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# The effect of the 1985 Nahanni records on the response of building structures

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ABSTRACT: A series of strong ground motions were recorded during a set of earthquakes which occurred in the North Nahanni River area of the Northwest Territories of Canada in late 1985. The strongest of these motions were recorded within 10 km of the epicentre of a magnitude 6.9 event; peak accelerations were well above 1 g and peak velocities exceeded 0.5 m/s. This paper describes a study of the engineering characteristics of the Nahanni strong motions, particularly as they affect the response of building structures. The investigation includes the shape of the response spectra, the response of typical building structures, strong motion durations and several measures of intensity. The characteristics of the Nahanni records are also compared with those of typical strong seismic motions and an ensemble of epicentral region seismic motions recorded under similar conditions. It is concluded that the Nahanni motions can be considered to be very strong seismic motions with an unusually high capability to excite low period structural systems.

## 1 INTRODUCTION

On October 5 1985, a magnitude [$M_S$] 6.6 earthquake occurred in the North Nahanni River area of the Northwest Territories of Canada. While no strong motion instruments were present at that time, three instruments were installed immediately after this earthquake. These instruments were triggered by a large number of aftershocks, including a second large earthquake [$M_s$ = 6.9] on December 23, 1985; this earthquake was located very near to the October 5 event

Of all of the triggered records, those having peak accelerations of about 0.1g or larger and durations of more than 2 s were considered to be of sufficient significance to be digitized immediately. The events, site locations and peak ground motion parameters of the resulting 17 components are summarized in Table 1. Detailed descriptions of the instrumentation, site locations, data processing and some seismological interpretations are provided by Weichert et al. (1986) and by Weichert, Wetmiller and Munro (1986). One vertical component is missing due to intermittent loss of accelerometer damping during the many events.

An examination of the peak ground motion parameters in Table 1 indicates that several of the motions have very high accelerations and velocities. In particular, the motions at site 1 during the main event on Dec. 23, 1985 have peak ground accelerations exceeding 1 g (over 2 g for the vertical component) and peak ground velocities exceeding 40 cm/s. It is clear that these are not only the strongest motions ever recorded in Canada but among the strongest ever recorded during an earthquake. It is therefore important that the implications of these records, e.g. for

Table 1. Description of Nahanni records and peak ground motion parameters.

| Event [all in 1985] | Site | Comp. | Peak Ground Motions | | |
|---|---|---|---|---|---|
| | | | A [g] | V [m/s] | A/V |
| Nov. 9 | S2 | L-N30W | 0.382 | 0.047 | 8.06 |
| | | T-S60W | 0.460 | 0.059 | 7.85 |
| | | V-up | 0.254 | 0.055 | 4.59 |
| Dec.23 Main Event | S1 | L-N10E | 1.101 | 0.462 | 2.38 |
| | | T-N80W | 1.345 | 0.451 | 2.98 |
| | | V-up | 2.367 | 0.588 | 4.02 |
| | S2 | L-N30W | 0.390 | 0.326 | 1.20 |
| | | T-S60W | 0.545 | 0.303 | 1.80 |
| | S3 | L-N | 0.194 | 0.034 | 5.66 |
| | | T-W | 0.186 | 0.063 | 2.96 |
| | | V-up | 0.181 | 0.061 | 2.97 |
| Dec.23 After Shock | S1 | L-N10E | 0.228 | 0.068 | 3.36 |
| | | T-N80W | 0.089 | 0.033 | 2.71 |
| | | V-up | 0.112 | 0.046 | 2.44 |
| Dec.25 | S3 | L-N | 0.105 | 0.011 | 10.00 |
| | | T-W | 0.089 | 0.014 | 6.27 |
| | | V-up | 0.074 | 0.009 | 7.87 |
| | Mean Value: | | | | 4.54 |

seismic code provisions and on the design requirements for building structures, be evaluated.

It is the purpose of this paper to evaluate the engineering characteristics of the Nahanni earthquake motions, i.e. response spectra, response of building structures, strong motion durations, and various intensity measures. This paper does not consider the implications of these records on the seismic risk in the region of Canada in which they were obtained.

Because the purpose of this study is to evaluate the engineering characteristics of the Nahanni seismic motions, it is important that their characteristics be compared with those of strong seismic ground motions which are typically used in engineering design. For purposes of this comparison, seven "typical" strong seismic ground motions have been selected; these records (labelled with prefix T) and their peak ground motion characteristics are listed in Table 2. More details on these records can be obtained from Hudson, Trifunac and Brady (1971) and Petrovski, Naumoski and Stamatovska (1984).

Table 2. Typical records, descriptions and peak ground motion parameters.

| No. | Comp., Site and Event | Peak Ground Motions<br>A<br>(g) | <br>V<br>(m/s) | <br>A/V |
|---|---|---|---|---|
| T1 | S00E, El Centro,<br>Imperial Valley,<br>May 18, 1940 | 0.348 | 0.335 | 1.04 |
| T2 | S69E, Taft Tunnel,<br>Kern County,<br>July 21, 1952 | 0.179 | 0.177 | 1.01 |
| T3 | S00W, Hollywood Str,<br>Kern County,<br>July 21, 1952 | 0.059 | 0.066 | 0.90 |
| T4 | N65E, Cholame Sh.2,<br>Parkfield,<br>June 27, 1966 | 0.489 | 0.781 | 0.63 |
| T5 | S16E, Pacoima Dam<br>San Fernando,<br>Feb. 9, 1971 | 1.170 | 1.132 | 1.03 |
| T6 | N86E, Olympia Hwy,<br>Western Wash.,<br>April 13, 1949 | 0.280 | 0.171 | 1.64 |
| T7 | N, Albatros Hotel,<br>Montenegro ,<br>April 15, 1979 | 0.171 | 0.194 | 0.88 |
|  |  | Mean Value: |  | 1.02 |

These T records include several which are considered to be "classics", e.g. the El Centro S00E component recorded during the May 18, 1940 Imperial Valley Earthquake. Six of the seven are from the western U.S.A., with five of these being from California. The seventh is a strong motion recorded during the Montenegro, Yugoslavia earthquake of April 15, 1979. The peak ground accelerations of the seven T motions range from 0.059 g to 1.17 g. The highest acceleration is associated with record T5, i.e. the Pacoima Dam record. This motion also produces the highest ground velocity (1.132 m/s).

Because the Nahanni motions were all recorded within about 10 km. of the epicentre, it is also helpful to compare their characteristics with those of previously recorded nearfield or epicentral seismic motions. To enable such a comparison to be made, the McMaster University strong motion database (Elop and Heidebrecht, 1986) was used to select a set of motions (designed as E records) which had been recorded on rock or firm soil at epicentral distances of 10 km. or less and for earthquakes having magnitudes of 6 or larger.

While space does not permit a detailed listing of the E motions, it should be noted that the peak ground accelerations of the E motions range from 0.044 g to 1.17 g; the peak velocities range from 0.02 to 1.132 m/s. It should also be noted that this set also includes the Pacoima dam record.

## 2 RESPONSE SPECTRA

Response spectra for all 17 Nahanni motions, for five values of damping, are provided by Weichert et al. (1985). For the purpose of this study, all the motions have been scaled to a peak velocity (PV) of 1 m/s and the response spectra for damping of 5% of critical have been computed for these scaled motions. The motions are scaled to a common base in order to evaluate the shape of the response spectra. Velocity scaling is preferred (rather than acceleration scaling) because most engineered facilities have fundamental natural periods in the range (i.e. greater than approximately 0.4 s) for which response is governed by peak ground velocity. These spectra are also compared with those of the T and E ensembles and with design spectra in common use.

For purposes of statistical analysis, the spectra for the following sets of Nahanni motions have been analyzed to determine the mean plus one standard deviation (M + SD) response level, assuming a normal distribution:

a) all components (17)
b) all horizontal components (12)
c) all vertical components (5)
d) main event components (8)
e) main event horizontal components (6)

The M + SD response spectrum for each of the above sets is shown on Fig. 1, using the standard tri-partite plot which simultaneously illustrates the displacement, pseudo-velocity (PSV) and pseudo-acceleration (PSA) spectra. Design spectra are commonly specified at this level (Rosenblueth 1980) in order to ensure that there is a relatively small probability that the response will be above the specified design level. For a normally distributed set, the M + SD level corresponds to 84.1% of all responses being below the specified level.

It can be seen that the M + SD spectra for all five sets are practically indistinguishable for $T > 0.2$ s. Moreover, even in the range $T <= 0.2$s, there is no distinction between the spectral shapes of the horizontal and vertical components. The spectral ordinates for sets d) and e) (i.e. the main event motions) are somewhat below the other sets when the periods are very low. This is to be expected, since these motions have considerably lower A/V (ratio of peak acceleration to peak velocity) values than the remaining motions, which would reduce the high frequency (low period) response amplification (for velocity scaling). The spectral characteristics of the horizontal main event components (set e) are essentially the same as the full "main event" set. In general, the response is velocity amplified with a constant amplification factor (AF) of approximately 2 for all periods arising in normal structures (i.e. $0.1\text{ s} < T < 4\text{ s}$).

Fig. 1 also includes the design spectrum specified in the commentary of NBCC 1985. This spectrum is an adaptation of the 5% damped spectrum specified in NBCC 1980 (Associate Committee on the National Building Code 1980), which is based on that proposed by Newmark, Blume and Kapur (1973). This design spectrum, also normalized to a peak velocity of 1 m/s, has a velocity amplification factor of 2. This AF envelopes that of the Nahanni sets.

However, in the NBCC 1985 design spectrum, the transition to acceleration amplification occurs at $T = \sim 0.4$ s. Below that period, the PSV falls off rapidly, corresponding to a PSA of 3 g. In this region, the design spectrum is based on a ground acceleration of 1 g (i.e. an A/V ratio of 1) with an acceleration AF of 3. However, the equivalent PSA of the Nahanni spectra is approximately 15 g. This is due to the high A/V ratios of the Nahanni spectra, which push down the transition period to approximately 0.07 s. If one assumes an acceleration AF of 3, this would be equivalent to a ground acceleration of 5 g, or an A/V ratio of 5. It should be noted, as indicated in Table 1, that the average A/V ratio of the Nahanni motions is 4.5.

The response spectra for the "T" and "E" motion ensembles, also normalized to a peak velocity of 1 m/s, were computed and analyzed statistically. The M + SD levels are compared with the Nahanni M + SD and the NBCC 1985 spectra in Fig. 2. This figure shows that the M + SD spectrum for the T motions is enveloped by the NBCC 1985 spectrum, with the exception of a few regions in the medium to high period range. The Nahanni and T motion ordinates differ significantly for $T < 0.4$ s, for the same reasons discussed previously in the comparison of the Nahanni and the NBCC 1985 spectra.

The M + SD spectrum for the E motions demonstrates that motions recorded in the epicentral region have higher ordinates in the low period range than is the case for the T ensemble. As can be seen from this figure, the design spectrum recommended in NBCC 1985 would not be appropriate for designing structures for epicentral excitations. Comparing the M + SD level spectra for the E and Nahanni ensembles indicates that the Nahanni spectrum is quite similar to the E spectrum for $T > 0.1$ s. However, for $T < 0.1$ s, the Nahanni spectrum is much larger than the E spectrum, especially in the very low period region.

Concerning the Nahanni response spectra, the primary conclusion is that the spectrum is velocity amplified, at a uniform AF of approximately 2, for periods down to at least 0.1 s. The NBCC 1985 spectrum is certainly not applicable to simulate the action of the Nahanni earthquake motions. Low period Nahanni response spectra are approximated by an acceleration AF of 3 applied using an A/V ratio of 5.

## 3 RESPONSE OF BUILDING STRUCTURES

In addition to evaluating the response spectra of the Nahanni motions, it is useful to determine how these excitations affect structural systems in which a number of modes contribute to the response; it is also useful to compare the resulting forces with those prescribed in seismic building codes. Even though structures are expected to respond inelastically during strong shaking, building codes typically specify design forces as a function of elastic response.

The results which are described in this study are obtained by subjecting uniform elastic wall and frame structures (with damping at 5% of critical) to the specific motions described in Table 1. In this context, wall structures are flexural cantilevers and frame structures are shear cantilevers. These two types of structural systems represent the two extremes of all response situations. Five modes are used to determine the dynamic response of these systems. Modal responses are computed by a time-history analysis and are then combined to determine the total response time-history.

The results given in the following section are expressed in terms of seismic response factor (S) spectra and compared with those specified in 1985 edition of the National Building Code of Canada (NBCC 1985) (Associate Committee on the National Building Code 1985). This paper uses a normalized version of the S factor specified in NBCC 1985, as outlined below. The base shear V in NBCC 1985 is specified as follows:

$$V = v\,S\,K\,I\,F\,W \qquad [1]$$

in which
v = zonal velocity ratio
S = seismic response factor
K = structural system coefficient
I = importance factor
F = foundation factor, and
W = dead load.

For convenience, the above equation is modified in this study as follows:

$$V = 0.44\,v\,S^*\,K\,I\,F\,W \qquad [2]$$

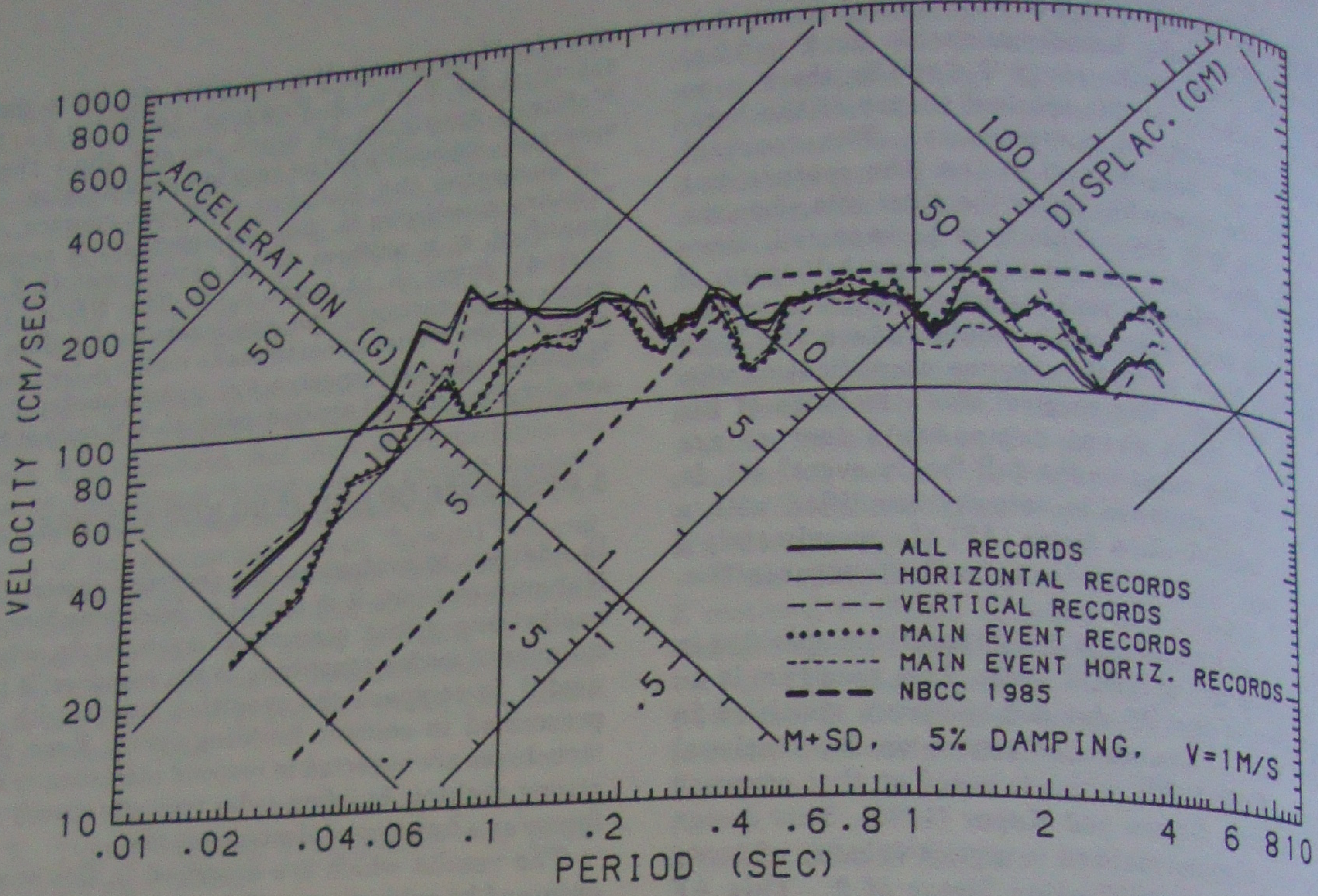

**Fig. 1** Response Spectra for Different Ensembles of Nahanni Motions

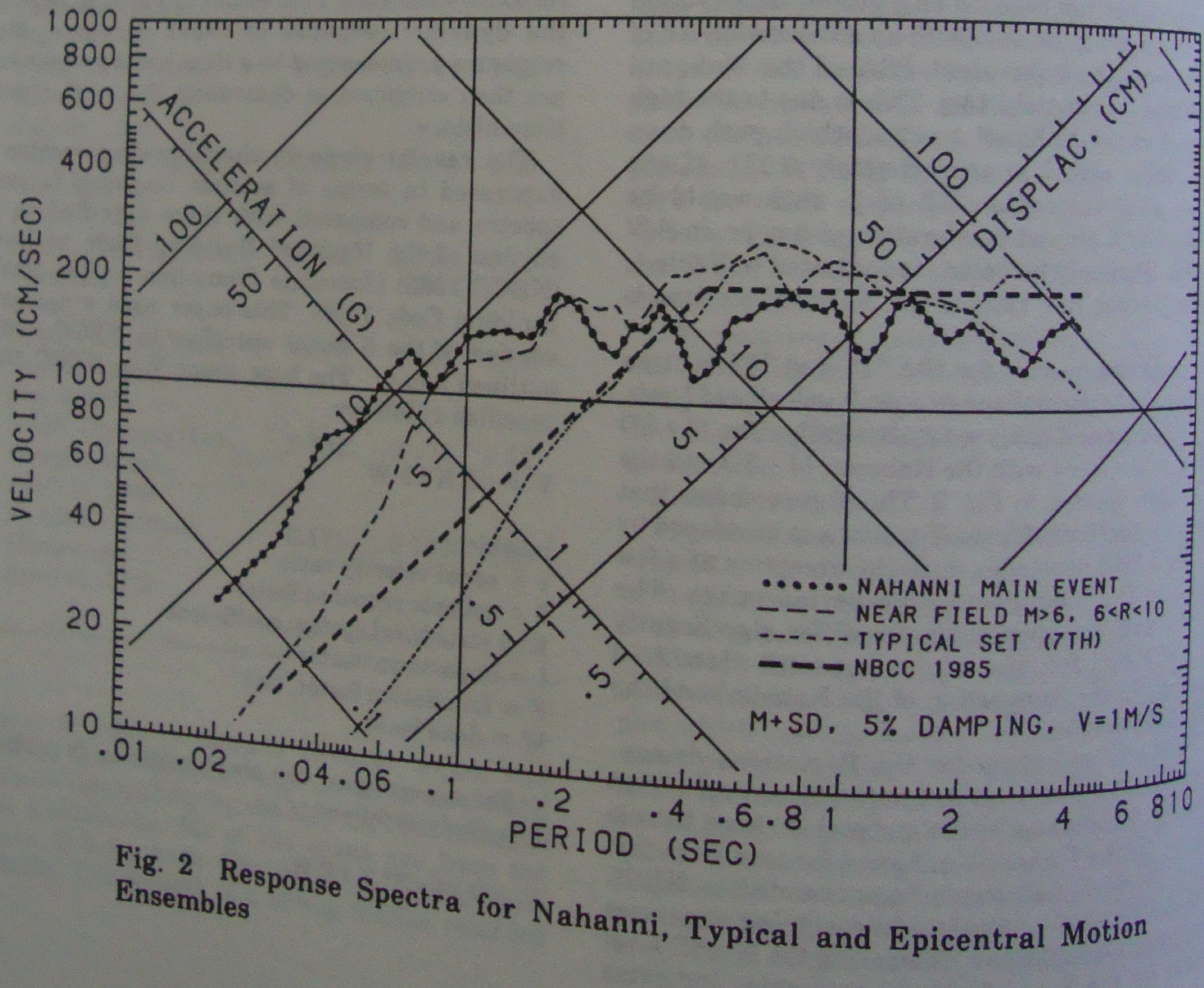

**Fig. 2** Response Spectra for Nahanni, Typical and Epicentral Motion Ensembles

in which the normalized seismic response factor $S^*$ is defined as

$$S^* = S/0.44 \quad [3]$$

The reason for doing so is that $S^*$ has a maximum value of 1.00 for the zonal combination $Z_a = Z_v$. This allows for easier comparisons of $S^*$ (as in NBCC 1985) and SRF (as determined from the dynamic analysis of frame and wall systems). Fig. 3 illustrates the $S^*$ spectra for the three combinations: $Z_a < Z_v$, $Z_a = Z_v$, and $Z_a > Z_v$.

In order to calculate the dynamic SRF, it is first necessary to determine the equivalent elastic base shear condition in the NBCC 1985 base shear formula. From other studies (Rainer 1986), it has been determined that the factored base shear (using a load factor of 1.5 applied as a multiplied to V) should be elastic when the factor K is approximately equal to 5. Using unit values for I and F, which represent the case of structures of normal importance on rock or stiff soil foundations, this results in the elastic base shear $V_e$ as follows:

$$V_e = 3.3\, v\, S^*\, W \quad [4]$$

which can be rewritten in the form

$$S^* = V_e/3.3\, v\, W \quad [5]$$

If the dynamic base shear $V_d$ is substituted into the above, then the dynamically determined seismic response factor can be obtained as follows

$$\mathrm{SRF} = V_d/\, 3.3\, v\, W \quad [6]$$

The SRF is independent of the actual value of the peak ground velocity "v", provided that the dynamic response $V_d$ is computed for the same value of "v" as is used in the denominator of eq. [6].

Rather than studying the SRF spectrum for each of the 17 Nahanni motions, it is useful to evaluate the entire ensemble of SRF spectra on a statistical basis. The SRF spectra were also analyzed for different subsets of motions (i.e. main event, horizontal and vertical motions). The only significant difference was found when considering the subset of main event motions.

Fig. 4 shows the results of such an analysis in terms of M+SD level SRF spectra for frame structures, for several Nahanni ensembles (all motions and main event motions) and for the T and E ensembles described previously. This figure also includes the $S^*$ spectra for the zonal combinations $Z_a = Z_v$ and $Z_a > Z_v$. The SRF for frame structures are larger than those for wall structures in the medium to low period range (i.e. $T < 0.5$ s); consequently all the results presented here are for frame structures. The standard deviation has been computed assuming a normal distribution. As indicated previously, the M+SD response level is typically used to specify the design level for structures of normal importance.

It is helpful to compare the dynamic SRF with the normalized seismic response factor $S^*$ prescribed in NBCC 1985 (see Fig. 3) When the estimated peak ground acceleration "a" (in g) is much larger than the estimated peak ground velocity "v" (in m/s), then $S^*$ is determined for the case $Z_a > Z_v$. As can be seen in Table 1, this is very much the case for all of the Nahanni motions.

It can be seen from Fig. 4 that the NBCC 1985 $S^*$ (for $Z_a > Z_v$) envelopes the Nahanni M+SD SRF for all $T >= 0.25$. Consequently, the seismic response factor in NBCC 1985 provides a conservative estimate of the contributions of the various modes to the overall structural response, for structures with fundamental periods $T >= 0.25$ s. For very low periods, both Nahanni ensembles have M+SD level SRF ordinates which are substantially greater than $S^*$; the ordinates are particularly large when $T < 0.1$ s.

Fig. 4 shows that the SRF spectrum for the main event subset is significantly smaller in the lower period range than the all motions spectrum . The main event motions are stronger and demonstrate a lower acceleration amplification, as was previously discussed with respect to the response spectra. The SRF spectrum for the main event horizontal subset was also computed and was found to be essentially identical to the full main event subset. Subsequent discussion will be based on the full main event subset.

It can be seen the M+SD SRF spectrum for the T motions is well below the M+SD level SRF spectrum of the Nahanni motions. This is entirely due to the much lower A/V ratios of the T set (mean value of 1.02; see Table 2). However, it can also be seen that the T set M+SD SRF spectrum is very nearly enveloped by the corresponding NBCC 1985 $S^*$ spectrum (for $Z_a = Z_v$). This indicates that the NBCC 1985 $S^*$ spectrum is quite satisfactory for typical strong seismic ground motions.

The M+SD level SRF spectrum for the E motions very nearly envelopes that for the Nahanni main event motions for $T > 0.1$ s. For lower periods, the Nahanni SRF spectrum is substantially greater. These observations parallel those for response spectra, as discussed previously.

The characteristics of the SRF spectra, and the response spectra discussed in the previous section, are entirely due to the very high A/V ratios for the Nahanni motions. The A/V ratio ranges from 0.63 to 1.64 (mean of 1.02) for the T motions and from 0.70 to 4.92 (mean of 2.07) for the E motions. However, for the Nahanni motions it ranges from 1.2 to 10.0 (mean of 4.54); the ratio for the main event motions is generally lower, ranging from 1.2 to 5.66 (mean of 3.0). In terms of the Canadian acceleration-related and velocity-related seismic zoning maps, the largest values of A/V are in the neighbourhood of 2. The exceedingly high A/V values of the Nahanni motions do produce very large low-period response factors, which is consistent with the high low-period response spectra (see Fig. 2). Given the anomalous character of the Nahanni motions in this regard, it should be expected that the NBCC 1985 $S^*$ spectrum falls well below the low-period M+SD SRF spectrum.

It is postulated that the high A/V ratios of the Nahanni motions are due primarily to the fact that all

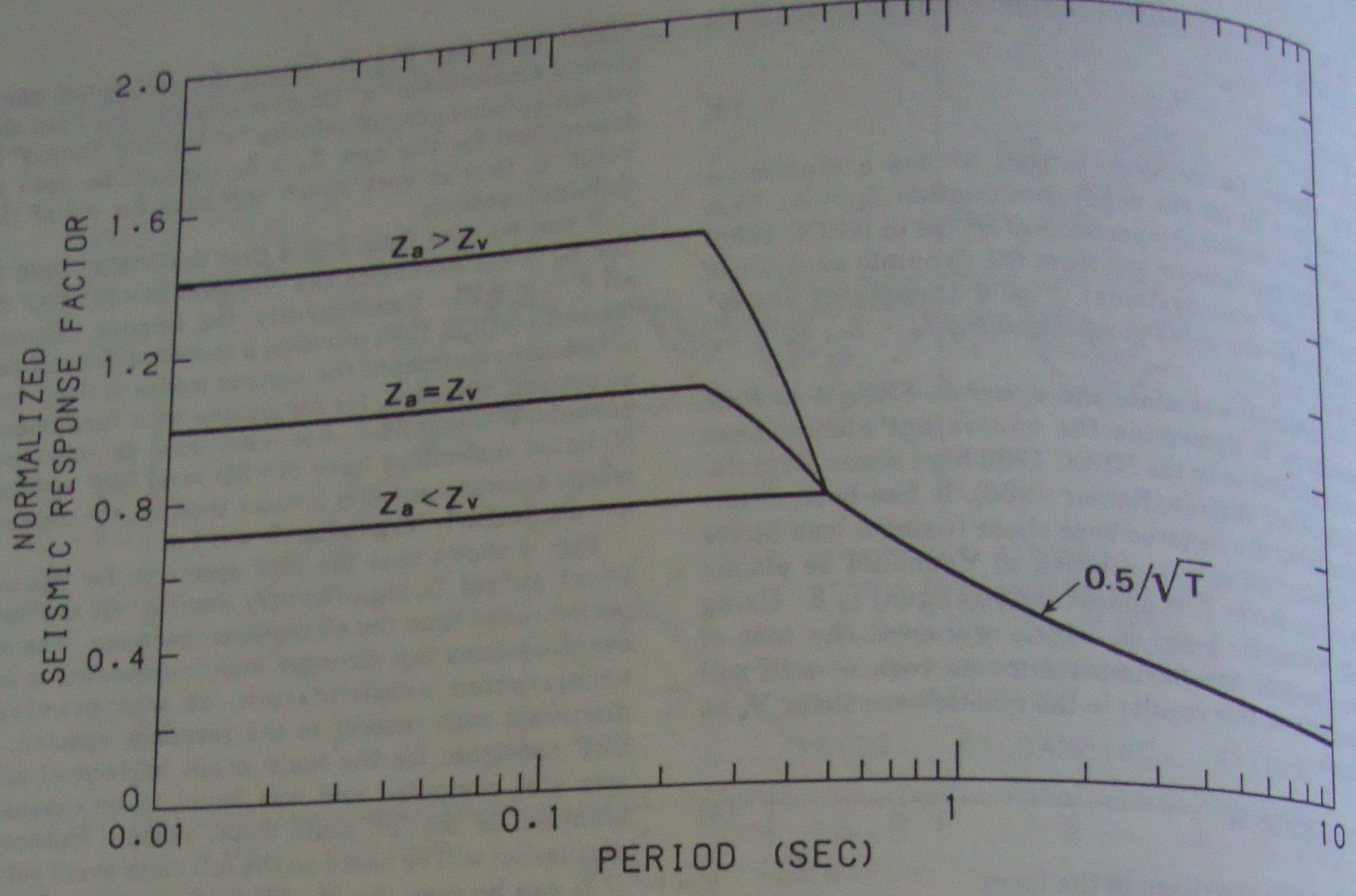

Fig. 3 Normalized Seismic Response Factors Specified in the National Building Code of Canda, 1985

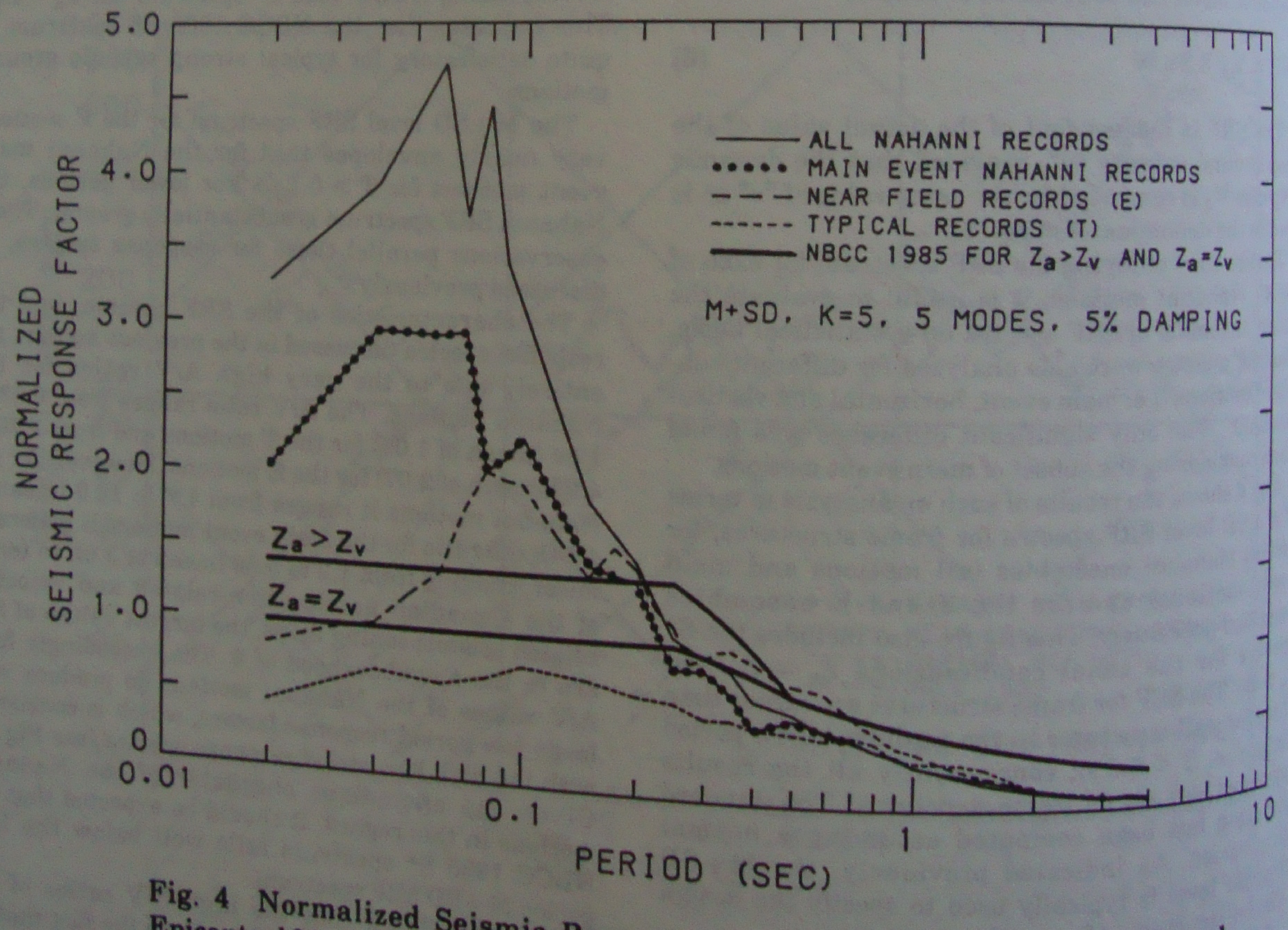

Fig. 4 Normalized Seismic Response Factors for Nahann, Typical and Epicentral Motion Ensembles

of the motions were recorded in the epicentral region. There is a rather homogeneous high-frequency field (Weichert, Wetmiller and Munro, 1986) in that region, which would normally attenuate quite quickly as one moves away from the epicentral area. Consequently, one would expect that seismic ground motions at epicentral distances of 30 km. or more would have lower A/V ratios and significantly reduced low-period SRF ordinates. The two Nahanni motions with the lowest A/V ratios have low-period SRF ordinates which are below 1.0.

On the basis of this investigation, it appears that the peak value of the M+SD level SRF spectra for frame structures are directly related to the average A/V ratio of the particular ensemble of motions for which the response is calculated. In fact, if the maximum value of S* in NBCC 1985 were made equal to the average anticipated A/V ratio, then the S* spectrum would essentially envelope the M+SD level SRF spectrum. It is likely that the seismic response factors in the NBCC 1985 should be revised to recognize that A/V ratios of up to 2 can be expected. The average value of A/V for epicentral motions on rock or firm soil is only slightly larger than 2; consequently the use of A/V = 2 to define the upper plateau in the S* spectrum would allow for "typical" epicentral conditions. The Nahanni motions must be considered somewhat anomalous and it would therefore be premature to recommend that there should be more substantial increases to recognize the higher values associated with the Nahanni motions.

## 4 STRONG MOTION DURATION AND INTENSITY

It is widely recognized that peak ground acceleration, velocity and displacement are often inadequate to fully characterize the structural damage potential of a strong seismic ground motion. First, these parameters do not give any indication of the duration of strong shaking. Second, peak values are not necessarily good indicators of the intensity of ground motion. This section considers strong motion duration and several measures of intensity.

While there are various methods for defining the strong motion duration (e.g. Trifunac and Brady (1975), McCann and Shah (1979) and Vanmarcke and Lai (1980)), a single definition is sufficient for the purpose of comparing the Nahanni and the T motions. McCann and Shah (1979) define the duration of strong motion as the interval of time during which the incoming seismic energy is always increasing. They define the cumulative RMS function of the acceleration as follows

$$\mathrm{CRF}(t) = \left[ \frac{1}{t} \int_0^t a^2(\tau)\, d\tau \right]^{1/2} \qquad [7]$$

Increasing rates of arrival of seismic energy result in a positive slope of CRF and, conversely, CRF has a negative slope when the rate of energy arrival is decreasing. CRF and its derivative are calculated for the accelerogram and for its time reversed form in order to obtain the beginning and the end of the strong motion interval; the duration is the length of that interval.

In terms of measures of intensity, the RMS acceleration Arms is a useful measure which was also defined by McCann and Shah (1979) and is related to their definition of strong motion duration $T_d$. Over the duration of strong motion, the RMS acceleration is given by

$$\mathrm{Arms} = \left[ \frac{1}{T_d} \int_{T_b}^{T_e} a^2(t)\, dt \right]^{1/2} \qquad [8]$$

in which $T_b$ and $T_e$ are the times at the beginning and end of the strong motion duration, respectively, and $T_d = T_e - T_b$. It is obvious that Arms represents the square root of the average rate of energy arrival over the duration of strong motion. As such, it is a much better measure of the strength of the motion than the value of a single maximum acceleration peak.

The so-called Arias Intensity was proposed by Arias (1970)

$$I_0 = \frac{\pi}{2g} \int_0^{t_0} a^2(t)\, dt \qquad [9]$$

The above equation is obtained by considering the dissipated energy per unit mass for a population of single degree of freedom systems having frequencies uniformly distributed over the interval $(0, +\infty)$.

The Spectrum Intensity (SI) was introduced by Housner (1975), who defined it to be the area under the pseudo-velocity spectrum for a damping of 20% of critical, between the periods 0.1 and 2.5 sec., i.e.

$$\mathrm{SI} = \int_{0.1}^{2.5} S_V(T)\, dT \qquad [10]$$

Table 3 presents the summary of strong motion durations and the other intensity measures for both the Nahanni and T sets of motions. Consider first the strong motion durations. This table shows that the Nahanni durations are on the whole somewhat shorter than those of typical strong ground motions. However, the durations of the main event motions are nearer the mean of the T motion durations.

Concerning the various intensity measures, consider first the parameter Arms. This is a measure of the acceleration levels associated with the duration of strong shaking. The largest Nahanni motions have Arms levels which are larger than levels associated with any of the T motions. This is to be expected, considering the very high levels of peak acceleration associated with the Nahanni main event site 1 motions. The other Nahanni motions yield levels which are within the T ensemble range.

The Arias Intensity (AI) values for the Nahanni main event motions are all within the range of the AI values for the T motions. The AI values for the other

Nahanni motions are all below the lowest AI value of the T ensemble.

Table 3. Summary of strong motion duration and intensity measures.

| Record Set | Dur* [s] | Intensity Measures Arms [cm/s2] | Arias [cm/s] | IS.I. [cm] |
|---|---|---|---|---|
| NAHANNI ENSEMBLE | | | | |
| All Records: | | | | |
| Maximum | 7.88 | 398.0 | 462.5 | 89.0 |
| Mean | 2.13 | 123.2 | 98.8 | 24.7 |
| Minimum | 0.24 | 22.6 | 1.9 | 1.3 |
| Main Event: | | | | |
| Maximum | 7.88 | 398.0 | 462.5 | 89.0 |
| Mean | 3.46 | 191.5 | 204.3 | 47.6 |
| Minimum | 0.77 | 42.6 | 28.5 | 6.4 |
| TYPICAL ENSEMBLE | | | | |
| Maximum | 16.20 | 267.7 | 842.3 | 230.1 |
| Mean | 7.69 | 115.1 | 207.0 | 87.4 |
| Minimum | 2.00 | 18.4 | 10.2 | 15.7 |

*Duration defined by McCann and Shah (1979)

Concerning the Spectrum Intensity (SI), only the strongest of the Nahanni main event motions yield SI levels which are within the range associated with the T ensemble. The largest Nahanni motions yield levels which are similar to the mean value of the T results.

In summary, the duration and intensity measure evaluations indicate that the records associated with the main event have properties similar to those of typical strong ground motions. However, with the exception of the Arms values for the site 1 motions, the Nahanni motions are not as intense in their effects as the most severe of the T motions (i.e. San Fernando, Feb. 9, 1971, Pacoima Dam). Nevertheless, the three main event site 1 motions are among the most severe ever recorded and the remaining main event motions can be considered to be very strong.

## 5 SUMMARY AND CONCLUSIONS

The summary of this analysis of the engineering implications of the Nahanni motions is as follows:

1. Only the main event Nahanni motions can be considered to be strong seismic ground motions; the "strength" of these motions is certainly comparable with those of "typical" strong seismic ground motions.

2. The spectral shape of the Nahanni motions is very considerably different from that normally used in seismic design; the transition period between acceleration and velocity amplification is below 0.1 s rather than in the neighbourhood of 0.4 s.

3. The spectral shape of the Nahanni motions is somewhat similar to that obtained from other epicentral motions; however the Nahanni motions have somewhat higher ordinates when periods are below 0.1 s.

4. The velocity amplification factor (2 for damping of 5% of critical) in the Nahanni spectra is similar to that used in seismic design; the acceleration amplification factor is also similar (AF = 3) provided that a ground motion A/V of approximately 5 is used to determine ground acceleration.

5. The low period (T < 0.2 s) building response to the Nahanni motions, as reflected in the comparison with the normalized NBCC 1985 seismic response factors, is substantially higher than would be expected during typical strong seismic ground motions. This is due primarily to the high A/V ratio of the Nahanni motions.

6. The low period (T < 0.2 s) building response to the Nahanni motions is also somewhat higher than would be expected from other epicentral motions, particularly for periods less than 0.1 s.

7. The strong motion durations of the strongest of the Nahanni motions (i.e. the main event motions) are comparable to those of typical strong seismic ground motions, but are lower than those of most of the typical motions examined in this investigation.

8. The intensity measures (RMS acceleration, Arias Intensity and Spectrum Intensity) of the main event Nahanni motions are comparable to the strongest of the typical motions.

It is concluded that the Nahanni records are very strong seismic ground motion records with relatively unusual spectral characteristics, even when compared with the spectra of other motions obtained within the epicentral region. The impact of these characteristics on engineering design is most significant for low period structures. Further seismological investigations are needed to determine the extent to which these unusual spectral characteristics would be expected to exist at distances well away from the epicentre of Nahanni-type earthquakes.

## ACKNOWLEDGEMENTS

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