TABLE OF CONTENTS

The Seismic Risk/Benefit Analysis of Privately Owned Buildings in the City of Vancouver consists of a Report in Two Phases and 6 Volumes of Supporting Data.

Report
Phase 1 - Earthquake Hazard Assessment and Seismic Vulnerability Survey
Phase 2 - Seismic Risk/Benefit Analysis

Supporting Data
Volume 1 Summary of Data and Seismic Indexes
Volume 2 Completed On-Site Screening Forms
Volume 3 Completed On-Site Screening Forms
Volume 4 Completed On-Site Screening Forms
Volume 5 Completed On-Site Screening Forms
Volume 6 Completed on-Site Screening Forms

TABLE OF CONTENTS - PHASE 1

APPENDICES

EXECUTIVE SUMMARY

The City of Vancouver is proceeding with a program to assess the hazards associated with the occurrence of an earthquake affecting Vancouver. This information is used to assess 1150 privately-owned buildings considered to be seismically "at-risk" in the City.

The selected buildings were generally constructed prior to the adoption of modern earthquake-related provisions in the City's building bylaws and may pose a life-safety risk to the occupants, neighbours and the general public. Additionally, loss of housing units and heritage resources is being assessed as part of the program.

The City selected the team of Delcan, Norecol Dames and Moore (DNDM) to assist in collection and categorization of seismically relevant structural and non-structural building data by rapid visual screening and to rank the building inventory by priority for closer evaluation.

This work is referred to as a Seismic Vulnerability Survey and is an integral part of a seismic risk/benefit analysis for a building inventory.

DNDM are now currently undertaking such an analysis for the City on the selected buildings. This report describes the work completed, and is Phase 1 of a 2 phase report. Phase 1 includes an overview of the earthquake hazard and magnitude range which may affect Vancouver, a seismic vulnerability survey of the selected buildings, a review of the priorities for future evaluation of the buildings and preliminary development of budgetary upgrade costs to reduce building vulnerability.

The risk/benefit analysis will combine differing levels of earthquake magnitude with budget construction costs for various levels of seismic upgrade to develop loss-reduction scenarios. The analysis can therefore be used to evaluate life-safety and socio-economic impacts from a number of possible loss-reduction measures targeting a given group of buildings.

With this information, the City will be in a position to consider such issues as appropriate levels of retrofit for high priority buildings, cost effective measures to enhance life safety, heritage preservation, business interruption, sequencing for

programs of seismic retrofitting, incentive methods to encourage seismic retrofit, emergency response and planning and research and development initiatives. The risk/benefit study will present a researched, rationalized body of knowledge to support any decisions taken and programs proposed.

Preliminary results from the Phase 1 report indicate a need to reduce the vulnerability of unreinforced masonry buildings, including both residential and office usages.

1 INTRODUCTION

The City of Vancouver has embarked upon a program of seismic hazard and risk analysis of 1150 potentially at-risk, privately-owned buildings in Vancouver. The program is intended to assess and rank:

- life safety risk to the building users, neighbouring building occupants and the general public;
- the risk of loss of housing units and architectural heritage resources;

in the event of an earthquake affecting Vancouver.

The 1150 potentially vulnerable buildings were selected by the City on the following basis:

- buildings designed and constructed prior to the dates of adoption of modern seismic provisions in the City's building bylaw;
- buildings three storeys or greater in height.

The City first adopted the seismic provisions of the 1965 National Building Code of Canada in 1967 and in 1973 adopted the complete 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 code.

A seismic hazard and risk analysis essentially involves assessing the structural and non-structural characteristics which influence the degree of damage experienced by a building (vulnerability) subjected to earthquake hazards (ground shaking, liquefaction, surface fault rupture, earthquake-induced slope instability etc.,). When combined with specific seismic hazard data, the seismic vulnerability data can be used to assess such risks as probability of injury or loss of life, loss of use, loss of heritage resource and many other risk scenarios.

Risk/benefit scenarios can be developed by introducing construction cost factors for various levels of seismic upgrade used to reduce building vulnerability. The scenarios can be used to evaluate potential life safety and socio-economic impacts of loss reduction measures applied to a given building group.

The team of Delcan, Norecol Dames & Moore (DNDM) was selected to assist the City in gathering building seismic vulnerability data to be used in the risk analysis program. This work is referred to as a Seismic Vulnerability Survey and involves the collection and assimilation of the building inventory and vulnerability data into a manageable database and the assessment of priorities for further evaluation of the buildings.

DNDM has supplemented the survey with a review of the potential earthquake related hazards and development of budgetary construction cost data for various levels of seismic upgrade for typical building structures and heritage buildings.

This report is therefore effectively, the first phase of a risk/benefit analysis and is the necessary data for carrying out the analysis. The risk analysis is now underway and will be the subject of the Phase 2 report to the City of Vancouver.

As an adjunct to the Seismic Vulnerability Survey the phase 1 report also serves as an example and guide to the methods of gathering seismic related data and establishing priorities, by visual screening of buildings using the National Research Council of Canada's "*Manual for Screening of Buildings for Seismic Investigation*".

The report contains an overview of the screening forms, the ranking methods and building types, vulnerabilities and typical damage caused by earthquake forces. In addition, a qualitative engineering judgement method has been introduced as a check and control on the validity of the data collected.

By study of the report, and review of the building data and appropriate reference to the Manual, City of Vancouver Inspectors should be able to develop the necessary skills to screen buildings and prioritize them for further evaluation.

1.1 SCOPE OF SERVICES

The City of Vancouver selected the team of Delcan, Norecol Dames and Moore to carry out a Seismic Vulnerability Survey based on DNDM's proposal dated April 1993. This proposal responded to the city's document entitled "*Proposal Call for Seismic On-Site Screening of Privately-Owned At-Risk Buildings in Vancouver - Terms of Reference*".

In addition to the original scope of services proposal and at the City's request, DNDM submitted an enhanced scope of services proposal in their letter dated June 23, 1993 with three options for enhancement. These enhancement options were included in the final agreement between the City and DNDM, with one option to be selected during the first phase of the project, to be the second and final phase of the project.

The scope of service was agreed to include the following:

- A seismic vulnerability survey in accordance with the NRCC "*Manual for Screening of Buildings for Seismic Investigations*" of 1150 buildings selected by the City of Vancouver;

- Vulnerability Survey to include:
  - General Building Inventory Data;
  - Vulnerability Review and Condition Assessment - (Structural and Non-Structural) based primarily on "walk-by" visual surveys of all buildings and "walk-through" surveys and drawing reviews of approximately 10 to 15% of the buildings;

- Ranking of buildings in terms of vulnerability to establish priorities for further seismic evaluation;

- Development of a computerized database to manage the information;

- Development of generic upgrade/retrofit concepts along with unit retrofit cost estimates.

The proposed enhanced services included:

- A comprehensive risk/benefit analysis to provide a scientific basis for critical earthquake risk reduction decisions such as appropriate levels of retrofit for high priority buildings, cost effective measures to enhance life safety, heritage preservation, reduced business interruption, sequencing for programs of seismic retrofit, incentives which the City may consider for benefits received, emergency response and planning and research and development initiatives;

- An increase in the number of buildings for which walk-through or drawing reviews are performed, to increase the reliability of the seismic vulnerability and inventory data and to refine retrofit concepts for difficult buildings;

- Enhancements to the computerized building seismic inventory database system.

During the course of Phase 1, the risk/benefit analysis was selected by the City as the option which best met their requirements. However, the remaining options have been incorporated to some degree. Additional buildings have had drawing reviews undertaken and the database will be supplemented by the inclusion of electronically scanned photographs and sketches during Phase 2.

1.2 USE OF SEISMIC SURVEY INFORMATION

The information collected and assimilated from the Seismic Vulnerability Survey of 1150 buildings in Vancouver is used to rank the buildings in terms of priority for further evaluations by a qualified Professional Engineer experienced in seismic design.

The screening procedure used in the survey is a rapid method that identifies, from a large inventory of buildings, those that may pose various risks such as loss of life, bodily injury, loss of usage or loss of heritage resource in an earthquake. Although structural and non-structural parameters are observed and judged as part of the screening process, it is not an evaluation for seismic or structural adequacy.
By its nature, a rapid examination and ranking method is limited in its ability to assess seismic performance and in some cases buildings that are seismically weak may be overlooked.

Every effort has been made to ensure that seismic vulnerability of the buildings is adequately identified. In cases where doubt existed in the field engineer's mind, a more conservative assessment has been recorded with appropriate "low confidence" ratings noted and recommendations for further review given.

The final survey document becomes a management tool for planning and policy decision making and is not to be considered as an engineering inspection for the structural or seismic competency of any building.

2 EARTHQUAKE HAZARD ASSESSMENT

2.1 REGIONAL TECTONICS AND SEISMICITY

The City of Vancouver is located in an active seismic region which encompasses the Pacific Northwest of the North American continent. The seismicity of the area is a result of stress and strain energy building between and within the rock plates of the earth's crust due to movement of the plates. This energy is released when the rock suddenly fractures or rapid slip occurs on faults between or in the plates, causing the ground to vibrate.

In the Pacific Northwest, the Cascadia subduction zone is the primary source of earthquake activity. (See plate O.) Here, the Juan de Fuca plate is slipping or subducting under the North American continental plate at an average rate of 3 to 4 cms/year. This movement between the plates can cause subduction earthquakes which are classified in two categories: Interplate and Intraplate. The interplate portion of the subduction zone is the interface between the Juan de Fuca plate and the crust of the North American plate. The intraplate portion is the brittle section of the Juan de Fuca plate beneath the crust of the North American plate. The Interplate boundary of the Cascadia Subduction zone is located west of Vancouver Island.

Although no large subduction zone earthquakes have been recorded there, scientific evidence suggests that great prehistoric interplate earthquakes have occurred in the Pacific Northwest. Results of recent geological investigations in coastal areas together with information gathered from other subduction zones around the world suggest that a magnitude M = 8.5 could occur in this region. According to Atwater (1987a,b), the latest event occurred about 300 years ago and may have been this large or possibly as large M = 9+.

Intraplate earthquakes can potentially occur beneath Puget Sound, Vancouver Island and the Strait of Georgia at depths of about 45 to 60 km and appear to be produced by tension within the Juan de Fuca plate. The 1946 (M - 7.3) on Vancouver Island and the 1949 and 1965 events beneath Puget Sound are such events. Current knowledge suggests that an earthquake of magnitude M 7.5 could potentially occur in this area on the intraplate portion of the Cascadia subduction zone.

In addition to the earthquake activity generated by the subduction zone, deformation within the plates can cause local shallow crustal earthquakes which occur at depths of less than 30 km below the earth's surface and are considered possible in this region. The greatest magnitude expected from a shallow crustal earthquake is M = 6.5 and is based upon the current understanding of the tectonics, geology and seismicity of the Pacific Northwest region. While the City of Vancouver is included in this region there are no known active faults with the City and the likelihood of a large (M = 6.5) earthquake location beneath the City if considered to be small.

As a comparison the recent earthquake in Northridge, Los Angeles measured M 6.7 with the origin approximately 19 km beneath the surface.

2.2 GEOLOGY

Plate 1 is the surficial geology map for the study area. The base consists of tertiary bedrock including sandstone, siltstone and conglomerate, part of the Coastal Mountain range. Inland water areas such as the Burrard Inlet were formed by deep trenches carved out by streams originating from the coastal mountains.

During several periods of glaciation, Vashon Drift and Capilano sediments were deposited by ice. Typically, a major portion of the study area is underlain by these glacial deposits.

Post glacial deposits (in the last 10,000 years) consists of Fraser River sediments (southern boundary of the study area) and shallow lake deposits in the upland areas. These shallow lake deposits contain peat overlying the glacial deposits.

More recently (in the past 300 years) manmade fills have been placed along certain parts of the shoreline. These areas are identified on ***Plate 1***, the filling of False Creek having the most impact in the study area. Typically, the landfill consists of end dumped sand, silty sand and gravel, and glacial deposits excavated from nearby upland sites.

2.3 GROUND-MOTION HAZARD

Two levels of earthquake ground motions in the City of Vancouver were estimated for use in the seismic evaluation of the selected buildings.

1. An Upper Level Earthquake (ULE) defined as the ground motion that has a 10 percent probability of being exceeded in 50 years, or stated another way, the ground motion that has an average return period of 475 years. This is the National Building Code of Canada (NBCC) "design" earthquake.

2. A Lower Level Earthquake (LLE) defined as the ground motion that has a 50 percent probability of being exceeded in 50 years, or stated another way, the ground motion that has an average return period of 72 years.

The LLE provides an estimate of the ground motion which is likely to occur during the lifespan of a typical building, whereas the ULE provides a reasonable upper bound of the ground shaking hazard.

For nearby sites in British Columbia, the LLE and ULE ground motion has been computed using information on seismic sources discussed above and published relationships developed by (1) Joyner and Boore (1988) for events of crustal original and (2) Crouse (1991a,b) for events originating in the subduction zone region. Considering the results of these studies, the horizontal ground accelerations on stiff soils (bedrock or glacial deposits) are estimated for the City of Vancouver as follows:

TABLE 2.1
Values of Peak Horizontal Ground Acceleration

Design Level of Earthquake Motion	Peak Horizontal Ground Acceleration
Upper Level Earthquake (ULE)	0.30g
Lower Level Earthquake (LLE)	0.15g

Ground motion during an earthquake may also contain a substantial vertical component. The NBCC suggests an average value for the ratio of vertical to horizontal ground acceleration, between 0.67 and 0.75.

As a basis for perspective, the engineering profession assumes that ULE ground accelerations on stiff soil of about 0.30g are typical for the Vancouver region and buildings designed to recent NBCC standards should be able to withstand this level of ground shaking without collapse. It should also be noted that the peak ground accelerations recorded in Seattle during the 1949 Olympia (M=7.1) and the 1965 Seattle M=6.5) earthquakes were between 0.05 and 0.10g, whereas the peak ground accelerations recorded in Olympia during the events were between 0.15 and 0.30g.

2.4 GROUND-MOTION AMPLIFICATION HAZARD

The ground motion hazard identified in ***Section 2.3*** provides values of peak horizontal ground acceleration on stiff soils such as bedrock or glacial deposits. A majority of the buildings under study are founded directly on the stiff soils and would be subjected to the anticipated horizontal acceleration given above.

A few structures are located in areas where available geological information and our experience suggests that the foundations are likely on post glacial sediments or on the landfill referred to in ***Section 2.2 Geology***. The type and depth of these loose or softer soils at a site affect the severity of ground surface shaking. These soils tend to amplify the ground shaking until the strength and stiffness of the soil is severely degraded.

2.5 FAULT-RUPTURE HAZARD

Available geologic maps show the locations of inferred or concealed faults in the Vancouver region. None of the buildings considered in this study are close to these faults, and therefore the potential for surface fault rupture at these locations is considered to be very low.

2.6 LIQUEFACTION HAZARD

Liquefaction is a phenonemon in which loose, saturated, granular soils lose their strength due to excess pore water pressure buildup during vibratory loading such as that from an earthquake. Liquefaction can produce ground settlement and lateral spreading of the soil which can affect foundation integrity. This phenomenon generally adds to the damage that would otherwise be caused by shaking alone.

The loose sand of the Fraser River sediments and the loose underwater landfills, such as the False Creek area are susceptible to liquefaction under the influence of a large earthquake.

2.7 LANDSLIDE HAZARD

A landslide can trigger along steep slopes during a large earthquake event. Certain areas of the City of Vancouver are considered to have a moderate landslide hazard, however most of the sites in the study area have a low hazard level. The bluffs along Spanish Banks and certain steep mountainous areas of North Vancouver likely have the highest landslide hazard.

3 SEISMIC VULNERABILITY SURVEY

The primary objective of this survey was to identify major structural and non-structural weaknesses and deficiencies which influence the degree of damage experienced by a building in an earthquake, and thus pose a threat to the life safety of the building occupants and to the use of the building.

Deficiencies or vulnerabilities, as they are referred to in seismic surveys, are determined by comparison of the behaviour of similar building types under constant levels of earthquake-induced shaking.

The identification of such vulnerabilities was made by conducting a limited rapid, on-site screening of the buildings.

The basis of the Seismic Vulnerability Survey is the Seismic Screening Form which allows a rapid evaluation of a large inventory of buildings in the field.

3.1 SEISMIC SCREENING FORM

The seismic screening form used in the field for the survey was developed by DNDM from the form provided by the City of Vancouver. This was the screening form from the National Research Council's *"Manual for Screening of Buildings for Seismic Investigations"* adapted for City of Vancouver Building Codes and Heritage Building Requirements (see ***Appendix 1***).

While the contents from the original form remain essentially the same, several items have been added or modified. The ranking index calculations have been removed from field use and integrated into the database.

A sample of the form used is also shown in ***Appendix 1*** and a brief explanation of the key input features follows including explanation of additions and modifications made from the original form.

In general, the form records:

- the inventory data for each building including a photograph and a sketch;

- structural and non-structural seismic vulnerability data;
- engineering judgement and confidence factors;
- recommendations for further evaluation.

3.2 BUILDING INVENTORY DATA

Neighbourhood Number/Item Number

Vancouver is divided into neighbourhoods as identified by the map on ***Plate 2***. Each building is identified by its neighbourhood number and an item or entry number within the neighbourhood. The number of buildings surveyed in each neighbourhood is also indicated on the map.

Address/Postal Codes

The City of Vancouver building records are organized by the building address. Addresses are listed alphabetically within each neighbourhood.

The City does not utilize postal codes and they are not therefore included in the survey.

Building Name

Where possible a building name is included for further identification. The name may be the actual name on the building or a name of the major occupying business.

Year Built

The year that the building was constructed is significant in establishing the type of construction and the building codes in effect. It should be noted, however, that the building may have been designed several years prior to construction and the codes may not necessarily correlate.

Where this information is unavailable an estimate to the nearest decade is used based on architectural and/or structural style and local building history.

Heritage Designation

Heritage designation is an important factor in this survey as one of the main objectives is the assessment and ranking of risk associated with loss of heritage structures. The City has designated heritage structures A, B and C depending on the quality and importance of the building as a landmark building.

- A - Designated Heritage Building

- B, C - Listed Heritage Building

Heritage information was provided by the City. Heritage designations were also noted in the field if a building was marked by a specific heritage sign.

Number of Storeys

The height of buildings is recorded in terms of number of storeys. Height of a building relates directly to its seismic vulnerability and may be used in ranking levels of vulnerability.

Design Vancouver Building Bylaw (VBBL)

This entry defines the year in which the City of Vancouver adopted the edition of the National Building Code of Canada (NBCC) current at the time of construction.

The modern approach to the effects of earthquakes on buildings was first adopted in the 1965 NBCC and subsequently refined as understanding of the problem increased, in the 1970, 1985 and the current 1990 edition of the code.

Prior to 1965, seismic provisions in the NBCC were based on limited understanding of earthquakes and the response of structures to them. With the advent of computer based analytical methods in the 1960s and the increased availability of ground motion information from actual earthquakes, understanding of building responses developed significantly. It became apparent that seismic design to lateral force levels in pre 1960's codes, in many cases, was inadequate to ensure that the structural strength provided was not exceeded by the demands of strong ground shaking.

This lack of strength does not always result in failure, or even severe damage. Provided the structure is ductile enough to absorb the energies produced by its response to an earthquake, it can survive the earthquake and often can be repaired economically. However, in many cases, especially on masonry and concrete frame structures, this ductility is not available and severe damage or collapse is common.

The 1965 NBCC introduced the concept of dynamic analysis and ductility requirements in buildings which was further developed in the 1970 code to refine the ground motion parameters used in seismic analysis.

The Vancouver Building Bylaw dated 1967, adopted the seismic provision of the 1965 NBCC while the VBBL of 1973 adopted the complete 1970 NBCC. Buildings designed between 1967 and 1973 may have been designed to either the 1965 or 1970 codes. Scores for ranking of vulnerability are set at appropriate levels based on the likely code used for design, judged from the year of construction, unless the year of design has been ascertained.

Zone/Coordinates

The zoning and coordinates of a building, as defined by the City, relate to the allowable development on the site and engineering requirements respectively.

These are alternative methods of defining the building location. They were not, however, used in this survey.

Site Area (square metres)

The site area is the actual or estimated area of the legal site on which the building is situated. It is not directly involved in the vulnerability assessment but allows an appreciation of the building surroundings and adjacent structures.

Total Floor Area (square metres)

The total floor area of a building is significant in calculating occupancy densities and thus estimating numbers of persons at-risk due to an earthquake. It is also a significant factor when calculating budgetary costs for building retrofit or replacement.

Comparison of site area and total floor area allows a quick assessment of the likely height of the building. Both these values may be estimated approximately if the actual data is not available.

Floor areas of buildings were supplied by the City but at this time, some inconsistency remains in the data. The data and resultant seismic rankings are therefore estimated based on ranges of occupant density and building usage. Once confirmed areas are available the data and rankings can be quickly modified.

Construction (City of Vancouver Survey)

The City of Vancouver's original inventory survey included a visual assessment of materials used in the building construction. The descriptions are general and do not necessarily distinguish between structural and non-structural materials or systems. They are, however, very useful for visual comparisons in the field.

Date/By

The date of the survey and the engineer who carried out the screening are recorded for reference.

Photographs/Sketches

Both a photograph and a plan sketch are important aids in the screening process. The screening process requires a major degree of visual assessment and inspection. A photograph therefore is necessary for immediate identification and refamiliarisation in reviewing the collected data.

Plan sketches are used to indicate the layout of the building, whether regular or irregular. This, alone, has a major effect on the seismic vulnerability as an irregularly shaped building can be subjected to concentrated forces due to torsional effects.

Sketches in elevation are necessary to identify vertical irregularities such as setbacks and height differences and also significant non-structural appendages such as chimneys and parapets which may present significant falling hazards in an earthquake.

3.3 NON-STRUCTURAL VULNERABILITY

This part of the screening form deals with non-structural building components which may fall, in an earthquake, causing a threat to human life. It also deals with hazards to continuous operations of specialized buildings (i.e. buildings requiring greater seismic reliability than post-disaster buildings as defined in the NBCC). Heritage buildings are also classified as specialized buildings. In addition, the City of Vancouver has modified the form to include vulnerable emergency equipment such as power equipment, fire pumps, sprinklers, voice communications etc.

The scope of the screening exercise, however, included only limited walk-through inspection of buildings and generally only the non-structural exterior building components and heritage parameters were included unless the interior components could be assessed from external visual inspection.

F1: Falling Hazards to Life or Vital Equipment

This entry is divided into three categories:

- exterior;
- interior;
- general.

The exterior falling hazards commonly include such items as chimneys, parapets, veneer, architectural panels and canopies. Items such as these are easily identified in a walk-by visual survey and are generally included in the screening.

Interior falling hazards include masonry partitions and storage shelving. These have not generally been identified unless obvious from walk by inspection.

General items include glass over means of egress and vulnerable emergency equipment as previously described. During the screening survey only glass hazards were identified, unless equipment vulnerability could be readily assessed.

F2: Hazards to Continuous Operations; Special or Heritage Buildings

Information for this item comes primarily from the building owners or authorities and concerns equipment and/or life lines and utilities required for continuous operations or special facilities. This is not part of the screening survey but can be readily incorporated as can other non-structural items not covered by the present screening process.

Heritage buildings have already been identified in the inventory data and are thus recorded with an F2 factor. This particular factor has been weighted by the City to highlight heritage buildings as a priority for evaluation.

3.4 STRUCTURAL VULNERABILITY - TYPES OF STRUCTURE

The building inventory consists of 1150 privately owned buildings. These buildings were selected for the screening study based on (1) buildings constructed prior to 1973, and (2) buildings of 3 storeys or greater. As such, the selection of structures is a broad cross section of building structural types, building styles, usages and heights, all potentially more seismically vulnerable than the remaining buildings in the City of Vancouver's building records.

During the screening process the type of building being evaluated, is chosen from among the following 15 common types as defined in the NRC Screening Manual.

1a. **WLF - Wood, Light Frame (less than 3 storeys):** These buildings are typically single- or multiple-family dwellings of one or more storeys. The essential structural character of this type is repetitive framing by wood joists on wood studs. Loads are light and spans are small. The buildings may have relatively heavy chimneys, often of unreinforced masonry and may be partially or fully covered with stucco or veneer.

Many of these buildings are not engineered as required under Part 4 of the NBCC "Structural Design" but fall into Part 9 of the code "Housing and Small Buildings". They usually have the components of a lateral-force-resisting system even though it may be incomplete. Lateral loads are transferred by diaphragms to shear walls. The diaphragms are roof panels and floors. Shear walls are exterior walls sheathed with plank siding, stucco, plywood, gypsum board, particle board, or fibreboard. Interior partitions are sheathed with plaster or gypsum board.

These buildings were not considered in the survey as they were considered to be relatively less vulnerable.

1b. **WLF - Wood, Light Frame (3 storeys and above):** Buildings of this type are generally apartment buildings. They are engineered with vertical framing of stud wall construction braced with plywood (or equivalent) or diagonals. Again loads are light and spaces small. Horizontal loads are transferred to walls through roof and floor diaphragms. In many cases the elevator core is formed from concrete or masonry which also assists in lateral resistance.

2. **WPB - Wood, Post and Beam:** Usually commercial or industrial buildings with a floor area of 500 square metres or more and with few, if any, interior walls. Warehouses, offices, churches and theatres can be included in this group.

   The essential structural character is framing by beams on columns. The beams may be wood, glulams, steel beams, or trusses either wood or steel. Lateral forces are typically resisted by wood diaphragms and exterior walls sheathed with plywood, stucco, plaster, or other panelling sometimes with stone or brick veneer. The walls may have rod bracing. Large openings for stores and garage often require post-and-beam framing. Lateral force resistance on those lines can be achieved with steel rigid frames or diagonal bracing.

3. **SMF: - Steel Moment Frame:** Buildings of this type have a frame of steel columns and beams. In some cases, the beam-column connections have very small moment resisting capacity but, in other cases, some of the beams and columns are fully developed as moment frames to resist lateral forces.

   In older buildings (pre-1940's) the steelwork may be encased in concrete for fire protection.

   On buildings constructed since 1950, the structure is usually concealed on the outside by exterior wall panels, which can be of almost any material (curtain walls, brick masonry panels, or precast concrete panels), and on the inside by ceilings and column furring.

   Lateral loads are transferred by diaphragms, usually concrete, (sometimes over steel decking) to moment resisting frames. The frames develop their stiffness by full or partial moment connections and can be located almost anywhere in the building.

Often the columns have their strong directions oriented so that some columns act primarily in one direction while the remainder act in the perpendicular direction, and the frames consist of lines of strong columns and their intervening beams.

Steel moment frame buildings are typically more flexible than shear wall buildings. This low stiffness can result in large interstory drifts that may lead to extensive nonstructural damage.

Steel frame buildings of all types except SLF are normally commercial, institutional or public buildings.

4. **SBF - Steel Braced Frame:** These buildings are similar to Type 3 buildings except that the vertical components of the lateral-force-resisting system are braced frames rather than moment frames. Lateral loads are carried by tension and compression in cross bracing. Minimal moments are developed in connections.

   Built since the 1800's with similar usage and exterior finishes as SMF buildings.

5. **SLF - Steel Light Frame:** Normally pre-engineered and prefabricated buildings with transverse rigid frames. The roof and walls consist of lightweight panels. The frames are designed for maximum efficiency, often with tapered beam and column sections built up of light plates. The frames are built in segments and assembled in the field with bolted joints.

   Lateral loads in the transverse direction are resisted by the rigid moment frames with loads distributed to them by shear elements. Loads in the longitudinal direction are resisted entirely by roof and wall diaphragms or rod bracing. Shear elements can be roof and wall sheathing panels, an independent system of tension-only rod bracing, or a combination of panels and bracing.

Most light frame building has been constructed since 1950 and are typically used for factories, warehouses and agricultural structures.

6. **SCW - Steel Frame with Concrete Shear Walls:** The shear walls in these buildings are cast-in-place concrete and may be bearing walls. The steel frame is generally designed for vertical loads only. Lateral loads are transferred by diaphragms of almost any material to the shear walls. The steel frame may provide a secondary lateral-force-resisting system depending on the stiffness of the frame and the moment capacity of the beam-column connections.

   In modern "dual" systems, the steel moment frames are designed to work together with the concrete shear walls in proportion to their relative rigidities. In this case, the walls would be evaluated under this building type and the frames would be evaluated under Type 3, Steel Moment Frames.

7. **SIW - Steel Frame with Infill Masonry Shear Walls:** This is one of the older types of building. In many cases, pre 1940's, the steel frames are encased in concrete for fire protection, making identification difficult without reference to the structural drawings.

   The infill walls are often offset from the exterior frame members, wrap around them, and present a smooth masonry exterior with no indication of the frame. Diaphragms are reinforced concrete or, in older buildings, wood. Solidly infilled masonry panels act as a diagonal compression strut between the intersections of the moment frame making the structure very stiff.

   In an earthquake, the infill walls may suffer substantial cracking, thus reducing their stiffness and putting additional demand on the steel frame. This in turn can cause soft storey or torsional problems. Falling masonry also constitutes a major hazard.

8. **CMF - Concrete Moment Frame:** Two construction sub-types fall under this category: a) non ductile reinforced concrete frames without reinforced infill walls, and b) ductile reinforced concrete frames. The most prevalent of this building type is non-ductile concrete frames without reinforced infill walls built between about 1950 and 1972.

   In many regions of Canada this type of construction continues to the present. Since 1975, however, the NBCC has required improved ductile detailing of steel reinforcement with full ductile detailing introduced in the 1985 code. Buildings can then be classed under category (b).

   The group includes large multi-storey commercial, institutional and residential buildings constructed using flat slab frames, waffle slab frames and the standard girder-column type frames. These structures are generally more massive than steel frame buildings, are often under-reinforced and display low ductility.

9. **CSW - Concrete Shear Walls:** The vertical components of the lateral-force-resisting system in these buildings are concrete shear walls that are usually bearing walls. In older buildings, which are typically schools, churches and industrial buildings, the walls often are quite extensive and the wall stresses are low, but reinforcing is light. When remodelling calls for enlarging the windows, the strength of the modified walls becomes a critical concern.

   In newer buildings, built since the early 1950's, especially residential mid-rise towers, the shear walls are often limited in extent. They are typically located along the perimeter, as interior walls or around the service core thus generating concerns about boundary members and overturning forces.

10. **CIW - Concrete Frame with Infill Shear Walls:** Buildings in this category are similar to Type 7 buildings except that the frame is of reinforced concrete. The members tend to be large although the amount and detailing of the reinforcement is questionable.

The analysis of this building is similar to that recommended for Type 7 except that the shear strength of the concrete columns, after cracking of the infill, may limit the semiductile behaviour of the system.

11. **PCW - Precast/Tilt-Up Concrete Walls with Lightweight Flexible Diaphragm:** These buildings have an extensive wood or metal deck roof diaphragm, that distributes lateral forces to precast concrete shear walls.

    The walls are thin but relatively heavy, while the roofs are relatively light. Older pre 1970 buildings often have inadequate connections for anchorage of the walls to the roof for out-of-plane forces, and the panel connections are often brittle.

    Tilt-up buildings may have more than one story. Walls can have numerous openings for doors and windows of such size that the wall looks more like a frame than a shear wall.

    Typically PCW buildings are low rise office or industrial/warehousing facilities.

12. **PCF - Precast Concrete Frame with Concrete Shear Walls:** These buildings contain floor and roof diaphragms typically composed of precast concrete elements with or without cast-in-place concrete topping slabs. The diaphragms are supported by precast concrete girders and columns, essentially, a post and beam style in concrete. The girders often bear on column corbels. Closure strips between precast floor elements and beam-columns joints usually are cast-in-place concrete. Welded steel inserts are often used to interconnect precast elements.

    Lateral loads are resisted by precast or cast-in-place concrete shear walls. Buildings with precast frames and concrete shear walls should perform well if the details used to connect the structural elements have sufficient strength and displacement capacity. However, in some cases, the connection details between the precast elements have negligible ductility. Although this system was first developed in the 1930's it was not used extensively until the 1960's.

13. **RML - Reinforced Masonry Bearing Walls with Wood or Metal Deck**

Diaphragms: Reinforced masonry buildings have perimeter bearing walls of reinforced brick or concrete-block masonry. The walls are the vertical elements in the lateral-force-resisting system. Floors and roofs are framed either with timber joists and beams with plywood sheathing (straight or diagonal) or with steel beams and metal deck usually with a concrete topping. Wood floor framing is supported by interior wood posts or steel columns; steel beams are supported by steel columns.

Occupancy varies from small commercial buildings to residential and industrial buildings, generally less than five storeys in height.

14. **RMC - Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms:** Buildings have bearing walls similar to those of Type 13 buildings, but the roof and floors are composed of precast concrete elements such as planks or tee-beams and the precast roof and floor elements are supported on interior beams and columns of steel or concrete (cast-in-place or precast). The precast horizontal elements often have a cast-in-place topping.

15. **URM - Unreinforced Masonry Bearing Wall Buildings:** Unreinforced masonry buildings include structural elements that vary depending on the building's age its usage and, to a lesser extent, its geographic location. Most URM buildings in Western Canada were built before the 1940's although some were built in areas of medium to high seismicity until the late 1940's and 1950's.

    In multi-storey industrial/warehouse buildings the floor and roof diaphragms typically consists of wood sheathing supported by heavy wood subframing, although in some cases, the floors may be cast-in-place concrete. The diaphragms are supported by the unreinforced masonry walls and/or steel or concrete interior framing. In regions of lower seismicity or in smaller recently constructed, commercial and residential buildings floor and roof framing may be metal deck and concrete fill supported by steel framing elements.

    The perimeter walls, and possibly some interior walls, are unreinforced masonry ranging from 200 to 600 mm depending on height and usage. The walls may or may not be anchored to the diaphragms. Ties between the walls and diaphragms are more common for the bearing walls than for walls that are parallel to the floor framing. Roof ties usually are less common and more erratically spaced than those at the floor levels. Interior partitions that interconnect the floors and roof can have the effect of reducing diaphragm displacements.

3.5 STRUCTURAL VULNERABILITY - BUILDING IRREGULARITIES

Building irregularities and deficiencies which are associated with seismic vulnerability are an important part of the screening process. They were identified for each building as observed or judged to be significant.

A short definition of each irregularity listed on the screening form follows:

Vertical Irregularity

Vertical irregularity in a building arises from a number of conditions. Abrupt changes in plan dimensions over its height, walls not perpendicular to the ground, or a height difference if a building is situated on a hill, are typical conditions. Basically the lateral force resisting system (LFRS) is discontinuous if the building mass varies from floor to floor and/or the building is on a setback or is unusual in the vertical dimensions in some fundamental way.

Vertical irregularities are also significant when considering vertical ground motion which may occur in an earthquake.

Horizontal Irregularity

If a building is unsymmetrical in plan shape or the layout of the LFRS is unsymmetrical, it is considered to be horizontally irregular. This can lead to high twisting or torsion of the building in an earthquake.

Sharp re-entrant corners in L, V, E and T shaped buildings are very vulnerable to seismic forces.

Other plan irregularities include long slender bearing wall buildings and very large slender bearing wall (or tilt-up wall) buildings (>10,000 m^2) with no interior walls to resist earthquake forces.

Short Concrete Columns

Where the height of columns in a building appears to be less than four times their width (4:1 aspect ratio) they are considered short columns. This may be caused by the construction of infill walls or edge beams between the columns which effectively reduce the original full storey height.

The decrease in height stiffens the columns and it "attracts" more lateral force, often higher than the design capacity. The column may fail dramatically in brittle shear.

Soft Storey

A soft storey of a building is essentially a storey which is approximately half as stiff as the storey above it. This arises from infill or shear walls not continuous to the foundation or from large openings, usually at ground level, due to windows or entrance hallways. A building can be "soft" in one or other, or both directions.

Pounding

Pounding occurs where there is little or no clearance between adjacent buildings. If separation is less than 20 Zv x the number of storeys (mm) pounding has to be considered. This value was refined to 100 x V x F during development of the final form.

In the field, however, the assessment of pounding potential tended to be a visual judgement rather than an actual measurement.

Zv is the NBCC velocity related seismic zone and in Vancouver is 4.0.

In an earthquake the buildings impact or "pound" against each other causing structural and non-structural damage. This can be serious if adjacent building floors are not aligned. The floors of one building can pound against, the columns of the adjacent building leading to possible collapse.

Major Modifications

A change in function, use, or addition to the building may result in significant increase in loading or weight of the building.

It often requires the close cooperation of the owner or inspection of design drawings to identify changes.

Deterioration

If structural elements are damaged, or poor conditions of the building is visually apparent, the deterioration factor must be included. Poor conditions of the building may take the form of corroded reinforcement or steel elements, rotted wood members, poor concrete or crumbling masonry elements.

3.6 ENGINEERING JUDGEMENT FACTORS

In order to provide a qualitative comparison and control of the vulnerability survey and eventual rankings, various judgement and confidence factors were introduced and used by the field engineers during the survey.

Structure Type Confidence Factor

Using the 15 building types, as described above, it was not always possible to categorize buildings into one of the structure types. In these cases, the type would be limited to two or three of the most likely types and then the more conservative selection made. A structure type confidence factor of low, moderate or high would then be assigned based on the confidence of the field engineer in selecting the structure type.

The building may require a walk through or drawing review to identify a structure hidden by architectural finishes or the building may be a combination of various structure types.

Structure Type Quality Factor is based on the expected performance of the building compared to buildings of the same type. This information is important in risk analyses and is used to determine varibilities of performance within building types. This quality descriptor takes into account the building irregularities noted above.

Overall Structural Vulnerability Factor is a qualitative, empirical factor determined by using engineering judgement based on the overall expected structural performance of the building. The materials of construction, building type, height, irregularities, and other related structural parameters are all considered. It is primarily a structural factor.

In general, the building structural types are categorized for judgement of overall vulnerability as follows:

TABLE 3.1
Overall Structural Vulnerability Categorization by Building Type

O.V. Category	Type	Descriptor
1	1a, 1b	Wood, Light Frame
	2	Wood, Commercial and Industrial (Post & Beam)
	5	Steel Light Frame
	3 Newer	Steel Moment Frame
	6 Newer	Steel Frame with Concrete Shearwalls
2	4	Steel Braced Frame
	9	Concrete Shearwall
	6 Older	Steel Frame with Concrete Shearwalls
3	3 Older	Steel Moment Frame
	13 Metal Deck	Reinf. Masonry Bearing Walls with Metal Deck Diaphragm
	14	Reinf. Masonry Bearing Walls with Precast Conc Diaphragm
4	7	Steel Frame with Infill Shearwalls
	11	Precast/Tiltup Concrete Walls with Lightweight Flexible Diaphragm
	12	Precast Concrete Frames with Concrete Shearwalls
5	8	Concrete Moment Frames
	10	Concrete Frames with Infill Shear Walls
	15	Unreinforced Masonry Bearing Walls
	13 Wood Deck	Reinforced Masonry Bearing Walls with Wood Diaphragm

TABLE 3.2 Overall Vulnerability Categories		
Category	**Seismic Quality and Performance of Building**	**Priority for Further Evaluations**
1	Well above average	Very low
2	Above average	Low
3	Average	Medium
4	Below average	High
5	Well below average	Very high

Survey Type after all observation and judgement have been entered, the type of survey conducted was recorded. These descriptions are self evident although it should be noted that "walk by" actually involves walking around the perimeter of the building.

Based on the type of survey and the confidence level of the engineer in his findings, a recommendation for further survey is then given.

3.7 TYPICAL EARTHQUAKE RELATED DAMAGE

Based on the building types and irregularities listed on the screening form, a guide to the type of earthquake damage which may be incurred, as a result of any particular building structural characteristic is very useful.

Details of performance and typical earthquake related damage are given in ***Table 3.3*** for reference.

4 RESULTS, RANKING AND RECOMMENDATIONS

The objectives of Phase 1 of the seismic risk/benefit analysis for the selected buildings were:

- to develop a database of the building inventory and vulnerability data;
- using structural, non-structural and engineering judgement factors developed from this data, rank the buildings in terms of priority for further evaluation;
- refine the scope of work for Phase 2 which may include further building inspections to verify difficult or uncertain vulnerability data and/or a seismic risk benefit analysis.

Phase 1 has achieved these objectives and the methods and results of the work are summarized in this section.

4.1 SUMMARY OF BUILDING VULNERABILITY SURVEYS UNDERTAKEN

At the commencement of the survey, 1149 buildings selected by the City of Vancouver, were listed as the base sample (refer to Volume 1 of Supporting Data). As the surveys proceeded several buildings were found to have been demolished or to have addresses which did not correspond to existing buildings. The demolished buildings, however, were recorded with a walk-by survey and were included in the base data of surveys completed, but in no other sampling or ranking.

All buildings are located in the City of Vancouver, primarily in the downtown core (neighbourhoods 26 and 27). Distribution of buildings is indicated on the neighbourhood map on plate 2.

In summary the sample consisted of the following:

	No. of Buildings
· Buildings selected by the City	1149
· Buildings demolished	(18)
· Buildings with incorrect addresses	(8)

		% of Valid Buildings
· Buildings valid for survey	1123	
· Buildings surveyed by walk-by	1061	
· Buildings surveyed by walk-through	85	8%
· Buildings surveyed by drawing review	31	3%

It is interesting to note that during the survey, the walk-through of a building did not generally reveal any more valid structural data than a properly conducted walk-by survey. This was due to the covering of the structure with architectural finishes in the majority of buildings. The number of drawing reviews were therefore increased while the walk-throughs were decreased from the original scope.

4.2 RANKING SYSTEMS

The primary ranking system for this project was based on the structural (SI) and non-structural (NSI) index ratings for rapid evaluation of buildings, provided by the City of Vancouver, modified from recommendations by the National Research Council of Canada and the Applied Technology Council in the United States.

These indexes are calculated as a method of ranking priorities for further evaluation of a building and are not true measures of seismic risk.

The indexes are calculated by applying numerical values to various factors which influence the vulnerability of a building; the greater the effect on vulnerability, the higher the value applied to the factor. By taking the product of these values, a final ***structural*** or ***non-structural*** index is calculated.

The original survey form (***Appendix 1***) included the scoring system for seismic indices to be utilized for ranking the building inventory. This was removed from the field form and incorporated into the computerized database.

For ranking purposes the indexes can be used separately or can be added to develop a ***Seismic Priority Index***, depending on the particular information required. A description of the indexes follows:

Structural Index

$$S.I. = A.B.C.D.E.$$

where	A	=	Seismicity
	B	=	Soil Conditions
	C	=	Type of Structure
	D	=	Irregularities
	E	=	Building Importance

Seismicity (A) is based on the review of seismicity data in the NBCC and ranges from 1.0 to 4.0 depending on the level of seismic activity estimated for the area of the country under consideration and the level of seismic capacity of a building, as defined by the year of design and applicable code.

Vancouver is considered in a relatively active zone (refer to paragraph 2.1) and is therefore given a value of 2.0 or 3.0 depending on the building code in effect at the time of the building design.

Soil Condition Factor (B) defines the ground type under a building and together with the seismicity (A) describes the ground motion delivered to the building. It ranges from 1.0 for rock or stiff soil to 2.0 for very soft or liquefiable soil.

In general, the buildings in the survey are located on stiff soil but there are some areas of soft, liquefiable soils (refer to ***Section 2***). The distribution of buildings over the soil types is shown in ***Figure 1, Appendix 2***. Plate 1, shows ***Section 2.2*** the various soil types throughout Vancouver.

Type of Structure (C) relates to the ability of the structural system to resist seismic forces with minimal damage. A low level (1.0) indicates the structure has good seismic properties or is designed to resist earthquake forces, whereas a high value (3.5 for URM buildings) indicates an inability to handle significant earthquake forces (refer to ***Figure 2, Appendix 2***).

Irregularity (D) is associated with the irregularities listed on the screening forms but also recognizes the introduction of seismic design improvements in the building codes.

Building Importance Factor (E) introduces the social significance of an earthquake affecting a building, by ranking the building in terms of use and occupancy level.

The focus of this particular survey is on life loss, loss of housing and of heritage resources. The City of Vancouver modified the scoring system for the building importance factor (E) in the original NRC form to weight the importance of residential and heritage buildings. High rise apartments (14 storey and above) were specifically assigned to the high occupancy category (E = 1.5). Listed heritage buildings were also assigned a similar importance factor while designated heritage buildings were given the highest rating (E = 3.0), higher even than post-disaster or very high occupancy buildings (E = 2.0).

Non-Structural Index

$$N.S.I. = B.E.F.$$

The non-structural index is developed from three factors: falling hazards to life safety or hazards to vital operations in post disaster buildings, building importance which in this survey, includes heritage designation and soil conditions.

The factors B, E and F have been previously defined (***Section 3.3*** and ***4.2***). However, it should be noted that in buildings that are flexible (frames, soft storeys, torsion) or have deteriorated, the risk of non-structural damage increases. The values of F therefore increased from 3.0 to 6.0 for these buildings.

Structural Priority Index

$$S.P.I. = S.I. + N.S.I.$$

The structural priority index is the sum of the structural and non-structural indexes and is the overall ranking index used for priorities, suggested by NRC. It is, fundamentally, related to the seismic risk for a building exposed to the 1990 NBCC design earthquake. However, it is only an indicator of the requirements for further evaluation, not an actual assessment of seismic risk.

4.3 RANKING OF THE BUILDING INVENTORY

Once the seismic indices were calculated, the building could then be ranked and priorities for further evaluation established. In order to achieve this however, the index values had to be distributed into ranking categories (Ranked Indexes).

The ranked indices can then be used to check the validity of the observed data by comparison with qualitative judgements of seismic performance (overall structural vulnerability (OV), ***Section 3.6***) and to establish priorities for further evaluation of the buildings.

Ranked Structural Index (RSI)

Using statistical analysis methods, the categories of overall structural vulnerability (field judgements) were compared with the ranked structural indexes (field observations) recommended by the NRC as given in ***Table 4.1***. The comparison showed reasonable correlation, thus establishing a level of confidence in the data.

The OV categories were then further checked using empirical relationships developed in ATC-13, 1985 "*Earthquake Damage Evaluation Data for California*". Building types in California are very similar to the buildings under study.

TABLE 4.1 Ranked Structural Indexes Recommended by NRC		
Ranked S.I.	**Range of SI**	**Descriptor**
1	1-10	Very low priority for evaluation
2	11-20	Low priority for evaluation
3	21-40	Medium priority for evaluation
4	41-80	High priority for evaluation
5	81+	Very high priority for evaluation

The expected earthquake performance of the buildings under the ULE and LLE (refer to ***Section 2.3***) scenarios was determined for several buildings. The earthquake damage potential was then estimated using the ATC13 empirical relationships that estimate damage as a function of earthquake ground shaking intensity. These relationships take into account factors such as type of construction and number of storeys and are modified for local site conditions and the seismic vulnerabilities of the buildings. A seismic risk rating was then assigned to each of the buildings similar to the categories used previously. The check provided acceptable results further justifying the use of the OV judgement factor.

With the confidence now develop in the OV factor, it was then used as a baseline for refining the ranked structural indexes. The relationship of the two factors was developed statistically and a more accurate correlation between ranked SI values and field observations, as measured by the OV factors established (***Table 4.2***).

TABLE 4.2 Ranked Structural Indexes Correlated to Overall Vulnerability		
Ranked S.I.	**Range of SI**	**Descriptor**
1	1-3	Very low priority for evaluation
2	4-7	Low priority for evaluation
3	8-28	Medium priority for evaluation
4	29-40	High priority for evaluation
5	40+	Very high priority for evaluation

The buildings were then ranked according to structural index (see ***Appendix 3***) and the priority categorization in ***Table 4.2***.

4.4 REVIEW OF RANKING

For this study DNDM elected to rank the buildings in terms of the structural index, due to the limited nature of the non-structural screening. However, ranking by either the structural index or the seismic priority index does not generate a significant difference in ranking. Using the computerized database the ranking system can be adjusted very easily if required.

As an alternative to specific ranking, we have presented in ***Appendix 2***, ***Figure 5***, distribution charts indicating the percentages of buildings in each priority category based on the structural index distribution in ***Table 4.2***.

The distribution chart in ***Appendix 2***, ***Figure 6*** shows the percentage of buildings in the non-structural categories. It should be noted that the non-structural index is limited as screening for non-structural vulnerability was, in most cases, limited to external observations.

The focus of the present study is risk of life loss, loss of housing units and heritage resources and the reduction of such risks. ***Figures 3*** and ***4*** in ***Appendix 2*** indicate the percentage distribution of the surveyed buildings by both occupancy type and heritage class.

By comparing these distributions with the distribution of buildings by priorities for evaluation, priorities can be focused to life loss or heritage resource loss. ***Figures 6*** and ***7*** in ***Appendix 2*** show the relationship of structural and non-structural priorities to building occupancies and indicate a significant proportion (80%) of "very high priority" buildings are high occupancy (residential and office). Actual number of buildings and % are shown in ***Table 4.3***.

Priority / Occupancy Type	Very Low	Low	Medium	High		Very High		Totals	
	No. of Buildings				% in priority	No.	% in priority	Total No.	% of Total
A		1	21	7	6	20	7	49	4.5
B			3	1	<1	2	<1	6	<1
C		**87**	**369**	**58**	**47.5**	**133**	**48**	**647**	**58**
D	**6**	**18**	**137**	**38**	**31**	**87**	**32**	**286**	**25.5**
E		1	18	8	6.5	11	4	38	3
F		10	43	10	8	20	7	83	7
P		4	8	0	0	2	<1	14	1
Total No.	**6**	**121**	**599**	**122**		**275**		**1123**	

TABLE 4.3
Building Distribution by Occupancy Type and Priorities

Legend: A = Assembly; B = Institutional; C = Residential; D = Office; E = Mercantile; F = Industrial;

Another selected analysis is shown on ***Table 4.4*** where the building structural types and structural priorities are compared. As can be seen, the majority of buildings fall in the URM and CSW types, with a significant portion (84%) of the "very high priority" category being URM buildings.

TABLE 4.4
Building Distribution by Building Types and Priorities

Priority / Bldg. Type	Very Low	Low	Med.	High		Very High		Totals	
	No. of Buildings				% in priority	No.	% in priority	Total No.	% of Total
CIW		3	31	12	10	15	5.5	61	5.5
CMF		1	50	29	24	20	7	100	9
CSW	**2**	**96**	**305**	**18**	**15**	**6**	**2**	**427**	**38**
PCF		1	2					3	.25
PCW		2	2					4	.35
RMC		1	8	3	2.5			12	1
RML		7	15	1	<1	2	<1	25	2
SBF			1	1	<1			2	.2

TABLE 4.4 Building Distribution by Building Types and Priorities									
Priority	Very Low	Low	Med.	High		Very High		Totals	
Bldg. Type	No. of Buildings				% in priority	No.	% in priority	Total No.	% of Total
SCW		1	2					3	.25
SIW			1			2	<1	3	.25
SMF	4		1					5	.45
URM		**1**	**170**	**58**	**47.5**	**230**	**84**	**459**	**41**
WLF		4	5					9	.8
WPB		4	6					10	.9
Total	**6**	**121**	**599**	**122**		**275**		**1123**	
% of Total	**.5**	**11**	**53**	**11**		**24.5**		**100%**	

4.5 RECOMMENDATIONS

Currently, DNDM are carrying out Phase 2 of this project, the actual risk/benefit analysis. Recommendations for this work and enhancement to the database were already addressed in our letter dated (***Appendix 4***. These recommendations were accepted by the City in their letter of May 6, 1994.

In terms of the survey work carried out to date, there are areas where it may be advisable to continue the collection of data to refine and expand the database.

1. Confidence in the structural types of several buildings (approximately 30) remains low and more drawing reviews would be advisable to complete the database.

2. Non-structural assessment carried out during the survey was generally limited to external observations of parapets, cladding and other architectural appendages.

   No significant information on operational and lifeline systems in the buildings has been collected. This may be desirable for emergency planning.

3. It will also be useful to review the non-structural indices and further refine them by ranking buildings for minor seismic upgrade of parapets, chimneys, and items which can be quickly and relatively inexpensively upgraded.

   The type and assembly of non-structural data and the methods of ranking may require to be reviewed and further refined to gain a clearer picture of individual non-structural parameters.

Preliminary results from our Phase 1 work lead us to the following tentative conclusions and recommendations, subject to revision as more detailed risk analysis develops:

- Approximately 400 buildings, or more than 1/3 of those included in the study, fall into the category of high or very high seismic risk, based on structural index (SI).

- The breakdown by construction type shows that nearly three-quarters of the buildings in the high or very high risk SI categories are of unreinforced masonry construction, with significant risks also seen for concrete abutment frame, concrete infill wall, and concrete shearwall construction.

- Breakdown by occupancy reveals that half of the buildings in the high or very high risk SI categories are residential construction, with another 30% used for office space. Lesser fractions of high or very high risk occupancy involve assembly and industrial building uses (each with about 7%).

- These results seem to indicate a need to reduce risks in unreinforced masonry buildings, including both residential and office uses. The forthcoming risk analysis should evaluate life-safety and economic impacts from a number of possible loss reduction measures targeting these buildings.

- Assessment of costs and damage.

5 UPGRADE CONCEPTS AND BUDGETARY COSTS

At this stage of the project, budget and construction costs for seismic upgrading and retrofit have been assembled but require to be incorporated into the risk/benefit analysis.

The costs are presented for information and planning purposes only and must be used with caution until the level and extent of upgrading requirements are established and the basis of the cost development is applicable.

Costs required to seismically upgrade buildings are dependent upon the desired seismic performance of the structure, original building deficiencies, materials of construction, building area, historical value, current use, etc. The costs are therefore generalized and will likely vary from building to building. In some cases, they are based on Californian costs converted to local Vancouver costs.

Costs are for structural upgrade only. They do not include removal/replacement of architectural finishes, engineering or testing fees, or electrical, mechanical, or architectural upgrades which take place during seismic renovation. This can increase the basic structural costs by up to 100%.

Costs for the upgrade of Heritage buildings may increase with the vintage of the building. Cost can often vary by 300 to 400% between upgrade of buildings built in the 1970's and 1980's when compared with buildings built early in the century.

Building Type	Seismic Upgrade Scheme	Unit Cost per Sq Ft
Type 1: Light Wood	Bolt wall to foundation Add plywood to cripple wall Replace gypboard with plywood Close out windows Add hold downs.	$1.00-7.00/sq.ft.
Type 2: Commercial Wood	Add wood walls Add steel moment frame Add steel braced frame Add masonry shearwalls	$3-8.50 sq.ft.

Building Type	Seismic Upgrade Scheme	Unit Cost per Sq Ft
Types 3,4,6: Steel With or Without Concrete Walls	Weld connections for moment capacity Weld connections for brace capacity Add cover plate on columns Brace flanges Add plate to compression braces Add steel bracing Add concrete shear walls Add horizontal bracing Gunnite existing concrete walls (Type 6)	$8-18/sq. ft.
Types 7,10: Steel or concrete infill	Add steel bracing (Type 7 only) Add concrete shearwalls Anchor infill Gunnite infill or support is with stud walls	$18-30/sq. ft.
Type 8: Concrete Frame	Add concrete wall Add masonry wall Add steel or concrete jacket on columns, beams Add steel bracing (not often)	$12-25/sq. ft.
Type 9: Concrete Shearwall	Fill openings Gunnite walls Provide boundary members Add concrete wall Add masonry wall	$8-18/sq. ft.
Types 11,13: Tilt-up or Masonry with Wood or Metal Deck Roof	Add wall anchors & continuity ties (wood roof only) Add drag strut Add interior braced frame or shearwall Add plywood to diaphragm Interconnect wall panels Add exterior buttress	$1-3.5/sq. ft. $2.5-10/sq.ft.
Type 12: Precast Concrete	Add diaphragm topping Add concrete shearwalls or gunnite Strengthen beam seats	$12-18/sq.ft.
Type 14: Reinforced Masonry with Precast Diaphragm	Fill masonry units Add masonry walls Gunnite masonry walls Add topping slab	$6-12/sq.ft.

Building Type	Seismic Upgrade Scheme	Unit Cost per Sq Ft
Type 15: Unreinforced Masonry (URM)	Anchor walls and parapets Add wood shearwalls Add steel moment frames Add steel braced frames Add concrete or masonry walls Center core technique Gunnite	$12-35/sq.ft.

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