Seismic Assessment of Syncrude Tailings Dyke

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SYNOPSIS: This paper describes the assessment of seismic risk at the Syncrude Site. It reviews the site physiographic and geologic setting and considers the site position relative to observed seismic events, strain release patterns, and main tectonic features in western Canada. Both deterministic and probabilistic approaches were employed in the seismic risk assessment. Data on seismic events that occurred between 1899 and 1985 were included in the evaluation. Of particular importance was determination of the impact on the site of a series of large earthquakes which occurred in the Nahanni area of the Northwest Territories during 1985. Hasegawa et al. (1981) attentuation relations were used for computing ground motion amplitudes at the site. The review confirmed that the seismic risk at the Syncrude Site remains low.

SYNCRUDE OIL SAND PROJECT AND TAILINGS IMPOUNDMENT

Syncrude Canada Limited operates one of the largest open pit mining operations in the world. The mine and plantsite are located 40 km north of Fort McMurray in northeastern Alberta (see Fig. 1). Operating at design capacity, the mine produces 96 million tonnes of oil sand per year from an area which will eventually cover 24 km^2. The mining operation results in the production of approximately 240 000 tonnes/day of tailings solids.

Approximately 475 million m^3 of sand, 400 million m^3 of thick sludge and 50 million m^3 of free water will require permanent storage within the Syncrude Tailings Pond. To accommodate these volumes, approximately 18 km of dyke ranging from 32 m to 90 m in final height will be constructed. At completion, the tailings pond will have a surface area of 17 km^2. Present plans call for the completion of dyke construction by 1992.

The general layout of the tailings pond and perimeter dyke is illustrated in Fig. 2. Figure 3 illustrates a typical design section for the tailings dyke. The compacted shell is constructed by utilizing hydraulic construction techniques. This procedure involves sluicing of the tailings stream into construction cells orientated parallel to the dyke centerline. The tailings sand placed in the construction cells is spread and compacted by wide pad dozers during the sluicing operation. During the winter months when cell construction is not feasible, the tailings stream is discharged upstream of the compacted shell. The coarse sand fraction settles out to form a beach with a 2% to 3% slope. The water and sludge fractions of the tailings stream flow into the pond.

The downstream slope angles are largely dictated by the underlying geology and associated shear strength parameters as well as pore pressure response and/or dissipation rates. In general, the foundation soils underlying the tailings disposal area consist of Pleistocene and

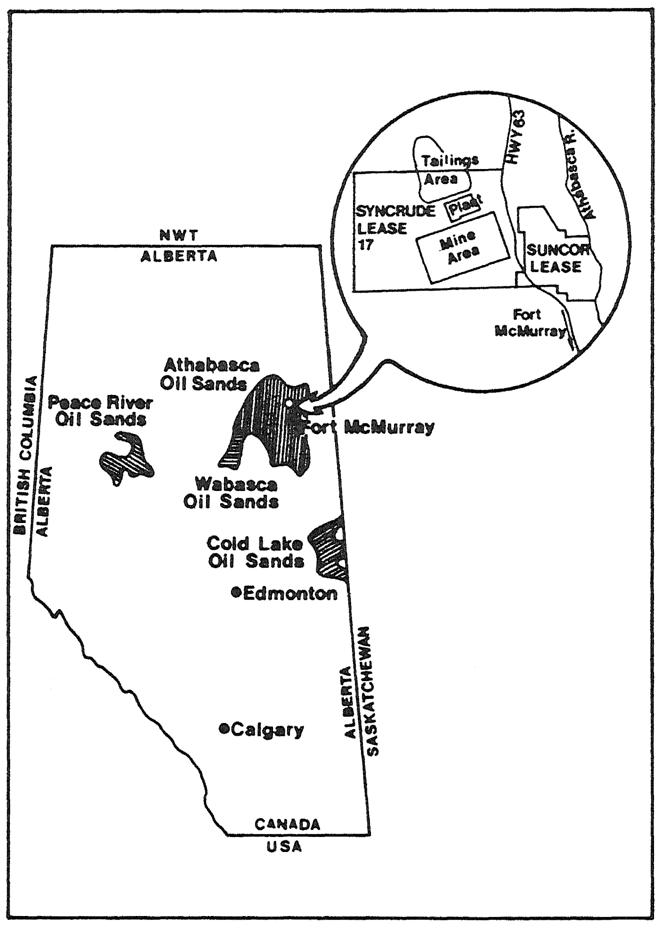

Fig. 1 Location of Syncrude Minesite and Tailings Area

Cretaceous overburden units which overlie the McMurray Formation (Km). The former Beaver Creek Channel defines an approximate boundary between two distinct foundation geology conditions (see Fig. 2). The portion of the dyke to the west of the creek valley is underlain by glacial till and the Clearwater Formation (Kc). The area to the east of the former creek channel is primarily underlain by Pleistocene fluvial sand and gravels (Pf) as well as glacial tills (Pg). The Clearwater Formation has been eroded in the eastern area with the exception of localized remnants of its basal units (Kcw and Kca).

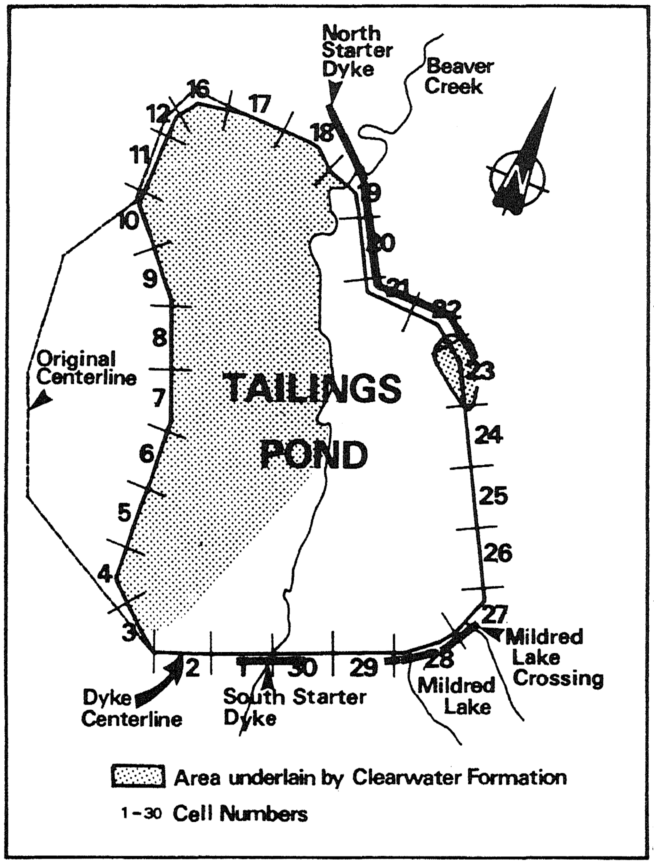

Fig. 2 Layout of Syncrude Tailings Disposal Area

SITE PHYSIOGRAPHIC AND GEOLOGIC SETTING

The Syncrude Site is located in the Alberta Plateau adjacent to the Saskatchewan Plain, both physiographic units belong to the Interior Plains Region (Bostock 1970). The Region, in turn, borders the Shield on the east and the mountains of the Cordilleran Region of the west (see Fig. 4). The Interior Plains are underlain by flat-lying Later Proterozoic, Paleozoic, and Tertiary strata. A smooth upland surface is the main feature of all the hills in the Alberta Plateau.

Locally, the Syncrude tailings pond is situated in the east-central part of a broad topographic lowland defined by the Muskeg Mountain and the Thickwood Hills to the east and south and the Birch Mountains to the west (Dean 1980). The

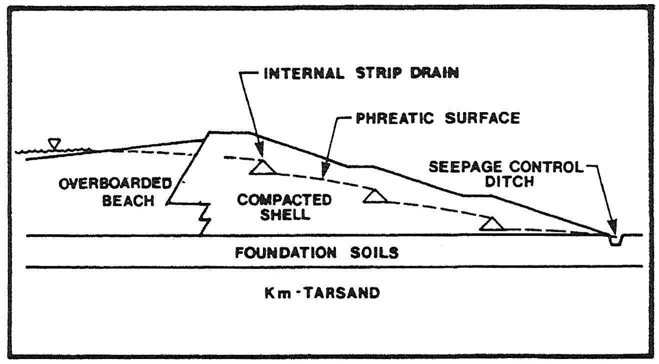

Fig. 3 Typical Design Section of Tailings Dyke

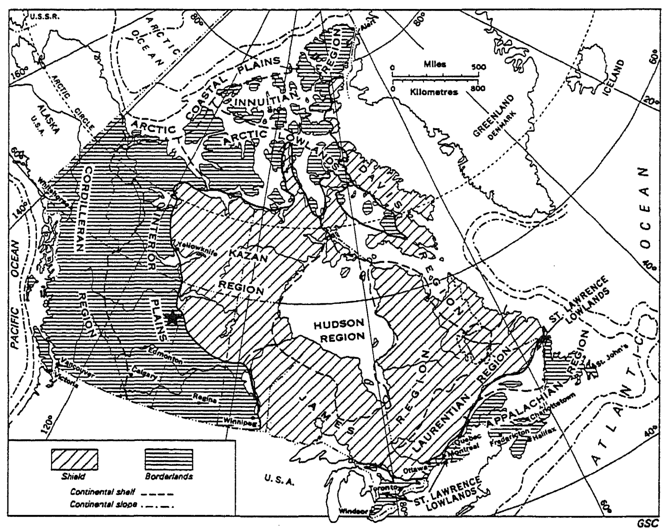

Fig. 4 Physiographic Regions of Canada (After Bostock 1970)

McKay and Athabasca Rivers flow through the central portions of this lowland produced by pedimentation.

Devonian highs of the Waterways Limestone Formation lie in the northwest and southwest areas of the tailings pond. An east-west trending broad trough-like structure lies between these highs. Cretaceous sediments of the McMurray and Clearwater Formations follow this basement configuration. Cretaceous sediments, in turn, are unconformably overlain by Pleistocene and Recent deposits over most of the tailings pond area.

Two faults affecting the Precambrian surface in the Athabasca Oil Sands Region were hypothesized by Hackbarth and Nastasa (1979). The north-northwest trending Sewetakun Fault follows approximately the Athabasca River north of Fort McMurray, while the other west-northwest trending fault is located south of Fort McMurray. The Sewetakun Fault appears to have affected rock units as old as Devonian in age.

SEISMICITY AND TECTONICS

Data on seismic events affecting the Syncrude Site that occurred between 1899 and 1985 were obtained from the Pacific Geoscience Centre. Figure 5 (Milne et al. 1978) shows western Canada regional distribution of earthquakes with magnitude greater than or equal to three, updated to 1985 for the Syncrude Site. Figure 6 from the same paper, shows the pattern of strain release over the time period of 1899 to 1975 for western Canada. Strain release is calculated as the square root of the total observed seismic energy released during an earthquake. The strain release contours shown in the figure have been smoothed regionally and normalized to be the equivalent number of magnitude 5 earthquakes for an area of 100 km x 100 km and a time of 100 years.

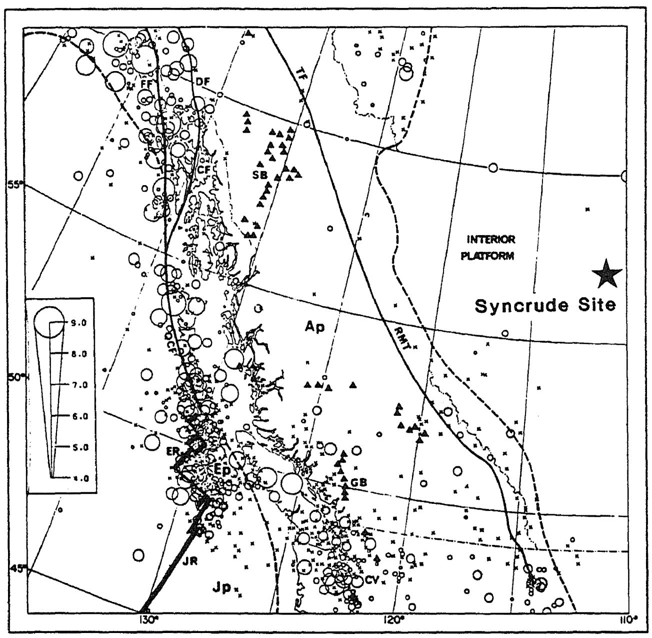

Fig. 5 Western Canada Seismicity Map and Tectonic Features (After Milne et al. 1978)

Figure 5 also shows the tectonic features of western Canada. As shown in the figure, the most active earthquake areas correspond, in general, to the boundaries between the major lithospheric plates. These plate boundaries include:

(1) the Queen Charlotte (QCF) - Fairweather (FF) fault system (Pacific (P_p) - America (A_p) plates);

(2) the offshore ridge-fracture zone system (Pacific - Juan de Fuca (J_p) plates); and

(3) the Vancouver Island - Puget Sound region (Juan de Fuca - America plates).

The Syncrude Site is plotted on Figs. 5 and 6 to indicate the site position relative to observed seismic events, strain release patterns, and main tectonic features in western Canada.

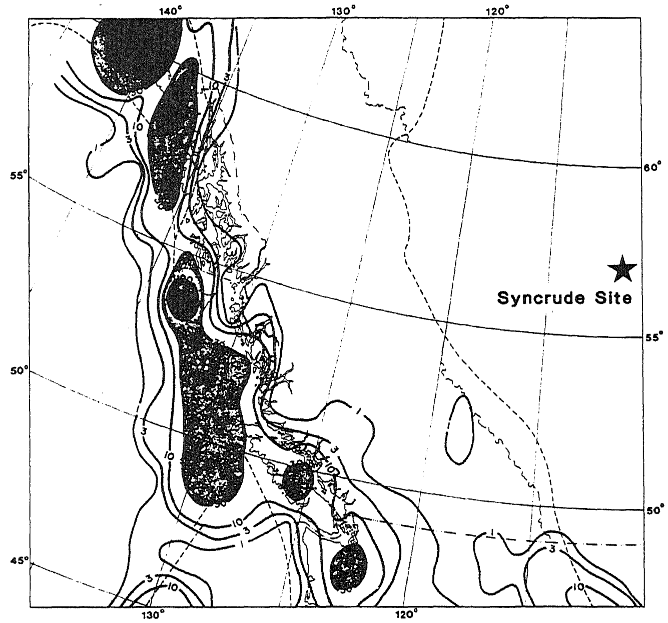

Fig. 6 Western Canada Strain Release Map (After Milne et al. 1978)

SEISMIC RISK ASSESSMENT

Seismic risk at the Syncrude Site was assessed using both deterministic and probabilistic approaches. The impact of a series of large earthquakes which occurred in the Nahanni area of the Northwest Territories during 1985 has been specifically addressed.

Both approaches used the same attenuation functions for computing ground motion amplitudes at specified distances from earthquakes of specified magnitudes. The amplitudes of acceleration (A) and velocity (V) are usually functions of (M) magnitude and (R) hypocentral distance. Hasegawa et al. (1981) defined the attenuation functions currently used in Canada for calculations for structures covered by the National Building Code of Canada (NBCC 1985). The attenuation functions for eastern and western Canada are presented in Table 1; both eastern and western relations are used in the National Building Code of Canada.

Based on the distribution of felt reports, earthquakes such as those in 1909, 1918 and others have shown that the area east of the Foothills has a low attenuation, such as the eastern function displays. Since the Syncrude Site is east of the Cordillera, the eastern type of attenuation function is used for this assessment. However, seismic waves do travel from the west to this site, so the attenuation function should be a combination of an east and west function. Hence, the usage of the eastern type of attenuation implicitly involves some degree of conservatism.

TABLE 1
SUMMARY OF HASEGAWA ET AL. 1981
ATTENUATION RELATIONS

Peak Horizontal Ground Acceleration	Western Canada	A_p (%g) = $1.02\ e^{1.3M}\ R^{-1.5}$
	Eastern Canada	A_p (%g) = $0.35\ e^{1.3M}\ R^{-1.1}$
Peak Horizontal Ground Velocity	Western Canada	V_p (cm/s) = $0.00040\ e^{2.3M}\ R^{-1.3}$
	Eastern Canada	V_p (cm/s) = $0.00018\ e^{2.3M}\ R^{-1.0}$

Where R = hypocentral distance in km
M = earthquake magnitude

Seismic wave amplitudes are usually estimated for two general frequency ranges. For acceleration, the frequency extends from often very high values in the range of 50 Hz down to about 2.5 Hz. These high frequencies are considered to be characteristic of the type of ground motions one might expect from nearby earthquakes of a variety of magnitudes. One would not, on the basis of the historical record, expect to find these high frequency seismic waves present at the Syncrude Site. The range of frequencies which are typical of the velocity ground motions are from 2.5 Hz to 0.2 Hz. These corner frequencies are, however, not to be taken too rigidly, because there are no observations of strong-motion, seismic waves in the general region around the Syncrude Site.

Deterministic Assessment

No probabilities are stated or implied in this deterministic calculation of ground motion. Simply one places the largest historical earthquake, or the largest possible earthquake at a location as close as reasonably possible to the site. In this case, except where noted, the largest historical earthquake is used for the deterministic assessment.

There are three sources of seismic activity (see Table 2) which can contribute to measurable ground motion at this site. In addition, a fourth site has been chosen (see Table 2) to represent the possible location of a large earthquake east of the Cordillera, although the likelihood of such an event is very remote.

The first is the site of the largest earthquake in Canada, and this earthquake was generally felt over much of western Canada. Although the coast of Alaska also has large earthquakes and is perhaps somewhat closer to the site, the Queen Charlotte event is used. The motion at the Syncrude Site from the Alaska and Queen Charlotte seismic events would be comparable, and was probably of low frequency. The second seismic source is in the Nahanni area. Until the fall of 1985, there were no significant earthquakes in the region, but in 1985 one rather strong earthquake did occur in Nahanni, Northwest Territories along with several related events (Horner et al. 1985 and Wetmiller et al. 1986). A strong motion seismograph located near the epicentre did record some strong accelerations, in excess of 1 g (Weichert et al. 1986). The third seismic source is at the location of an earthquake known to have occurred in 1922, north of Lake Athabasca which was reported in the International Seismological Summary (ISS). The distribution of the seismic stations which recorded this earthquake is not ideal, and the epicentre of the event could easily be in the Nahanni region, or further north in the Richardson Mountains. For this report we accept the ISS epicentre as the site of an event of magnitude 5.5. For the fourth event, a site in the eartern Foothills is assumed, and the ground motions calculated to check the sensitivity of this assumption. This event is selected to cover the possibility that a large earthquake similar to that which occurred in Nahanni on December 23, 1985 could migrate along the Cordilleran Fold and Thrust Belt (Adams et al. 1986). Table 2 lists the results for these four events.

TABLE 2
SUMMARY OF DETERMINISTIC ASSESSMENT OF PEAK GROUND MOTION PARAMETERS* AT SYNCRUDE SITE

EARTHQUAKE	EPICENTRE	DATE	MAGNITUDE	EPICENTRAL DISTANCE (km)	PEAK HORIZONTAL GROUND ACCELERATION (% g)	PEAK HORIZONTAL GROUND VELOCITY (cm/sec)
1	Queen Charlotte Island	1949	8.1+	1418	0.99	3.9
2	Nahanni	1985	6.9	890	1.6	1.6
3	North of Lake Athabasca	1922	5.5	340	0.7	0.2
4	Eastern Boundary of Rocky Mountain Foothills	Assumed	7.0	527	3.1	3.3

* Focal depths of all earthquakes are assumed at 20 km.
\+ For computation of Peak Ground Motion Parameters, M = 7.5 is used in Hasegawa et al. (1981) attenuation relations for all magnitudes greater than 7.5.

Model 1:
Same as that used for NBCC but with the use of eastern Canada attenuation relations only.

Model 2:
The Nahanni (1985) event was of magnitude 6.9 and has occurred in the MKZ source zone. To accommodate this event, the maximum magnitude in the MKZ zone is raised to 7.0. If the Nahanni earthquake were to be repeated anywhere along the eastern MKZ region, and along the eastern Foothills of the mountains, then the equivalent to a Nahanni event should be extended all the way down to the United States border. To accomplish this, the maximum magnitudes in the NBC and SBC zones are also raised to 7.0.

Model 3:
Since the Nahanni earthquake is a new real event, consideration must be given as to whether the above modification is the solution, or whether a new seismic source zone should be set in the southern part of the MKZ source zone. NBCC recognizes a small independent source zone in the region of the Richardson Mountain (RIC) towards the north central region of the MKZ. For this study, a source zone around the Nahanni area, with a maximum magnitude of 7.0 and an area larger than the RIC zone has been defined as LMK, for lower McKenzie.

Model 4:
Finally a model is run with the new LMK zone and the changes in the NBC and SBC zones set out in Model 2.

From Table 4, one can obtain the levels of ground amplitude for a range of probabilities of exceedance. NBCC employs a 10% chance of exceedance in 50 years, or an annual probability of exceedance of 1/475 = 0.0021. Results in this study are listed for an even lower probability down to an annual probability of 1/1000. Other lower values can be calculated, but the reliability of extending the computations to these low numbers is questionable. In the evaluation of the ground motion, a stochastic factor is employed to allow for the scatter of the data used for the calculation of the attenuation functions. For the NBCC computations, a value of this factor was set at 0.7. The use of this value increases the end result by a factor just under two. This procedure has been followed for the Syncrude study. Thus, another layer of conservatism has been added.

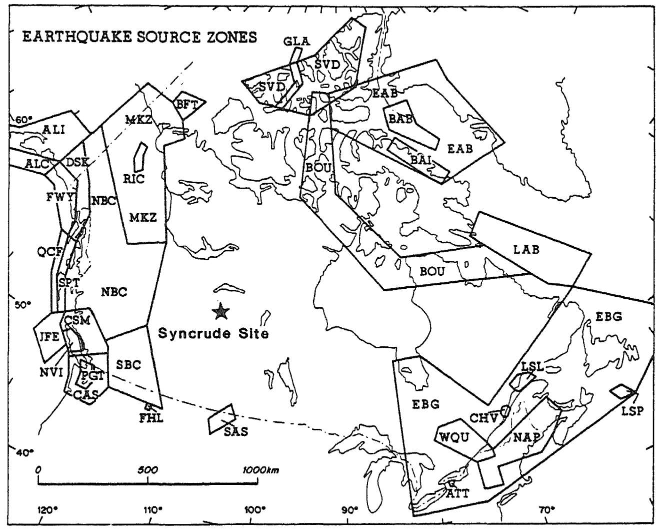

Fig. 7 Seismogenic Zones of Canada (After Basham et al. 1985)

TABLE 4

SUMMARY OF PROBABILISTIC ASSESSMENT OF PEAK HORIZONTAL GROUND ACCELERATION (PGA) AND VELOCITY (PGV) AT SYNCRUDE SITE

	Probability of Exceedance per Annum	0.01	0.005	0.0021	0.001	Remarks on Model
	Probability of Exceedance in 50 years	40%	22%	10%	5%	
NBCC 1985	PGA (% g)	0.9	1.1	1.4	1.6	National Building Code of
	PGV (cm/sec)	2.5	3.2	3.9	4.7	Canada 1985
Model 1	PGA (% g)	2.3	-	3.9	4.9	Eastern Attenuations
	PGV (cm/sec)	3.0	-	6.0	7.7	
Model 2	PGA (% g)	2.3	-	4.0	5.1	Eastern Attenuations and
	PGV (cm/sec)	3.1	-	6.0	7.8	Modification of Zones
						MKZ, NBC and SBC
Model 3	PGA (% g)	2.5	-	4.1	5.2	Eastern Attenuations and
	PGV (cm/sec)	3.1	-	6.1	7.8	New Zone LMK
Model 4	PGA (%g)	2.5	-	4.2	5.3	Eastern Attenuations and
	PGV (cm/sec)	3.2	-	6.1	7.9	New Zone LMK and
						Modification of Zones
						NBC and SBC

SUMMARY

The Syncrude Site is situated in the Alberta Plateau with a smooth upland surface and underlain by flat-lying Cretaceous sediments. There are some evidences suggesting nearby fault activities may have affected rock units as old as Devonian in age. Historically, the Site is positioned at considerable distances from seismic events observed over the last nine decades, main areas of strain release, and major tectonic features in western Canada. Our assessment summarized in Table 5 demonstrates that the large earthquakes in the Nahanni area which occurred in 1985 do not increase significantly the seismicity of the Syncrude Site. Therefore, our review confirms the assumption of low seismicity at the Syncrude Site.

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ASSESSMENT APPROACH	PROBABILITY OF EXCEEDANCE PER ANNUM	PEAK HORIZONTAL GROUND ACCELERATION % g	PEAK HORIZONTAL GROUND VELOCITY (cm/sec)
Deterministic	-	0.7 to 3.1	0.2 to 3.9
Probabilistic	0.01	0.9 to 2.5	2.5 to 3.2
	0.0021	1.4* to 4.2	3.9* to 6.1
	0.001	1.6 to 5.3	4.7 to 7.9

* These values correspond to NBCC 1985 code, which does not include the consideration of 1985 Nahanni earthquakes.

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