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The Use of Innovative Technologies in the Seismic Retrofit of Canadian Federal Buildings

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ABSTRACT

The casualties and damage associated with the recent Northridge and Kobe earthquakes illustrate the catastrophic impact of a major earthquake on urban cities, and demonstrate that an earthquake does not necessarily have to be the "Big One" to cause widespread destruction. Public Works and Government Services Canada (PWGSC) is the federal agency responsible for providing a safe and productive work environment to federal departments. In order to mitigate the seismic risk associated with an aging building stock, which has an average age of forty years, PWGSC is currently developing strategies and implementation plans for the well being of federal buildings. An integral part of the overall seismic risk reduction program is to evaluate and apply innovative technologies such that the federal buildings can be retrofitted in a cost effective manner. During the past three years, PWGSC has demonstrated the successful and cost effective application of innovative technologies such as passive damping devices and advanced composite materials in a number of seismic upgrading projects on federal buildings. Passive damping devices reduce the level of lateral forces applied to the building provided that the structure is responding elastically, while wrapping structural components with carbon fibre reinforced plastic sheets increases their strength and ductility. The use of these innovative technologies in building retrofit projects is far less intrusive to building occupants and can offer significant cost savings in construction costs. Additional and potentially greater savings can be realized by avoidance of tenant relocation and associated productivity losses. This paper gives an overview of PWGSC's progress in the reduction of seismic risk to federal buildings and discusses the effectiveness of and the experience gained through the use of innovative technologies for seismic upgrading.

BACKGROUND

Building code requirements for seismic lateral forces for high seismic areas in Canada have increased by as much as 100 per cent since the early 1970's. The results are that new buildings have adequate seismic protection. Since building codes are not applied retroactively, older buildings are therefore found to be potentially vulnerable to severe damage or collapse when subjected to seismic lateral forces as specified in the current code. The recent earthquakes in Northridge, California (1994) and Kobe, Japan (1995) revealed the fact that an earthquake does not necessarily have to be the "big one" to cause widespread destruction, especially among older buildings. Past earthquakes have also demonstrated that these older building would have survived, in most cases, with a reasonable upgrading.

Recent advances in earthquake engineering result in more refined methods for analysis and design, and an increasingly better determination of site and soil parameters. The current edition of the National Building Code of Canada or NBC 1995 (NRC 1995) does not prevent the designer from using better analysis tools to determine the expected level of forces induced in the building during an earthquake as long as certain minimum levels are met. At the same time we recognize the fact that building code requirements are written for the design of new buildings, leaving minimum requirements for existing construction to other documentation and published guidelines.

In less than a decade, much progress has been made in developing innovative structural and non-structural hazard reduction measures in buildings. Advanced composite materials and new technologies have been extensively researched

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and, to a lesser extent, applied in seismic retrofit projects. As most building codes, including the National Building Code of Canada, are moving from prescriptive to objective based, more flexibility in meeting stated performance requirements is allowed. The use of innovative technologies lends itself well into adopting the new code development criteria.

An integral part of the PWGSC's seismic risk reduction program is to evaluate and apply innovative technologies such that the federal buildings can be retrofitted in a cost effective manner. During the past three years, PWGSC has demonstrated the successful and cost effective application of innovative technologies in a number of seismic upgrading projects on federal buildings. These retrofit projects have three things in common: older buildings in need of a reasonable upgrading, performance evaluation using refined analysis method and use of innovative technologies. This paper gives an overview of the seismic risk reduction program and of the use of innovative technologies in the seismic retrofit of a few federal buildings.

SEISMIC RISK REDUCTION

The primary consideration of a seismic risk reduction program is to prevent the partial or total structural collapse of a building. In general, the life-safety objective is not met if either the building collapses or partially collapses and/or exit and entry routes are blocked. Life can be saved by virtue of a building's capability to withstand seismic ground motions. Seismic risk reduction is not restricted to structural components. Non-structural components such as stairs, rigid partition walls, ceilings, mechanical equipment, office components, etc. are also part of the risk reduction program. This paper deals only with the structural risk reduction issues and results of an implementation plan in British Columbia.

PWGSC is currently developing specific earthquake risk reduction strategies and implementation plans to bring older federal buildings to a standard consistent, in most cases, with current Canadian building code requirements. As stated above, there is no specific code in Canada that addresses existing construction. Commentary K of the NBC 1995 establishes a guide for loads and recommended procedures to follow. Consistent with the NBC 1995 and other guidelines (NRC/IRC 1993a, NRC/IRC 1993b, NRC/IRC 1995, PWGSC 1995, PWGSC 1999a, PWGSC 1999b), PWGSC's seismic risk reduction strategy is a three-phase risk reduction program that encompasses screening, evaluation and upgrading.

The screening process defines basic criteria for potential structural and non-structural hazards and involves the screening of buildings to prioritize the buildings according to their degree of seismic risk. In the evaluation process, a detailed investigation of buildings in moderate to high seismic areas is performed including buildings that as a result of the preliminary screening are classified medium or high priority for a more detailed evaluation. 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 Screening

This is the first level of the 3-phase risk reduction program. Screening entails assessing buildings to ascertain their level of seismic risk (low, moderate or high) following a simplified procedure whose main objective is to determine if the building should or should not be subject to a more detailed investigation. The methodology used follows the document entitled *"Manual for Screening of Buildings for Seismic Investigation"* developed by the National Research Council's Institute for Research in Construction (NRC/IRC 1993a). Its purpose is to establish numerically a Seismic Priority Index (SPI) which results from the addition of a Structural Index and a Non-Structural Index.

Major factors to determine the screening score are the building location (seismicity of the area), soil conditions, type and use of the structure, obvious building irregularities, the presence or absence of non-structural hazards, building age (i.e. design code used), and the building importance and occupancy characteristics. The bench mark for the screening is the 1990 edition of the National Building Code of Canada or NBC 1990. That is, for a building built in full compliance with NBC 1990 on firm soil, the Structural and Non-Structural Indexes are both equal to 1.0.

The purpose of the screening process is to identify and prioritize which buildings pose a potential seismic hazard. Buildings are ranked according to their SPI score. 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. As a guide to make decisions with respect to potential building vulnerability and a more detailed evaluation need, the following rating system may be used: For SPI less than 10, low priority; For SPI between 10 and 20, medium priority; For SPI larger than 20, high priority. 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. A cut-off value of 12.0 for SPI is used to propose a more detailed evaluation.

Performance Evaluation

This is the second level 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 entitled *"Procedure for Seismic Assessment of Existing Buildings"*, (PWGSC, 1999a). 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 1885 to full NBC 1995 conformity,

(5) Follow the *"Guideline for Seismic Evaluation of Existing Buildings"* (NRC/IRC 1993b) for applicable evaluation statements and check calculations to identify potential structural and configuration deficiencies for the 60% level of NBC 1995. Adjust the results for the desired performance level,

(6) Identify significant non-structural hazards following the criteria established in the *"Guideline on Seismic Evaluation and Upgrading Non-Structural Building Components"* (PWGSC 1995).

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 (NBC 1995) or more refined linear or non linear dynamic analysis, including the use of a series of suitably modified earthquake time-histories in the linear or non-linear range. The 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 plan, and cost estimates of the work for the benefit of our clients.

Of the nineteen PWGSC buildings in British Columbia that have undergone a performance seismic evaluation, two belong to low risk, three belong from low to moderate risk, six belong to moderate risk, five 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 risk reduction program. The purpose of seismic upgrading is to enhance the overall resistance of the building and individual structural and non-structural 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), minimum cost for the intervention, and in general achieve a minimum intervention if objectives of life-safety and damage control are met. Seismic upgrading becomes necessary if it is shown that, through a seismic performance evaluation, the structure does not meet minimum requirements up to the current building code and may suffer severe damage or even collapse during a seismic event.

Conventional upgrading techniques usually include the strengthening of existing shear walls, addition of new walls and/or steel bracing, upgrading connections, etc. The building foundations often require strengthening, and eventually anchorage to bedrock. Adopting these recommendations often leads to heavy demolition, lengthy construction time, reconstruction, and tenant relocation with all the associated direct and indirect costs. 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 can be 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 carry out cost-effective seismic upgrading projects. The objective was to provide the buildings with an equivalent seismic safety, as specified in the intent of the national building codes and existing guidelines that address these issues, at an affordable cost.

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

INNOVATIVE TECHNOLOGIES AND SEISMIC RETROFIT OF BUILDINGS

During the past three 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 nineteen, 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: 6,243m^2, concrete) the Revenue Canada Building in Victoria (built 1965, area: 4,785m^2, concrete) the Federal Building in Port Alberni (built 1960, area: 2,400m^2, concrete) and the Standards Building in Vancouver (built 1963, area: 1,562m^2, steel and concrete). While Victoria building underwent conventional seismic upgrading with the addition of new reinforced concrete walls and extensive foundation upgrading, all the others 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. Figure 1 shows one of the X-braced friction dampers installed in the building.

The Standards Building in Vancouver has been upgraded incorporating conventional techniques (new steel bracing) with multi-layered fibreglass reinforced cement (FRC) to transform existing non-load bearing unreinforced masonry block walls to shear walls which are connected to the steel framing. The fibreglass mesh being plastered to the back wall is illustrated in Figure 2. Figure 3 shows the upgraded masonry block wall in the front, with the original unreinforced masonry block walls visible in the background.

The Port Alberni Federal Building was the first application of CFRP in western Canada to a number of reinforced concrete columns. Figure 4 illustrates the application of CFRP sheets onto the column. The tenants remained on site during construction, with the columns boarded for the application (Figure 5).

Initial recommendations for the seismic retrofit of the Harry Stevens Building were based on a conventional upgrading approach which was found to be both cost excessive and intrusive. The construction cost of this upgrade was estimated to be around C$1,400,000. To achieve cost savings while meeting equivalent seismic safety requirements, PWGSC decided to consider the use of friction dampers in this building. Evaluation of seismic performance using refined analysis confirmed that this technology would be suitable and much less intrusive. In this particular case, foundation upgrading was not required due to sufficient energy dissipation in the upper stories. The project has been completed with the tenants allowed to remain on site during the upgrading. The total cost of the structural upgrading was approximately C$800,000. Overall direct cost savings in the order of 35% were realized upon completion. Indirect costs calculated at about C$650,000 (phased relocation) were not incurred.

Other projects employing alternative technologies include the seismic upgrading of Government of Canada buildings in New Westminster and Nanaimo, for which the simultaneous application of friction dampers and CFRP have been investigated and are now being considered. It is expected that savings of 30-40% in direct upgrading construction costs can be achieved with respect to conventional solutions.

CONCLUSION

In order to mitigate the seismic risk associated with older buildings, PWGSC is currently developing strategies and implementation plans for the well being of federal buildings. An integral part of the overall seismic risk reduction program is to evaluate and apply innovative technologies such that the federal buildings can be retrofitted in a cost effective manner. During the past three 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 in building retrofit projects has been proven to be far less intrusive to building occupants and cost effective. Potentially great savings can be realized by reduction in construction cost and by avoidance of tenant relocation and associated productivity losses.

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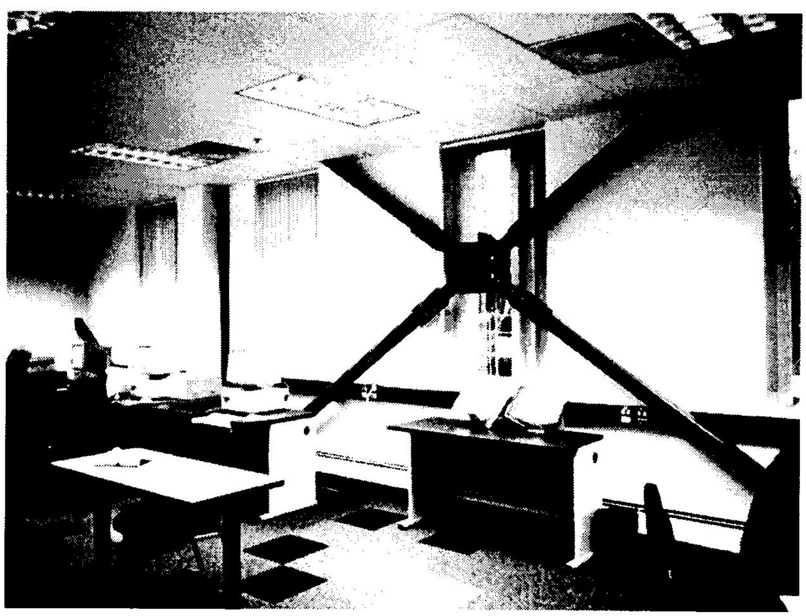

Figure 1 An X-braced friction damper

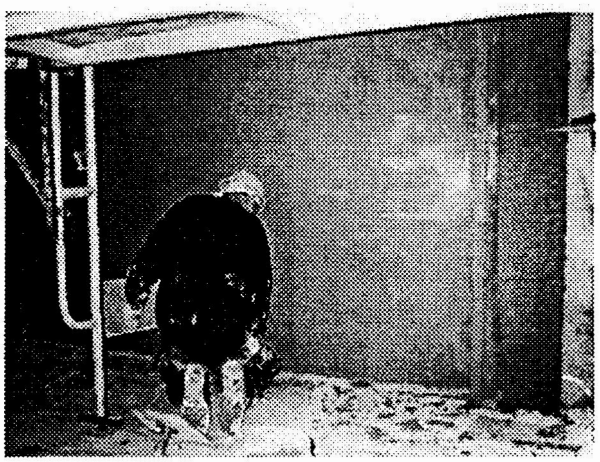

Figure 2 Fibreglass mesh being plastered to URM

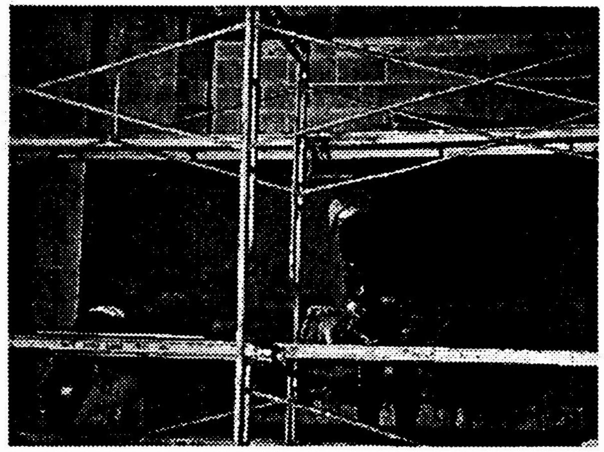

Figure 3 URM with (front) and without (back) fibre reinforced cement

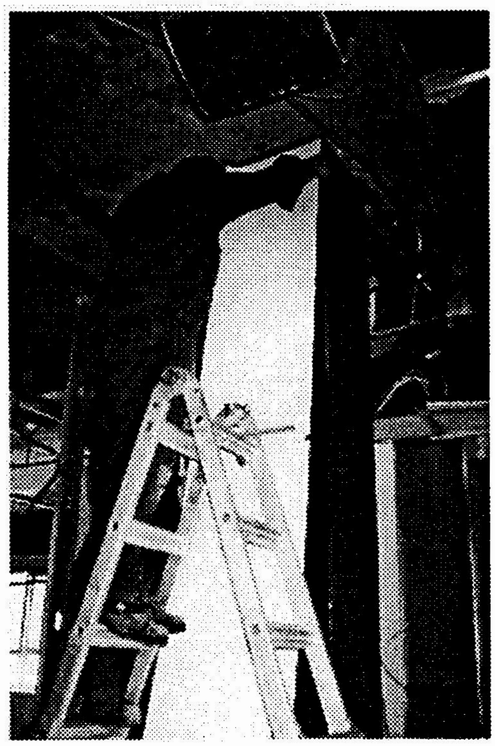

Figure 4 Application of CFRP sheets on column

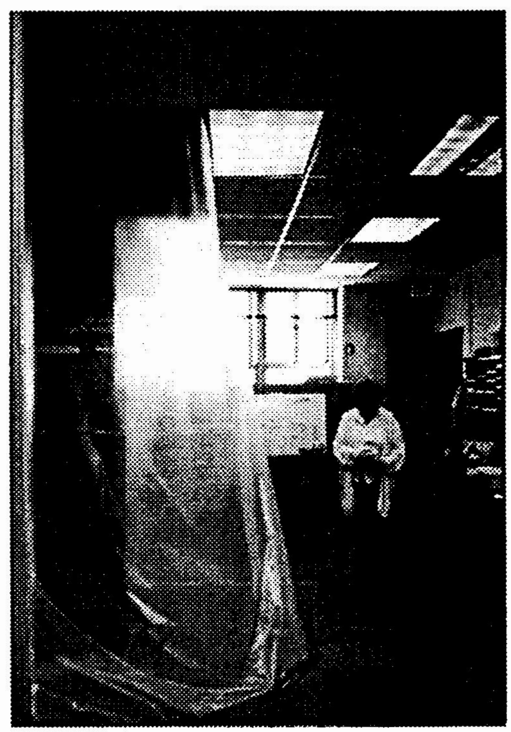

Figure 5 Localized construction with minimum disturbance to building occupants