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RESPONSE CHARACTERISTICS OF THE 1985 CANADIAN EARTHQUAKES AT NAHANNI RIVER

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SUMMARY

A series of strong ground motions were recorded near the epicentre of a magnitude 6.9 event which occurred in the Nahanni River area of northern Canada in late 1985; peak accelerations were above 1g and peak velocities exceeded 0.4 m/s. This paper presents response spectra and elastic base shear coefficients for multi degree of freedom frame structures, results are compared with those for ensembles of typical strong motion and nearfield records. Strong motion duration and intensity measures are also evaluated. Results indicate that the Nahanni River records are very strong ground motions with characteristics which are considerably different than typical strong motion records

INTRODUCTION

Strong motion instruments installed after an earlier event in the North Nahanni River region of the Canadian Northwest Territories were triggered by a large number of aftershocks, including a second large earthquake [M_s = 6.9] on December 23, 1985. This paper is concerned with the response characteristics of the 6 horizontal components recorded during this latter "main event" (ME).

The site locations and peak ground motion parameters of these 6 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. (Ref. 1) and by Weichert, Wetmiller and Munro (Ref. 2). An examination of the peak ground motion parameters in Table 1 indicates that the components recorded at site S1 have peak ground accelerations exceeding 1 g and peak ground velocities exceeding 0.4 m/s. It is clear that these are not only the strongest records ever obtained in Canada but among the strongest ever recorded during an earthquake. It is therefore important that the implications of these records, e.g. for seismic code provisions and on the design requirements for critical structures, be evaluated.

Table 1 also includes the description of two other ensembles of recorded strong ground motions which are being used for comparison with the Nahanni (N) records. Ensemble T comprises 7 "typical" records, including several which are considered to be "classics". Ensemble NE are a set of 10 "typical nearfield" records (i.e. epicentral distance less than 20 km.) obtained from events with magnitude 5.8 or larger.

RESPONSE SPECTRA

For the purpose of this study, all the time histories (TH) have been scaled to a peak velocity (V) of 1 m/s and the response spectra for damping of 5% of critical have been computed for these scaled THs. The TH 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

Table 1 Description of Records and Peak Ground Motions

Event	Site	Component	Peak Ground Motions A(g)	V(m/s)	D(cm)	A/V
Nahanni Main Event						
Horizontal Ensemble (N):	S1	Long.,N10E	1.101	.462	10.41	2.38
Dec. 23, 1985, 05:16		Trans.,N80W	1.345	.45	15.25	2.98
	S2	Long.,N30W	.390	.326	5.02	1.20
		Trans.,S60W	.545	.303	6.60	1.80
	S3	Long.,N	.194	.034	.80	5.66
		Trans.,W	.186	.063	2.38	2.96
					MEAN	2.83
Typical Ensemble (T):						
Imperial Valley, May 18, 1940	El Centro	S00E	.048	.335	10.9	1.04
Kern County, July 21, 1952	Taft L.S. Tunnel	S69E	.179	.177	9.2	1.01
	Hollywood Storage	S00W	.059	.066	4.5	.90
Parkfield, June 27, 1966	Cholame Shand. #2	N65E	.489	.781	26.5	.63
San Fernando, Feb. 9, 1971	Pacoima Dam	S16E	1.170	1.132	37.7	1.03
Western Wash., Apr. 13, 1949	Olympia Lab.	N86E	.280	.171	10.4	1.64
Montenegro, Apr. 15, 1979	Albatros H., Ulcinj	N00E	171	.194	6.5	.88
					MEAN	1.02
Nearfield Ensemble (NE):						
Helena, Oct. 31, 1935	Mont. Carroll Colg.	S00W	0.146	0.072	0.94	2.03
		S90W	0.145	0.133	3.70	1.02
Eureka, Dec. 21, 1954	Eureka Fed. Bldg.	N11W	0.168	0.316	12.5	0.53
		N79E	0.258	0.294	14.0	0.88
Banja Luka, Aug. 13, 1981	B.L. Seism. Stn.	N00W	0.066	0.044	0.8	1.50
		N90W	0.074	0.032	0.4	2.31
Friuli, Sept. 15, 1976	S. Rocco	N00E	0.136	0.101	1.9	1.35
		N90E	0.236	0.165	2.2	1.43
Tangshan, Aug. 31, 1976	Hebei	N00E	0.135	0.031	0.2	4.26
		N90E	0.099	0.030	0.5	3.30
					MEAN	1.86

periods in the range (i.e. greater than approximately 0.4 s) for which response is governed by peak ground velocity.

For purposes of statistical analysis, the spectra for the three ensembles (N, T and NE) have been analyzed to determine the mean plus one standard deviation (M+SD) response level, assuming a normal distribution. The M+SD response spectra are shown in Fig. 1, which also includes the design spectrum specified in NBCC 1985 (Ref. 3). Design spectra are commonly specified at this level (Ref. 4) in order to ensure that there is a relatively small probability that the response will be above the specified design level.

The major differences between the N, T and NE spectra occurs in the low period region, i.e. $T < 0.4$ s; the three spectra have similar ordinates for periods higher than 0.4 s. It is clear that both the N and NE spectra have significantly higher ordinates than the T spectrum in the low period region; this is essentially due to the nearfield character of both the N and NE spectra. However, the N ordinates are somewhat higher than those of the NE spectrum.

The primary reason for these differences is the A/V ratio of each ensemble, which is included in Table 1. Since the spectra in Figure 1 are scaled to peak velocity, the application of the mean A/V ratio

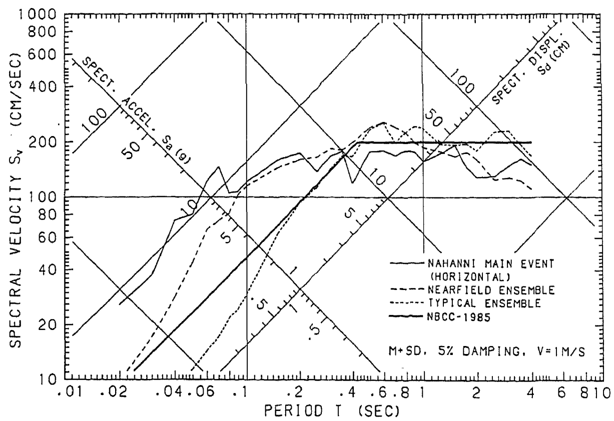

Fig. 1 Response Spectra

for each ensemble provides an estimate of the corresponding peak acceleration. The A/V ratio of the T spectrum is approximately 1; this spectrum agrees fairly closely with the NBCC 1985 spectrum which assumes an A/V ratio of 1. However, the A/V ratios for the NE and N spectra are approximately 2 and 3 respectively, which explains why the low period spectral ordinates differ so much. In both those cases, the low period response spectra are approximated by an acceleration amplification factor of 3 applied to the ground acceleration determined from the mean A/V for the ensemble.

The primary distinction of the Nahanni records is the very high A/V ratio, even when compared with other nearfield records at similar magnitudes and epicentral distances. It is clear that both A and V (or alternatively A/V and V) need to be known in order to generate an appropriate response spectrum.

BASE SHEAR COEFFICIENTS

When the earthquake time-history is scaled using velocity, the maximum elastic base shear can be expressed in the form:

$$V_e = C_v \, v \, W \tag{1}$$

in which

C_v = unit velocity base shear coefficient

v = peak ground velocity, m/s, and

W = total weight of the structure (i.e. dead load).

The unit velocity base shear coefficient, C_v, is a useful parameter by which to measure the manner in which a particular earthquake affects a multi-degree of freedom system. The results presented here are obtained by subjecting uniform elastic frame structures (with damping at 5% of critical) to the specific time-histories of the records described in Table 1. The statistical variation of C_v at each period has been evaluated for each ensemble; Fig. 2 illustrates the C_v spectra at the M + SD level of response.

It is also useful to be able to compare the C_v spectra with the equivalent coefficients used in the 1985 edition of the National Building Code of Canada (NBCC 1985). After some manipulation of coefficients (Ref. 5), the NBCC 1985 unit velocity base shear coefficient C_v^* is as follows

$$C_v^* = 6.75 \, S \tag{2}$$

in which S is the period-dependent seismic response factor specified in NBCC 1985. Fig. 2 includes the C_v^* spectrum equivalent to A/V > 1 (Ref. 3), which would be applicable for the Nahanni situation.

It can be seen from Fig. 2 that the NBCC 1985 C_v* essentially envelopes the C_v for all $T \geq 0.25$ (for all three ensembles); this indicates that NBCC 1985 adequately simulates elastic design forces for that period range. However, the C_v for the N and NE spectra in the low period region are much higher than would be calculated using NBCC 1985. Again, the N ensemble provides much higher values than the NE ensemble. These characteristics are also due to the very high values of the A/V ratios, as discussed in the section on response spectra. The NBCC 1985 coefficient shown in Fig. 2 corresponds approximately to an A/V ratio of 1.5; if this were doubled, it would be equivalent to A/V of 3 and would also very nearly envelope the Nahanni C_v curve.

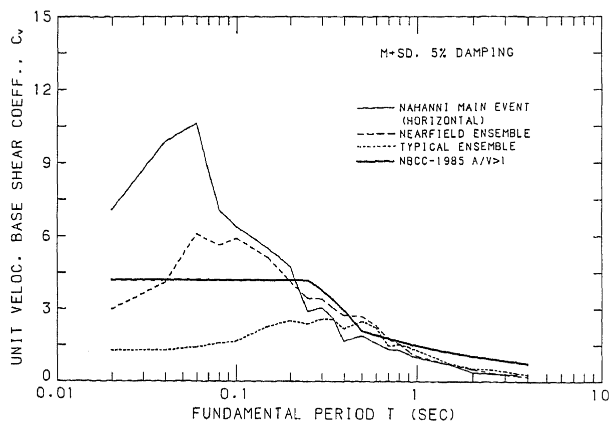

Fig. 2 Elastic Base Shear Coefficients

In the low period region, the peak value of C_v is approximately equal to 3 times the mean A/V for the ensemble; the value 3 is equivalent to the acceleration amplification factor of 3 in the response spectrum. If the low period plateau in the NBCC 1985 coefficient were set at this level, it would be appropriate for any of the three ensembles. However, it is necessary that the A/V ratio be estimated in advance.

STRONG MOTION DURATION AND INTENSITY MEASURES

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.

Three different methods for defining the strong motion duration are used in this study, as given by Trifunac and Brady (Ref. 6), McCann and Shah (Ref. 7) and Vanmarcke and Lai (Ref. 8). In terms of measures of intensity, the following three definitions are used:

a) the RMS acceleration, A_{RMS} (Ref. 7),
b) the Arias Intensity, AI (Ref. 9), and
c) the Spectrum Intensity, SI (Ref. 10).

Table 2 summarizes the strong motion durations and the intensity measures for the N, NE and T sets of records. Consider first the strong motion durations. This table shows that the Nahanni records have somewhat shorter strong motion durations than those of typical records. The largest durations of the Nahanni records are nearer the mean of the T motion durations. In terms of comparing the Nahanni and NE records, the Trifunac and Brady definition gives similar durations for both ensembles. The other two definitions give durations for the Nahanni records about two times longer than those of the NE records.

Table 2 Strong Motion Durations and Intensity Measures

Ensemble	Strong Motion Duration [s]			Intensity Measures		
	McCann & Shah	Trifunac & Brady	Vanmarcke & Lai	Arms [cm/s^2]	Arias I [cm/s]	S.I. [cm]
Nahanni Main Event Horizontal						
MAX:	7.88	11.29	8.64	359.9	462.5	81.4
MEAN:	3.27	9.83	4.22	181.8	191.5	46.8
MIN:	.77	7.92	.63	49.1	36.8	6.4
Typical						
MAX:	16.20	30.70	12.88	267.7	842.3	230.1
MEAN:	7.69	18.33	6.63	115.1	207.0	87.4
MIN:	2.00	6.98	1.78	18.4	10.2	15.7
Nearfield						
MAX:	4.00	14.18	4.89	79.3	71.0	54.0
MEAN:	2.69	7.17	2.72	43.6	17.9	22.9
MIN:	1.79	2.02	0.85	25.4	2.9	4.8

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 aceleration associated with the Nahanni main event site 1 motions. The other Nahanni main event motions yield levels which are within the T ensemble range.

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

In terms of comparing the Nahanni main event and the nearfield motions, all three definitions for the intensity measures show that the Nahanni motions are much more intense than the NE motions. Even though the Nahanni records are in nature nearfield records, they have high frequency content and peak acceleration levels significantly higher than the typical nearfield motions, which produce larger intensities.

In summary, the duration and intensity measure evaluations indicate that the Nahanni main event records are much stronger than the NE motions, and they 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 main event site 1 motions are among the most severe ever recorded.

SUMMARY AND CONCLUSIONS

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

1. The spectral shape of the Nahanni records 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. An acceleration amplification of 3 (for 5% damping) is appropriate provided that the mean A/V ratio of approximately 3 is used to determine the equivalent peak ground acceleration.

2. The low period ($T < 0.2s$) building response to the Nahanni records, as reflected in the comparison of the unit velocity base shear coefficient with the equivalent NBCC 1985 coefficient, 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 records.

3. The strong motion durations of the strongest of the Nahanni main event records are comparable to those of typical strong seismic ground motions.

4. The intensity measures (RMS acceleration, Arias Intensity and Spectrum Intensity) of the main event Nahanni records are comparable to the strongest of the typical records, and they are significantly larger than those of typical nearfield records.

It is concluded that the Nahanni records are very strong seismic ground motion records with relatively unusual response characteristics, even when compared with those of other records 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 response characteristics would be expected to exist at distances well away from the epicentre of Nahanni-type earthquakes.

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