1998), and the Standards Building in Vancouver (built 1963, area 1,562m2, steel and concrete, retrofitted 1998). While the Victoria building underwent conventional seismic upgrading with the addition of new concrete shear walls and extensive foundation upgrading, all the other were first applications in western Canada of innovative technologies.

The Harry Stevens Building used friction damping which has resulted in significant cost savings. Both diagonal and X-braced friction dampers were used and staggered over the entire building. A nonlinear study, coupled with the use of real earthquake records, ensured that the damping technology was appropriate for the building not damaging nearby structural components. The layout of steel braced frames carrying the dampers did not require vertical continuity from floor to floor and the installation was staged. Figures 1 and 2 show the dampers installed in the building at the main lobby and upper floors respectively.

Added value from the innovative use of materials for seismic retrofit can be demonstrated from a financial perspective. For the Harry Stevens Building a conventional direct construction cost for the structural upgrade was estimated at CDN$1,400,000 with additional indirect costs calculated at CDN$650,000 (relocation) that were not incurred. Using the innovative technology of passive damping, the structural upgrading cost was CDN$810,000 with the tenants remaining on site and with minimal disruption and no loss of productivity and revenue. For the Port Alberni Federal Building, innovative upgrading cost of CDN$310,000 compared to a conventional upgrading cost of CDN$438,000 for a saving of CDN$128,000. In this case the innovative upgrading technique saves relocation costs of CDN$102,000. Finally, for the Standards Building in Vancouver, the first application in Canada of FRC (polypropylene fibre reinforced cements with high tensile fibreglass mesh) to strengthen existing masonry walls to resist earthquake loading, the structural upgrading cost was

CDN$180,000 as opposed to the estimated cost for a conventional upgrading of about CDN$410,000. Figures 3 and 4 show the applications in these last two buildings.

SEISMIC RISK REDUCTION FOR HERITAGE BUILDINGS

Heritage buildings, regardless of their type of construction, continue to present a challenge to both structural and conservation engineers. A balance must be found between the need to provide adequate strength and the requirements to conserve heritage. This fine balance is best achieved by following some of the widely accepted conservation principles:
(1) conserve through minimum intervention;
(2) adopt tested and reliable repair technology;
(3) use of the full spectrum of assessment, including visual inspection, site surveying, non-destructive testing as well as analytical methods, before judging performance;
(4) use compatible materials for repair, and
(5) adopt repair techniques that will not cause structural damage.

NRC/ IRC's guidelines on seismic evaluation of existing buildings address the most commonly found brick URM construction but do not include the special types of structures and construction materials found in heritage stone masonry buildings. To fill the void, PWGSC has developed guidelines for assessment of stone masonry construction [PWGSC 1997]. This guideline presents analytical methods and criteria developed to assess the seismic adequacy of heritage stone masonry and outlines repair techniques.

The new assessment guideline for stone masonry structures addresses the following major steps:
(1) identify the structural sub-systems of the structure;
(2) for the stone masonry sub-systems of the structure, establish the level of seismic risk on the basis of past performances of similar structures;
(3) compute the response of the sub-systems using appropriate evaluation procedures;
(4) establish the vulnerability of the sub-systems on the basis of the following performance criteria: strength, deformation, and local and global stability criteria.

RESEARCH AND INVESTIGATIONS FOR SEISMIC MITIGATION

Experimental Study of Reinforced Concrete Shear Walls Strengthened with CFRP Sheets

The study is part of a collaborative research program between Carleton University in Ottawa and PWGSC. The purpose of this investigation is (1) to verify that externally bonded carbon fibre sheets can be used for flexural and shear strengthening of reinforced concrete and block masonry walls, and (2) to determine constitutive hysteretic curves as data for nonlinear finite element analyses required in the practical investigation of this application in building upgrades. A total of four reinforced concrete and four concrete block walls will be tested and simulated with and without layer(s) of CFRP sheets. The first part of the investigation reported [Lombard, Lau and Foo, 1999] consists of tests on three 2.0x1.5x0.1m reinforced concrete shear wall specimens. Two of these specimens are shown in Figure 5 left.

Shake Table Testing of Functional and Operational Components of Buildings

PWGSC commissioned a series of tests using the shake table at the Earthquake Engineering Research Laboratory of the University of British Columbia in Vancouver [UBC, 1998]. The tests were conducted in July 1998. The components involved in the tests included office furniture and equipment (bookshelves, file cabinets, storage racks), a fully furnished office work station, LAN rack, a motor control centre, base isolation platforms and numerous types of restraining devices. The tests were used to investigate the effectiveness of restraint and base isolation devices under different simulated earthquakes. Figure 5 right shows the testing of LAN racks on a base isolation platform.

Figure 1 : Harry Stevens Building: Main Lobby with Damper in Lower End of Diagonal Brace

Figure 2 : Harry Stevens Building: Upper Floors X-Braced Dampers

Figure 3 : Standards Building: FRC Application to Masonry Block Walls

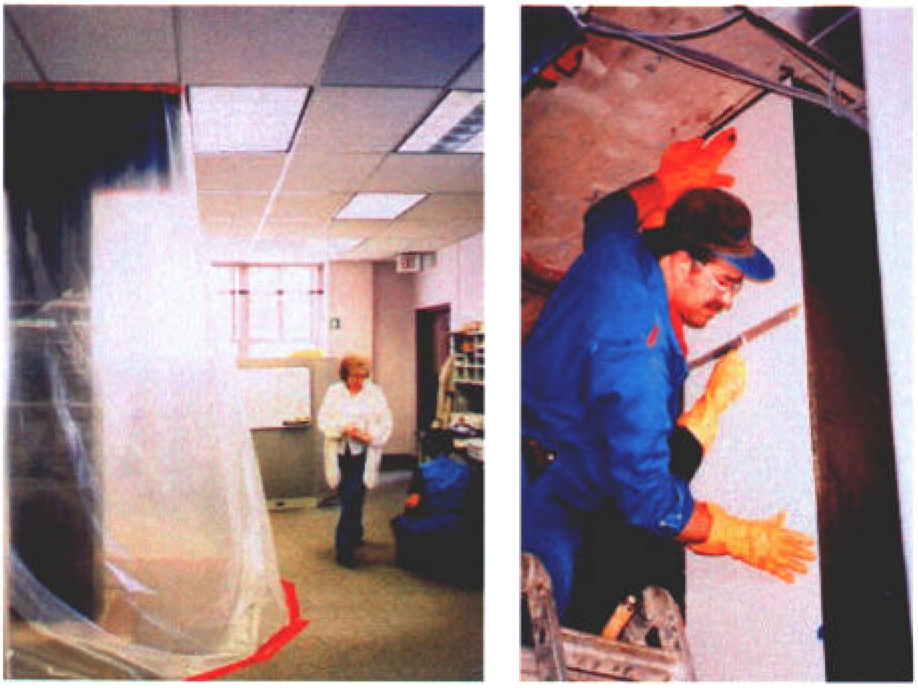

Figure 4 : Port Alberni Federal Building: CFRP Application to Columns with Minimal Disruption

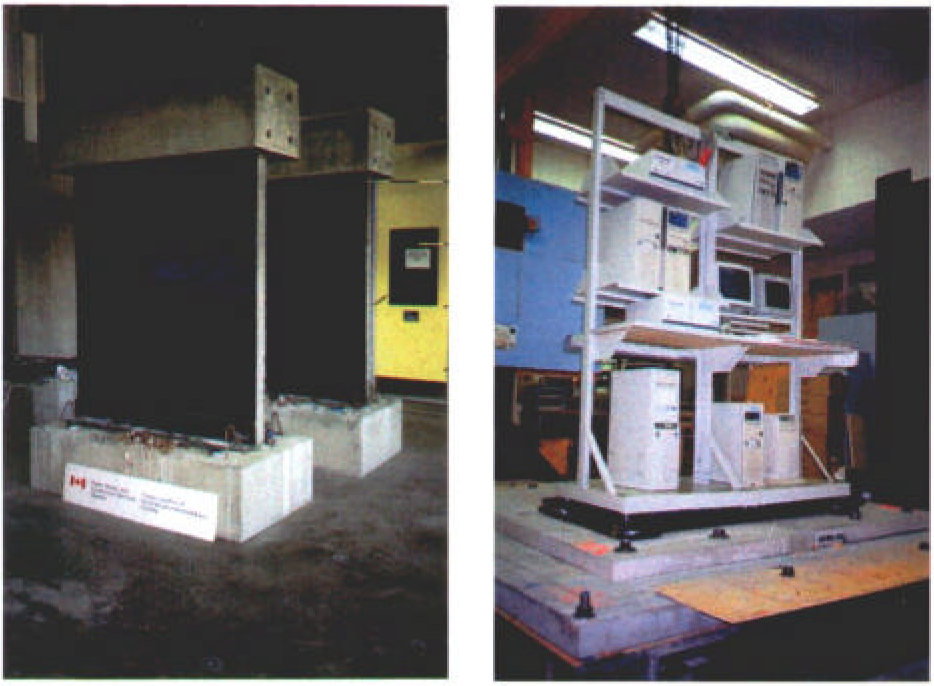

Figure 5 : Research of CFRP on Shear Walls and Shake Table Testing for Non-Structural Components

Seismic Risk Methodology for Comparative Assessment of Multiple Sites

Indian and Northern Affairs Canada is concerned about the potential risks to native communities in the British Columbia Region should a large earthquake occur. As a first step in mitigating the potential effects of such an event, a methodology was developed to assess relative risks among various communities in the region. Evaluation of structural deficiencies in existing facilities, scheduling of mitigative work, implementing appropriate land-use zoning and establishing emergency response plans are undertaken according to an unbiased priority rating that emerges from application of the methodology [Davy, Olsen et al. 1992]. Site specific conditions that could exacerbate the effects of an earthquake are evaluated. These include geological and hydrogeologic conditions in each community, natural and man-made features that could have a direct adverse impact on the community or access to it, and other conditions outside the community that could have an indirect adverse impact on it. A risk assessment matrix provides a quantitative and unbiased basis for evaluating relative risk among a number of communities in the region. Weighting factors are used to account for loss of life, loss of property, and security of access.

CONCLUSION

In order to mitigate the seismic risk associated with the federal government's inventory of buildings, PWGSC has developed strategies and implementation plans for the preservation of public safety. An integral part of the seismic risk reduction program is to evaluate and apply innovative technologies such that federal buildings can be retrofitted in a cost effective manner. During the past four years, PWGSC has demonstrated the successful application of innovative technologies such as passive damping devices and advanced composite materials in a number of seismic upgrading projects on federal buildings. The proper use of these innovative technologies has proven to be far less intrusive to building occupants and cost effective. Significant savings can be realized by reduction in construction costs and by avoiding tenant relocation and associated productivity losses.

REFERENCES

Canadian Standards Association CSA (1998), Draft 5, February 1999, S832-2000, *Guideline for Seismic Risk Reduction of Functional and Operational Components (FOC) of Buildings* 52p.

Davy G., Olsen I. et al. (1992), "A Seismic Risk Assessment Methodology for Comparative Assessment of Multiple Sites", *Proceedings First Canadian Symposium on Geotechnique and Natural Hazards*, pp251-262

Lombard, J.C., Lau D.T., Foo, S. (1999), "Experimental Study of Reinforced Concrete Shear Walls Strengthened with Fibre Reinforced Plastic Sheets", *Proceedings 8th CCEE*, pp543-548.

National Research Council of Canada, Institute for Research in Construction NRC/IRC (1990), *National building Code of Canada*, Ottawa, Ontario.

National Research Council of Canada, Institute for Research in Construction NRC/IRC (1993a), *Manual for Screening of Buildings for Seismic Investigation*, Ottawa, Ontario.

National Research Council of Canada, Institute for Research in Construction NRC/IRC (1993b), *Guidelines for Seismic Evaluation of Existing Buildings*, Ottawa, Ontario.

National Research Council of Canada, Institute for research in Construction NRC/IRC (1995a), *National Building Code of Canada*, Ottawa, Ontario.

National Research Council of Canada, Institute for Research in Construction NRC/IRC (1995b), *Guidelines on Techniques for Seismic Upgrading of Building Structures*, Ottawa, Ontario.

Public Works and Government Services Canada PWGSC (1995), *Guideline on Seismic Evaluation and Upgrading of Non-structural Building Components*, Ottawa, Ontario.

Public Works and Government Services Canada PWGSC (1997), *Seismic Assessment Guidelines for Stone Masonry Structures*, Ottawa, Ontario.

Public Works and Government Services Canada PWGSC (1999), *Procedure for Seismic Assessment of Existing Buildings*, Ottawa, Ontario.

University of British Columbia UBC (1998), *Shake Table Testing of Functional and Operational Components of Buildings*, Department of Civil Engineering, Vancouver, British Columbia.