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A SEISMIC PROBABILITY MAP FOR CANADA

by

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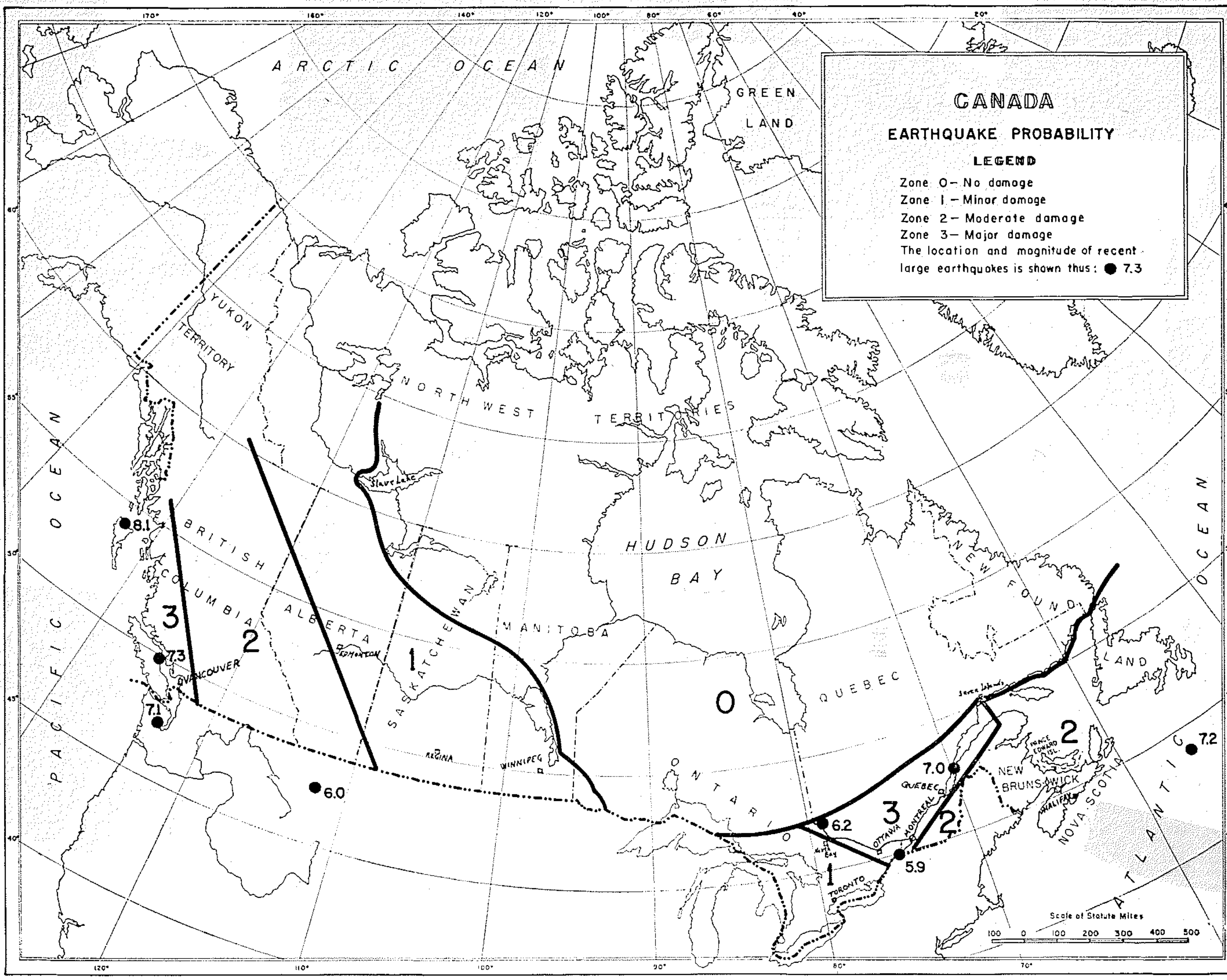

Figure 1

A SEISMIC PROBABILITY MAP FOR CANADA

By JOHN H. HODGSON
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IN recent months the Seismological Division of the Dominion Observatory has received many letters asking about earthquake risks in various parts of Canada. This interest undoubtedly reflects the fact that architects and engineers have become aware of the existence of earthquake risks through the National Building Code of Canada. The new Code, issued in 1953 by the National Research Council, makes provision for the forces due to earthquakes and includes an Earthquake Probability map.

This map is reproduced as Figure 1. It divides Canada into zones, according to the damage which is to be expected from future earthquakes. These range from Zone 3, in which major damage is to be expected, to Zone 0, in which no damage is anticipated. Zone 3 has been applied to two areas, the coast of British Columbia, and the Ottawa-St. Lawrence valley area.

The Zone designations used in the Canadian map are similar to those established for the United States by the United States Coast and Geodetic Survey. Their map[1] agrees with ours in the two Zone 3 areas, for this rating has been applied to the adjacent sections of the United States. But the United States map also shows California and Nevada, in which so many serious earthquakes have occurred, as Zone 3. Can it be true that the St. Lawrence valley and the coastal area of British Columbia are as potentially dangerous as California? Most Canadians would question this, for the total damage caused by earthquakes in Canada has been quite small, and there has been little loss of life.

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Earthquake Intensity

If we are to compare the seismicity of different areas we must have some means of comparing the relative sizes of earthquakes. Until fairly recently it has been necessary to rate earthquakes according to their effects, that is to say, the damage done or the alarm caused. The most recent scale[2] devised for this purpose is reproduced on the next page.

Scales based on damage have not been completely satisfactory. A very large earthquake occurring in a remote area may cause little damage, whereas a much smaller earthquake

MODIFIED MERCALLI INTENSITY SCALE OF WOOD AND NEUMANN
(Abridged)

I Not felt except by a very few under especially favorable circumstances.

II Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing truck. Duration estimated.

IV During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.

V Felt by nearly everyone; many awakened. Some dishes, windows, etc. broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.

VI Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

VII Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.

VIII Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbs persons driving motor cars.

IX Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed over banks.

XI Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

occurring under a city may be disastrous, particularly if the city has many buildings that are poorly constructed or that stand on poor ground. Similarly, the alarm which an earthquake causes, and the attendant amount of newspaper space devoted to it, are no indication of its size. An earthquake which would alarm the inhabitants of Toronto, for example, would pass almost unnoticed in Tokyo.

The damage which an earthquake will do to a particular building depends on four factors:

(i) The actual energy released by the earthquake;

(ii) The distance of the building from the centre of the earthquake;

(iii) The nature of the site and of the soil on which the building stands;

(iv) The type of building, and the care with which it has been designed and constructed.

The Intensity scale of Wood and Neumann, which is certainly the best yet devised, incorporates these factors, but not in a way which makes the effect of each clear. Let us examine each factor in turn.

Earthquake Energy and Earthquake Magnitude

Seismologists at the California Institute of Technology[3] have defined a term known as *earthquake magnitude* and have determined the relationship between the magnitude of an earthquake and the energy it releases. The magnitude of an earthquake is determined from the record which it writes at seismograph stations throughout the world, and is independent of the damage which the earthquake causes. In computing magnitudes one must take account of the depth of the earthquake within the earth and of its distance from the recording station, but when this is done one arrives at about the same value regardless of the distance of the station from the earthquake. It is thus possible to determine the magnitudes of earthquakes fairly accurately, and Professors Gutenberg and Richter of the above Institute have published the magnitudes for all the principal earthquakes which have occurred since instrumental seismology began about fifty years ago.[4]

The relationship between magnitude and energy varies with the depth of the earthquake. In California the following relationship holds:

$$\text{Log } E = 12 + 1.8M$$

where E is the energy in ergs released by the earthquake and M is its magnitude. The relationship for the seismic areas of Canada cannot be much different from that for California for modern research shows that the focal depth of Canadian earthquakes is about the same as for Californian earthquakes.

The above equation has been plotted as a graph in Figure 2. To understand what the graph means, consider the point A, corresponding to a magnitude of about 5.6. An earthquake of this magnitude usually does minor damage to any buildings close to its epicentre. Some plaster may fall and some chimneys may be broken, but well-constructed buildings are normally not seriously damaged. We may regard this as the threshhold magnitude at which damage begins. From the graph we see that the energy released by an earthquake of this magnitude would be 10^{22} ergs.

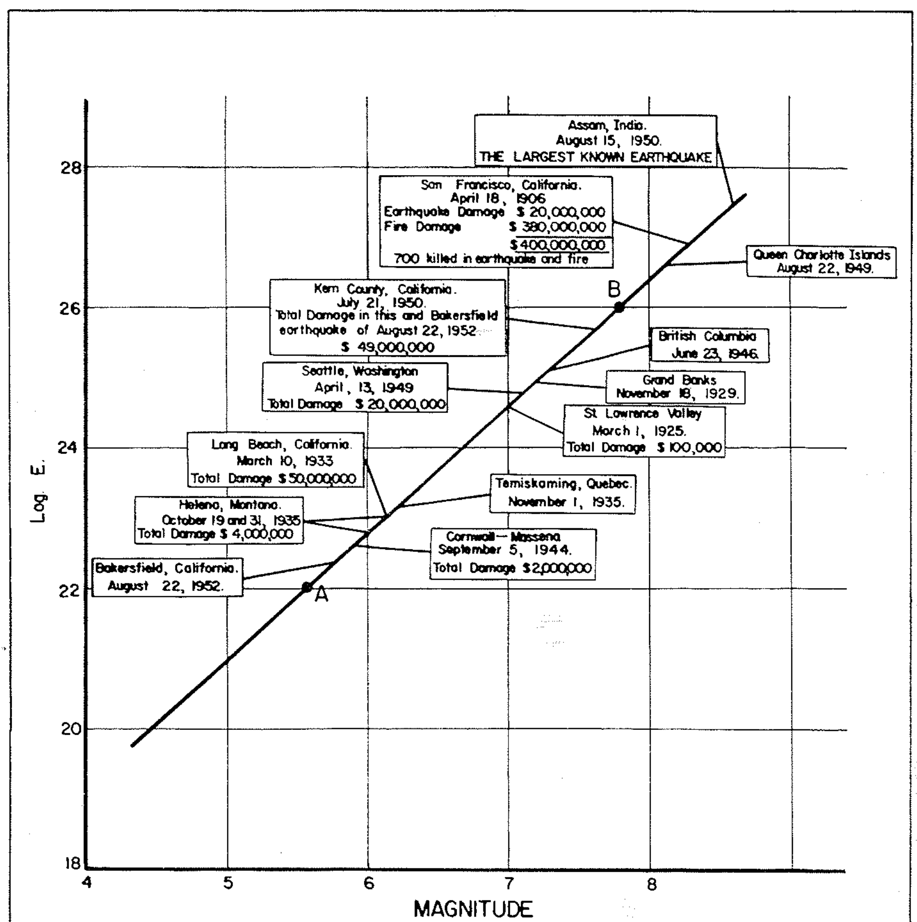


Figure 2

As a matter of interest this is about as much energy as that released by the atomic bomb dropped on Hiroshima.

Now consider the point B, corresponding to a magnitude of 7.8. If an earthquake of this magnitude occurs in a settled area it may be expected to do great damage. Many buildings will be damaged beyond repair, fissures may open in the ground, and underground pipelines such as water mains may be put out of service, with resultant fire hazard. From Figure 2 we see that an earthquake of this magnitude would release 10^{26} ergs, 10,000 times as much as is released by our threshold earthquake of magnitude 5.6.

The largest earthquake of the last 50 years occurred in Assam, in 1950. It had a magnitude of 8.6. This is equivalent to an energy release of more than 10^{27} ergs, corresponding to the energy released by 100,000 of our threshold earthquakes, or of an equal number of atomic bombs.

The magnitude scale gives us a method of comparing the intrinsic energy of earthquakes. The scale must be used with discretion, for it is a very compressed one. As we have seen, the difference in magnitude between an earthquake which does only minor damage and the largest earthquake ever recorded is only three scale divisions. Because the scale is logarithmic this small increase corresponds to a very large increase of 100,000 times in the energy released.

The epicentres of recent Canadian earthquakes have been plotted on the Earthquake Probability Map, with their magnitudes beside them. How do these magnitudes compare with those for California earthquakes? The magnitudes of both Canadian and Californian earthquakes have been shown on the graph of Figure 2, the Canadian earthquakes to the right, the Californian earthquakes to the left. Total damage estimates have been given for the Californian shocks and for two of the Canadian ones.

It is apparent from the chart that, from the standpoint of magnitude, Canadian earthquakes have been about as severe as those for California. The fact that they did so little damage has been a matter of good fortune. Only the two smallest Canadian shocks were located near cities. The Temiskaming earthquake was close to a very well constructed town, built almost entirely on rock, and it did little damage. The Cornwall Massena shock, the smallest of those considered, did $2,000,000 damage.

Only recent Canadian earthquakes have been indicated on the map. However, studies by E. A. Hodgson[5] show that the St. Lawrence valley has a history of seismic activity dating back to the time of Jacques Cartier. The largest Canadian earthquake on record occurred in 1663; its epicentre was probably near the site of the 1925 shock. To judge by contemporary reports the earthquake must have been at least as large as the San Francisco earthquake. Whole areas of forest were levelled by it, and landslides caused by the earthquake dammed the Saint Maurice river below Shawinigan Falls, causing it to change its course.

The history for the west coast has been traced back to 1841 by W. G. Milne[6]. He finds that several earthquakes with magnitudes of 7 or more, and at least one with a magnitude probably greater than 7.5, occurred in the years prior to the installation of sensitive seismographs at Victoria.

It seems clear that large earthquakes have been occurring in these two areas as far back as records are available. Earthquake damage in Canada has been low, not because of the lack of earthquakes, but because the earthquakes have not happened close to the large cities and towns.

The Effect Of Distance

It is obvious that the farther a building is from the centre of an earthquake the less damage that building is likely to sustain. It is difficult to define this effect exactly, but the damage probably drops off about as the square of the distance. We may seek some examples from Canadian earthquakes.

The British Columbia earthquake of June 23, 1946[7], (magnitude 7.3), occurred under water, so that the effects at the centre of the shock could not be appraised. The nearest towns were fifteen miles from the epicentre and the damage there was moderate. Large numbers of chimneys were damaged with some consequent damage to roofs, and much plaster was knocked down. Minor damage was reported at distances of as much as 200 miles and the earthquake was felt to distances of 500 miles or more.

The Queen Charlotte earthquake of August 20, 1949[6], (magnitude 8.1) was felt generally at distances of as much as 800 miles and alarmed residents of Prince George, more than 400 miles away. The damage in the epicentral region was very severe; trees were felled and many landslides occurred. Yet there was no major damage at Prince Rupert, 125 miles from the epicentre.

In the St. Lawrence earthquake of March 1, 1925[8], (magnitude 7.0) almost every building within the epicentral zone was damaged. Most chimneys within fifteen miles of the epicentre were destroyed and some stone churches were completely demolished. Even frame buildings, which normally resist earthquakes, were twisted out of shape. At Quebec, distant 80 miles from the epicentre, damage was confined to areas of bad ground. Minor damage was reported at distances in excess of 200 miles.

On the basis of Canadian experience, it appears that damage from large earthquakes is likely to be severe within 20 miles of the epicentre, and to be minor at distances of 100 miles; some damage may occur beyond this distance.

The Effect Of Soil And Site

H. F. Reid, who studied the relationship between damage and foundation in the San Francisco earthquake, found that if the damage on the most solid rock was taken as 1, then the damage on made land ranged from 4.4 to 11.6, on loose sand from 2.4 to 4.4, and on sandstone from 1 to 2.4. These findings are in accordance with Canadian experience. Particularly in eastern Canada, where many towns are built on alluvium, soil type is the principal factor controlling damage. A second important factor is the actual nature of the site. Experience suggests that a building on the side of a hill is more subject to damage than one built on the level.

Earthquake-Resistant Construction

The fourth factor — the nature of the building and of its design and construction — is a very important one. After the southern California earthquake of 1952, two engineers, K. V. Steinbrugge and D. F. Moran of the Pacific Fire Rating Bureau, made a very comprehensive study[9] of the damage caused by the earthquake*. They review insurance practice and make recommendations based on their detailed examination of buildings of all sorts.

They find that, in general, buildings designed to resist earthquakes, with rigid construction and with adequate provision for the effects of

* A copy of the report may be purchased from the Secretary, Seismological Society of America, University of California, Berkeley, California, price $2.00.

lateral forces, came through the earthquake almost undamaged. For example, the total damage to schools in Kern County was in excess of $12,500,000; this was confined almost entirely to schools which has not been made earthquake resistant. On the other hand the $2,800,000 Arvin High School, designed to resist earthquakes, suffered less than 1% damage. The slight damage that did result could be traced to faulty construction and indicated poor application of a satisfactory design.

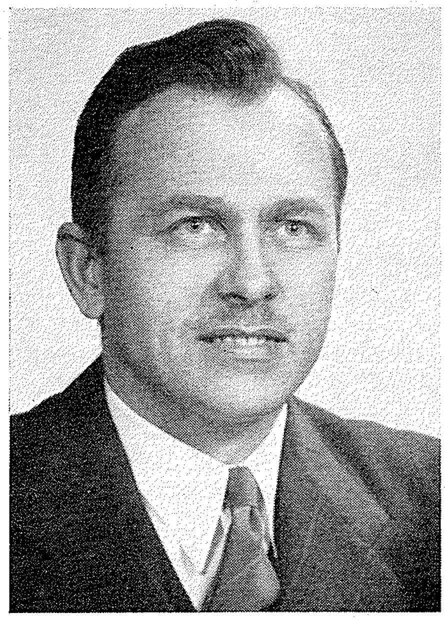
The Earthquake Probability Map

In designing the earthquake probability map we had first of all to recognize that two areas of Canada — the St. Lawrence valley and the coast of British Columbia — had a seismic history comparable to that of California. There is no evidence that building practices are any better in Canada than in California, nor that soil conditions are safer. Indeed in eastern Canada, where there are so many glacial deposits, soil conditions are probably worse. There was no choice but to place these two areas in Zone 3.

At the other end of the scale we have the Canadian Shield, with little known seismic history, and regarded by geologists as a stable land mass. Prior to 1935 we would have placed the entire Shield area in Zone 0, but the Temiskaming earthquake occurred well within the border of the Shield and the boundary of the Zone 0 has had to be adjusted in consequence. This is an illustration of the fact that earthquakes may occur anywhere, even where they have never been known to occur before.

Aside from these two extreme areas of Zone 3 and Zone 0 we have very little to go on, as is suggested by the straight-line boundaries. Serious earthquakes have occurred in Montana and we know of no reason why they should not occur north of the International boundary. A Zone 2 has therefore been placed in eastern British Columbia and western Alberta, with a Zone 1 separating this from the Zone 0 of the Canadian Shield. Similarly, in the east, there have been earthquakes in Maine and New Hampshire, in the St. Lawrence valley and off the Atlantic coast. The Eastern Townships and the Maritime provinces have therefore been placed in Zone 2. Southern Ontario has been placed in Zone 1, for it has very little history of seismic activity.

As time goes on it should become possible to modify the boundaries of the zones shown on the map. The Dominion Observatory maintains 11 seismograph stations across Canada and is gradually extending the network. Research into the travel-times of earthquakes have made it possible to locate the epicentres of even small earthquakes within about one or two miles. We may look forward to the day when, at least in the more seismic areas, the active faults will be mapped. In the meantime the present map, with its generalized boundaries, is a good first approximation.



ABOUT THE AUTHOR

Dr. J. H. Hodgson, the author of this article, was educated at the University of Toronto, where he received a B.A. in Applied Mathematics and an M.A. and a Ph.D. in Geophysics. He worked for several years in petroleum geophysics in California, Texas and Louisiana and then returned to the University of Toronto as Assistant Professor of Geophysics in 1945. In 1949 he joined the staff of the Dominion Observatory, and in 1952 he succeeded his father, Dr. E. A. Hodgson, as Chief of the Seismological Division. Dr. Hodgson has specialized in studies of the earth's crust and of the mechanism of earthquakes and has published a number of technical papers in these fields. He is a Director of the Seismological Society of America, is Chairman of the Section of Seismology of the Canadian National Committee for the International Union of Geodesy and Geophysics and is a member of the Executive Committee of the International Seismological Association.

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