7th Canadian Conference on Earthquake Engineering / Montreal / 1995
7ième Conférence canadienne sur le génie paraséismique / Montréal / 1995

Seismic Risk/Benefit Analysis of 1150 At-Risk Buildings in Vancouver, B.C. - Phase 1 : Seismic Vulnerability Survey

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ABSTRACT

Vancouver is located in one of the highest earthquake hazard zones in Canada. The City of Vancouver (CoV) is aware of the seismic risks that face the city and wishes to quantify and mitigate these risks. A seismic risk/benefit study can supply relevant information to assist in policy decisions. This paper presents a seismic vulnerability survey, the first phase of a seismic risk/benefit study, carried out on over 1100 privately owned, at-risk buildings in Vancouver. The methods and results of the survey are described, identifying the higher risk building types and their usages.

INTRODUCTION

The west coast of Canada is an area of potentially high earthquake activity. Vancouver, British Columbia, the largest city on this coast, has a high number of seismically vulnerable, privately-owned buildings. The City of Vancouver (CoV), wish to reduce this seismic risk by encouraging voluntary upgrade by owners and investigating possible mandatory measures that may be appropriate and acceptable to the community.

A Seismic Risk /Benefit Analysis of the city's vulnerable building population is a valuable tool in the development of the necessary policies and procedures. This paper will describe the implementation of the first phase, which is a survey and analysis of seismic vulnerability.[3]

SEISMIC RISK/BENEFIT ANALYSIS

A seismic risk/benefit analysis measures the risks related to an earthquake occurrence and the extent of risk reduction (benefits) achieved by varying levels of building upgrade. This analysis provides a scientific basis for critical earthquake risk reduction decisions.

The ***risk*** scenario involves assessing the structural and non- structural characteristics which influence the degree of damage experienced by a building subjected to earthquake hazards such as

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3 The extent of the study is too large to be dealt with in one paper and at time of writing the second phase of the work, the actual risk/benefit analysis, is just being completed and is not yet available for publication. It is anticipated that further papers will be prepared for future publication.

ground shaking, liquefaction, surface fault rupture, slope instability etc. This information, collectively referred to as the seismic vulnerability data, combined with specific seismic hazard data can be used to assess such risks as probability of injury or loss of life, loss of building use, loss of heritage resources and many other risk scenarios. ***Benefit*** scenarios are developed by comparing the construction costs for various levels of seismic upgrade to the reduction of building vulnerability achieved. These scenarios can be applied to a given building group and used to evaluate potential life-safety and socio-economic impacts of loss reduction measures.

The seismic risk/benefit analysis can be applied in many seismic mitigation assessments:- appropriate levels of retrofit for high priority buildings, cost effective measures to enhance life safety, heritage preservation, reduction of business interruption, sequencing for programs of seismic retrofit, incentive measures, emergency response planning and research and development initiatives.

OBJECTIVES OF THE STUDY AND SELECTION OF BUILDINGS

The broad objective of the study was to establish a base of knowledge which would allow the CoV to develop policy on seismic upgrading for private building owners. Initially risk assessment and ranking objectives study were:-

- develop a database of building inventory and vulnerability data;
- rank buildings for further evaluation in terms of seismic vulnerability;
- assess and rank life safety risk to building users, neighbours and the general public;
- assess the risk of loss of housing units and architectural heritage resources;

These objectives were to be achieved using a sample of approximately 1150 buildings from the City building inventory,estimated to contain 100,000 plus buildings of every major structural type. It is important to note the basis for selection of this sample. The buildings are all privately owned and considered by CoV to be seismically at risk. The criteria for this assessment of risk were buildings:-

- designed and constructed prior to 1973 the date of adoption of modern seismic provisions in the City's Building By-Laws; ***and***
- three storeys or greater in height.

The City first adopted the seismic provisions of the 1965 National Building Code of Canada (NBCC) in 1967 and in 1973 adopted the entire NBCC, 1970 edition. Requirements based on modern seismic analysis of structures were first introduced in the 1965 code and refined in the 1970 and subsequent codes. These requirements recognise dynamic response of buildings to seismic forces. The selected buildings generally fall into two groups:-

- those designed and constructed prior to the use of modern seismic design practices;
- those probably designed with seismic forces applied but unlikely to have been detailed for an appropriate level of ductility.

The selection of the height factor is somewhat arbitrary but reasonable considering the total number of buildings in the city. Most buildings in the city's inventory are 1 and 2 storey residential units of wood light frame (WLF) construction. This type of structure is generally considered to perform reasonably in an earthquake and is not, therefore, significantly at risk.

The sample was developed as a "worst case" scenario rather than a representative sample of all buildings in Vancouver in order to rank the most at-risk buildings in the City. It is recognised, however, that any projections for city-wide levels of life loss and damage based on this sample, could be misleading and need to be appropriately qualified.

PLANNING OF THE VULNERABILITY SURVEY

Existing Screening Methodology

The physical seismic survey of 1150 buildings requires careful planning to ensure the data collected is both relevant and accurate enough for the proposed objectives of the study. A methodology for such a survey has been developed in Canada by the National Research Council in their publication "Manual for Screening of Buildings for Seismic Investigation" and the planning aspects are presented therein. Briefly, the procedure is to assess the seismic vulnerability of a building by considering the following parameters:-

- building size
- date built
- structural type
- height
- structure irregularities
- floor area
- ground seismic hazards
- layout irregularities
- non-structural falling hazards (e.g. parapets, chimneys)
- usage
- occupancy level and type
- heritage designation
- post-disaster assignment
- hazards to continuous operation of the building

Information is collected by field survey and/or drawing and file review and entered on a specially designed screening form. Weighted numerical values are then applied to the various parameters depending on the seismic risk they present. Structural and non-structural indices are then calculated for each building to rank them in terms of vulnerability in an earthquake.

Further Development of the Screening Methodology

In view of the large number of buildings encompassed by this study, the survey team decided to computerise the NRC data processing methods and introduce further quality control parameters. The methodology presented in the NRC manual was developed in four areas:-

- data management processes;
- measures of confidence levels in field data;
- quality assessment;
- modifications to suit survey objectives.

Data Management Processes

A major objective of the study was to create a computerised database of the building seismic data. The team used a commercially available database program as a platform for the survey database. The program was set up to generate weightings and indices automatically as the building data was entered. This eliminated the necessity for the calculation page of the NRC screening form. The form was therefore modified to record pre-field and field data only. The data was entered along with electronically scanned photographs and field sketches to build a complete description and rating of a building.

Measure of Confidence Levels in Field Data

An explicit parameter was introduced to measure confidence in the data.

Structure Type Confidence Factor (low, medium, high rating) is the parameter used by the inspecting engineer. As an example, a medium or low confidence rating would be assigned if the structure of a building is hidden by architectural finishes and not readily identifiable or a building consists of several structure types and the most conservative type is selected.

Type of Survey and Recommendation for Further Survey identifies the type of survey undertaken and recommends further survey if considered necessary by a low confidence rating. The survey types are:- Walk-By; Walk-Through; and Drawing Review. The differences between the types are important in planning the initial level of survey required and assessing the quality of the survey achieved.

Quality Assessment

The study, using the NRC methodology, attempts to quantify seismic vulnerability of a building in order to rank them for further evaluation. As another evaluation method, the team introduced subjective parameters based on engineering judgement of the overall performance of a building generally and as compared to similar buildings.

Structure Type Quality Factor (1 = well above to 5 = well below) is based on the expected performance of the building compared to buildings of the same type. It also takes into account the building irregularities noted above. This information is important in risk analyses and is used to determine variabilities of performance within building types.

Overall Structural Vulnerability Factor (OSV) (1 = good to 5 = poor) is determined by engineering judgement based on the overall expected structural performance of the building. It considers the materials of construction, building type, height, irregularities and other relevant structural parameters. The OSV is a subjective measure of the likely seismic performance of a building. It is used as an approximate validation of the calculated indices and as a method of highlighting possible inconsistencies within them.

Modification to Suit Survey Objectives

Introduction of Vancouver Building By-laws (VBBL): An entry was added to relate the date of building design to the VBBL in effect at the time and thus to the applicable edition of the National Building Code and its seismic design requirements.

Modification of Scoring Indices to Suit Study Objectives: Assessment of the seismic risk to heritage buildings required that their importance be highlighted in the ranking of buildings at risk. A heritage factor was added to the calculation of the building importance index. The NRC Importance index ranges from 0.7 for low occupancy buildings to 2.0 for post disaster or very high occupancy. The City differentiates heritage structures as "listed "or" designated". Values of 1.5 and 3.0 were assigned respectively to this index.

IMPLEMENTATION OF THE VULNERABILITY SURVEY

Start-up and Control of the Survey

In order to implement survey checking and control, the team utilised a combination of all three methods of survey referred to previously. All buildings were surveyed using a walk-by survey. Walk-through and drawing reviews were applied to samples from the surveyed buildings as a cross-check on consistency and quality of data. Plans were to walk through approximately 10% of the inventory and review the drawings of about 10 high-priority buildings.

Logistics of the Screening Survey

In planning the field work for this survey, the team addressed several details that ensured optimisation of resources and minimal public impact. These included:-

- Efficient route planning
- Use of restricted parking areas to minimise time for parking
- Methods of travel between buildings - walk, bicycle, automobile
- Photographic methods - film, CD camera
- Data collection method - forms, laptop computer
- Form and photograph control
- Safety of inspectors
- Interaction with owners, occupiers, public and media

Route planning is important for optimising time on the survey. In this case, 65% of the buildings were within a 1.5 km radius in the downtown area, 23% within a 3 km radius and the remaining 12% within a 6km radius. The average travel time between buildings was approximately 10 minutes in this survey.

The survey team considered the use of electronic data gathering and photography but ruled it out. Supply of several teams with equipment and production of photographs from CD's were both expensive and impractical.

This particular survey, by a public authority, of privately-owned buildings presented an element of possible misunderstanding by owners and occupiers. Teams were supplied with identification and letters of authority by the CoV. Letters did not explicitly state the reason for the survey but simply that a structural review of City records was underway.

Enquiries from the general public and the media were referred to the CoV for explanation of the work. This was to minimise any biased or inconsistent reports which might cause over-reaction or unnecessary concern, especially among building owners or occupants.

RESULTS OF THE SEISMIC VULNERABILITY SURVEY

The number of buildings surveyed by walk-by was 89%, by walk-through 8% and by drawing review 3%. It is worth noting from a structural point of view that a walk-through did not generally reveal any more valid structural data than a properly conducted walk-by. This is due to the interior architectural and non-structural finishes which hide the structure in the majority of buildings surveyed. The number of walk-through were therefore reduced and the drawing reviews increased.

Distribution of Buildings Surveyed

The objectives of the screening survey require three primary distributions of the building portfolio: Structural Type (NRC classification); Use and/or Occupancy; and Heritage Class.

Structural Type	% of total	
Unreinforced Masonry	(URM)	41%
Concrete Shear Wall	(CSW)	38%
Concrete Moment Frame	(CMF)	9%
Concrete Frame with infill masonry walls	(CIW)	5%
Reinforced Masonry Bearing Walls wood/metal deck floors and roofs	(RML)	2%
All Other Types		5%

Use and/or Occupancy Type	
Assembly	4%
Institutional	1%
Residential	58%
Office	26%
Mercantile	3%
Industrial	7%
Parking	1%

Heritage Class	
Heritage Classification	22%
Non-heritage	78%

Ranking of Buildings Surveyed

Scoring Systems

The survey team used two correlated scoring systems to rank the buildings for further structural evaluation. These were the *Structural Index (SI)* from the NRC screening manual and the *Overall Structural Vulnerability (OSV)* developed by the team.

Briefly, the SI is a function of seismicity, soil conditions, type of structure, building irregularities and building importance. It is a quantitative index compared to the qualitative OSV, previously described.

The team also considered the *NRC Non-Structural Index (NSI)* and *Seismic Priority Index (SPI)*. The NSI is a function of soil conditions, building importance, interior and exterior falling hazards and hazards to continuous operations of special or heritage buildings. It must be noted that the screening survey was primarily a walk-by survey, the collected data was therefore limited to exterior items (chimneys, parapets, glass over exits etc.). Interior falling hazards or equipment and lifeline operations were not addressed. The team chose not to use the Seismic Priority Index as a tool for setting priorities for two reasons. Firstly, the SPI includes the non-structural index which is based on limited building data and, secondly, using the structural index met the objectives of the study more closely, especially regarding loss of use of a building.

The use of the SPI is debatable and in the author's opinion should only be used if the objectives of the study are clearly defined and the influence on setting priorities is understood. Typically, structural and non-structural issues can be dealt with separately and are therefore ranked separately.

	Range of Scores
Structural Index	2 to 168
Non-Structural Index	1 to 24
Seismic Priority Index	4 to 192

Ranking of Scores and Correlation of Evaluation Priorities

The team developed a series of priority categories and related scoring ranges in conjunction with the NRC. The ranges were correlated with the OSV judgement factors and modified to establish a system which accounts for quantitative measurement and engineering judgement in ranking the building portfolio.

Structural Index Ranking	Range of SI	Priority for Further Evaluation
1	1 - 3	Very Low
2	4 - 7	Low
3	8 - 28	Medium
4	29 - 40	High
5	40+	Very High

Distribution of Buildings by Evaluation Priorities

	% of Buildings	
Priority for Further Evaluation	Structural	Non-Structural
Very Low	0.5	11
Low	11	26
Medium	53	16
High	11	27
Very High	24.5	20

From this distribution it is seen that 35.5% or 400 buildings are in the high and very high categories for further structural evaluation. Non-structural evaluation amounts to 47% in these categories.

CONCLUSIONS FROM THE SURVEY

Phase 1 of this risk/benefit study meets two of the initial objectives set out by the CoV, namely:-

- Develop a database of vulnerability information for the selected buildings; and
- Rank the buildings in terms of priority for further seismic evaluation.

This work is the beginnings of an information base to support development of policies and procedures for seismic risk mitigation in Vancouver.

Structural Evaluation

Prior to evaluation of the data, a statistical analysis indicated a strong correlation between the subjective OSV factor and the objective structural type and irregularity factors. This correlation strengthened the validity and consistency of the vulnerability data.
Some highlights of the structural evaluation:-

- In the high priority SI categories, nearly 75% are of unreinforced masonry construction.
- The remaining 25% are concrete frame and shearwall construction.
- Nearly half the buildings in the category are residential occupancy.
- One-third of the category are office buildings.

- A total of 316 buildings are high occupancy types (office and residential).
- 248 buildings in this category are heritage buildings.

The findings indicate that the need to further evaluate URM residential and office buildings is the highest priority. These buildings present a significant seismic risk in terms of life safety and building losses.

The large number of heritage buildings in the high priority category is not unexpected due to the increased weighting applied to this group and the fact that their construction generally predates modern building codes.

Non-Structural Evaluation

The non-structural evaluation undertaken is limited to exterior appendages and architectural features. Priorities for further evaluation and risk assessment are therefore only valid in that context. Nonetheless, nearly 50% of the buildings surveyed are in the high priority categories.

The Next Phase

In the next phase, seismic risk levels will be quantified in terms of losses to human life, injury estimates and repair costs for damage to the selected buildings in their present condition. Benefits will be assessed by considering the reduction in losses resulting from the implementation of various feasible levels of seismic upgrade. A separate, ranked listing of buildings will be developed for non-structural upgrade of exterior items. These items can be quickly and relatively inexpensively upgraded. Further analysis will demonstrate the cost/benefit and risk reduction/ benefits of such measures.

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ACKNOWLEDGEMENTS

The authors wish to thank the following individuals who made invaluable contributions to this work with their advice and knowledge.

City of Vancouver: R. Maki, A.Geraghty
National Research Council: J. H. Rainer
Delcan, Norecol,Dames and Moore: A. Porush, W. P. Graf, E. Trahern, N. Abhyankar, G. Gauld, S. Akbari