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Because earthquakes occur on a geological rather than a human time scale most Canadians tend to shrug them off as improbable and therefore ignorable events. Yet even within the limited period of recorded history in Canada there have been several major earthquakes[1]. The earliest known one occurred, according to Indian accounts, between the voyages of Jacques Cartier in 1534-35. The first documented event dates back to 1663. It caused landslides in the St. Lawrence-Saguenay region and was felt well into the New England States.

A more recent example is the St. Lawrence earthquake of 1 March 1925[2]. It too was felt strongly over a large area of Eastern Canada and the New England States. Although no one was injured, considerable damage was caused in a narrow belt covering both sides of the St. Lawrence River and extending from Trois Rivières to Shawinigan Falls. The disturbance was recorded at seismograph stations round the world. Other important events in Eastern Canada were the Timiskaming earthquake in Western Quebec in 1935 and the Cornwall-Massena earthquake on the upper St. Lawrence River in 1944.

In the West, the coastal region of Canada forms part of the circum-Pacific earthquake belt, which includes such seismically active regions as Alaska, California, Mexico, Nicaragua, Chile, New Zealand and Japan. Earthquakes have caused some damage at locations on Vancouver Island and on the Queen Charlotte Islands. In recent years special interest has focussed on the seismic risk in various parts of northern Canada because of proposed resource development[3].

Measuring Earthquakes

Responsibility for keeping track of earthquakes in Canada rests with the Division of Seismology and Geothermal Studies, Earth Physics Branch, Energy Mines and Resources (EMR), Canada. It has published detailed studies of major events and produces an annual catalogue of all Canadian earthquakes, large and small[4]. To this end the Seismology Division has established a network of some 50 seismograph stations across the country. These permit accurate determination of the origin (epicentre), time of occurrence, and "magnitude" of seismic events originating in Canada, as well as contributing data for the study of the major ones originating elsewhere.

The magnitude of an earthquake is a measure of the total energy released and is expressed in terms of a number on a logarithmic scale known as the Richter Scale. A magnitude of 8 or greater is usually defined as a great earthquake; an example is the Alaska earthquake of 1964, magnitude 8.4. A magnitude of 4 denotes a minor event, scarcely noticed beyond the immediate epicentral area.

Another scale, the Modified Mercalli Intensity Scale, is used as an index of the seismic shaking produced at a given site. The scale is based largely on field observations ranging from human awareness of vibrations to structural movements and damage, collapse of buildings, and permanent distortions of the ground. Each earthquake has only one magnitude, but it may have a range of intensities generally decreasing with increasing distance from the epicentre.

In addition to magnitude and distance from the epicentre, other factors are relevant in determining the intensity of an earthquake at a given point. Ground motion characteristics can vary significantly between solid rock and deep soil deposits, with stronger shaking generally associated with the latter. As a result, some regions located further from the source may have a higher intensity than nearer ones.

As well as the sensitive seismographs capable of recording small and distant events, there is a network of strong-motion seismographs operated in the higher risk areas of the West Coast (by EMR) and the St. Lawrence Valley (by NRC). These instruments can record the strong ground movements that occur near the epicentre of a major earthquake and provide information that is particularly useful for seismic design of buildings and other structures.

Earthquake Prediction and Seismic Risk

It would be convenient if the time and place of occurrence of an earthquake could be accurately predicted, but despite some progress towards this end it is still not possible to forecast an individual event. What can be done is to predict the long-term probability of earthquake occurrence in a given region, i.e., the seismic risk associated with the region[5].

The seismic risk map of Canada (Figure 1), published in a National Building Code document[6], delineates the various seismic risk zones in Canada in terms of probable severity of ground motion that may occur in future earthquakes. It is designed primarily as a guide to those concerned with the design and construction of buildings. Some regions, for example the Prairies, have a record of limited seismic activity and thus the probability of damage in a future earthquake is very low (Zone 0); other regions have experienced serious earthquakes in the past and this is reflected in the highest risk zone (Zone 3). For cases where the zoning map is not sufficiently refined, more detailed information is obtainable from the Division of Seismology of EMR.

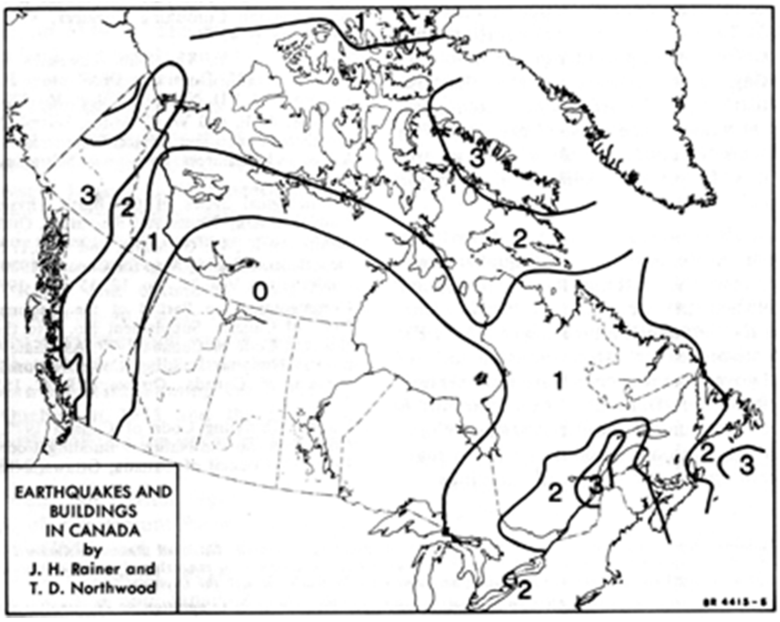

Figure 1. Seismic zoning map for Canada, 1970. Probability of damaging earthquakes: Zone 0 -- negligible; Zone 1 -- small; Zone 2 -- moderate; Zone 3 -- greatest.

Earthquake Resistant Design

Earthquake resistant design attempts to provide a structure, its foundation, and its contents with the strength and deformation characteristics necessary to enable it to survive the design earthquake. Although it is theoretically possible to design a structure to be "earthquake proof," implying no damage or malfunction under the maximum predictable ground motions, this would be prohibitively expensive. Instead, the design philosophy for ordinary buildings is to guard against total collapse and consequent loss of life but accept the possibility of some damage.

During an earthquake the ground moves in a random manner in both horizontal and vertical directions. Buildings are inherently strong in the vertical direction since they are designed to resist the vertical loads due to gravity, but they are relatively weak in the horizontal direction. Thus the horizontal forces and deformations assume a dominant role in earthquake engineering for buildings. There is an obvious similarity to the horizontal forces imposed by wind, and indeed protection against wind may sometimes constitute a large portion of the protection needed against earthquakes. An essential difference exists, however: buildings are usually designed to deform elastically up to the design wind load, whereas some inelastic deformation is expected at the design earthquake load; attention must therefore be given to the ductile performance of the structure.

The following steps are involved in earthquake resistant design:

1. Establish the desired level of protection; buildings such as hospitals and fire stations are assigned a higher degree of protection than ordinary buildings.
2. Determine the seismic risk applicable to the location under consideration.
3. Select suitable architectural, structural and mechanical properties of structural components and equipment with special attention to deformation behaviour at high loads.
4. Assess the cost of seismic-resistant design comparison with the projected risk to people and to property, i.e., perform a cost-benefit analysis.

Some of these steps are interrelated so that an iterative design process may be required. It should be mentioned that, in general, a quantitative cost-benefit analysis is a complex operation that may have to rely heavily on judgement.

Increasing attention has been focussed on the vulnerability of essential lifeline services, both within a building and throughout urban centres. Included are power lines, water supply, sewage disposal, communications, oil and gas pipelines, and transportation facilities. Interruption of such services in a period of crisis can pose severe hardship to a community or a threat to the health and safety of the population. Besides providing adequate strength and ductility to resist ground motion, it may be advisable to introduce multiple paths or loops in a distribution network in order to provide alternate paths of supply. This limits the regions that can be affected by a failure or interruption at one point of a network.

As Canada has not experienced a major destructive earthquake in recent decades, similar events in other parts of the world are examined and the lessons learned are adapted to local geology, engineering practice and economic and social conditions. Observations are complemented by theoretical and experimental studies carried out in design offices, universities, and government laboratories. Ultimately they may be utilized by regulating bodies in the form of improved design requirements.

Construction details that have proved particularly vulnerable to earthquakes include:

1. building layouts that involve large open spaces at ground level or asymmetric distribution of walls and columns;
2. inadequate connections between main structural members such as columns and beams, and between walls and roofs;
3. inadequate connections between the main structure and appendages or interior components such as partitions, false ceilings, equipment racks, shelving, machinery and elevators;

4. brittle materials in regions of high stress;
5. loose foundation soils that tend to slump or slide during an earthquake.

Earthquake Resistant Design and Building Codes

Most seismic design requirements in Canada follow closely those formulated in the National Building Code of Canada (NBC)[7]. Code requirements for a given site are based on design earthquake ground motions calculated to have an even chance of being exceeded at least once in 100 years. This results in a risk analogous to that assumed in the design for wind resistance.

For a building to achieve a minimum level of seismic resistance the Code specifies certain lateral design forces and construction details. The seismic requirements of Part 4 of the NBC, intended for engineered construction, depend on the geographical location of the building (i.e., the seismic zone), the type of structure and materials employed, type of foundation soils, and the importance of the building in the event of an earthquake. Some background information on seismic requirements is given in Commentary J of Supplement No. 4 to the NBC[6]. For unusual types of building for which the Code requirements may not be representative a more detailed method of seismic analysis is presented in Commentary K.

For residential and commercial buildings of limited size falling within the scope of Part 9 of the NBC, the seismic requirements simply specify reinforcing requirements for masonry, thus lending some ductility to an otherwise brittle construction. Properly constructed small buildings of wood frame or steel are judged to possess adequate capacity to absorb energy and consequently to prevent collapse in a major earthquake.

To stimulate research and inform the engineering profession on earthquake engineering matters the National Research Council has established the Canadian National Committee on Earthquake Engineering (CANCEE), on which seismic experts from industry, universities, and government agencies are represented. Among its other functions, this committee makes recommendations to the Associate Committee on the National Building Code on matters concerning seismic design of buildings.

Concluding Remarks

Large earthquakes have occurred in areas adjacent to the St. Lawrence River, on the West Coast and in northern regions of Canada, and can be expected again. In order to limit the risk to life and property it is prudent to anticipate the consequences of a projected seismic event and to employ principles of seismic resistant design. Minimum requirements for this purpose are given in building codes such as the National Building Code of Canada. Generally the emphasis has been on protection of the building occupants rather than on prevention of structural damage. If in specific instances greater seismic resistance seems appropriate to guard against some special hazard, more stringent measures can and should be adopted.

The field of earthquake engineering is still evolving; new observations from destructive earthquakes and continuing theoretical investigations will result in improved methods of seismic resistant design.

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