ANALYSIS OF STRONG-MOTION DATA FROM THE NEW HAMPSHIRE EARTHQUAKE OF 18 JANUARY 1982*

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SUMMARY

This paper presents an analysis of the strong-motion data from the New Hampshire earthquake of 18 January 1982 which occurred at latitude 43.5°N, longitude 71.6°W. Thirty-six accelerograms, mainly on Corps dams, were recorded, digitized, corrected, and processed. The earthquake records were obtained by the U. S. Army Corps of Engineers (CE) Strong-Motion Instrumentation Program (SMIP).

INTRODUCTION

An earthquake (epicenter, 42.5°N and 71.6°W) occurred at 19:14:42 EST, 18 January 1982 (UT 00:14:42) north of Tilton, New Hampshire. Slight damage was observed at Bristol, Canaan, and Danbury, New Hampshire, and North Hartland and White River Junction, Vermont. The shock (MM Intensity VI) was felt throughout most of New England, northern New York, and as far away as southern Quebec and northeastern Ontario. The earthquake had a Richter magnitude of 4.7 ($m_b = 4.4$, $m_{bLg} = 4.5$, Ref. 1) and a focal depth between 4.5 and 8.0 km.

For the first time in the eastern United States, 36 accelerograms were recorded for a single earthquake. The accelerograms were recorded by accelerographs at five dams monitored by the U. S. Army Corps of Engineers Division, New England (NED) and by one instrument at a Veterans Administration (VA) Hospital (Figure 1). These instruments are maintained by the U. S. Army Engineer Waterways Experiment Station (WES) under the U. S. Army Corps of Engineers (CE) Strong-Motion Instrumentation Program (SMIP).

Franklin Falls Dam (FFD) is an earth dam located about 8 km from the epicenter. At this location nine channels of acceleration data were recorded. The maximum acceleration recorded was 0.55 g's (Figure 2). The predominant frequency recorded at FFD (11 to 21 Hz) is higher than those typical of the West Coast (4 to 6 Hz).

DATA DIGITIZATION AND PROCESSING

The 36 accelerograms were digitized with a laser line digitizing machine by IOM-Towill of Santa Clara, California. The 3 accelerograms recorded at the right abutment of FFD were digitized at 600 points per second, the remainder at 200 points per second.

The 36 corrected accelerograms, velocities, displacements, and their response spectra were processed by the Seismic Engineering Branch, U. S. Geological Survey (USGS), using their standard computer program AGRAM.

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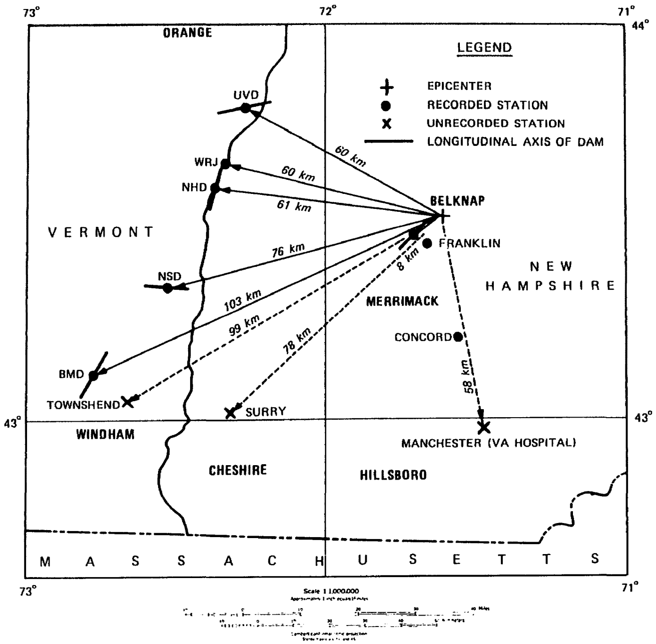

Figure 1. Location of epicenter and recording station.

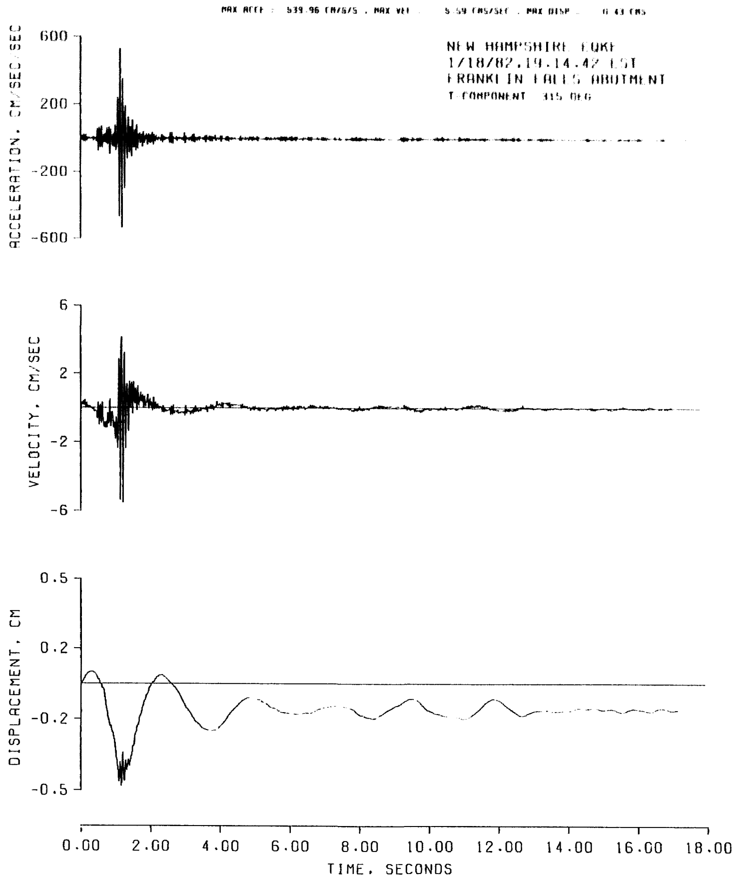

Figure 2. Acceleration, velocity, and displacement plots.

DATA PRESENTATION

Station, site location, coordinates, epicentral distances, azimuth from source to accelerograph site, instrument component, uncorrected maximum acceleration, corrected maximum acceleration, maximum particle velocity, maximum displacement, velocity spectrum intensity, and ratio of $a \cdot d/v^2$, v/a, and a_v/a_h are listed in Table 1. By definition, the spectrum intensity is the area under the velocity spectrum curve, for 5 percent critical damping, between the 0- and 4.0-sec periods:

$$SI_\zeta = \int_0^{4.0} S_v(\zeta, T)\,dT$$

where ζ is taken as 5 percent of critical.

DATA ANALYSIS

The 27 records from the Union Village Dam (UVD), North Hartland Dam (NHD), White River Junction (WRJ), VA Hospital, North Springfield Dam (NSD), and Ball Mountain Dam (BMD) were all obtained at sites located in Vermont, to the west of the epicenter, at distances between 60 and 103 km as shown in Figure 1. The VA Hospital accelerograph at Manchester, New Hampshire, about 57.5 km south of the epicenter, was not triggered by the earthquake, nor were strong-motion stations at CE dams located near Townsend, Vermont and Surry, New Hampshire about 99 km and 78 km, respectively, from the epicenter. No strong-motion instruments in Massachusetts were triggered by the earthquake. The ground motion was evidently strongest westward from the source. The directions of the horizontal resultant peak ground acceleration at the downstream, crest, and abutment sites at FFD were in the range between N64°W to N74°W as shown in Figure 3. The resultant was approximated as

$$(a_L)\ \max \rightarrow (a_T)\ \max$$

where

$\rightarrow$ = addition of two vectors L and T

(a_L) max = maximum acceleration of longitudinal component

(a_T) max = maximum acceleration of transverse component

The corrected maximum acceleration of 0.55 g's recorded on the transverse component of the accelerograph at the right abutment (rock) of FFD is the highest acceleration ever recorded in the eastern United States. However, the corresponding integrated maximum velocity is 5.59 cm/sec. In comparing this value with the Melendy Ranch records of the 4 September 1972 Stone Canyon earthquake (M = 4.7) with maximum acceleration of 506.12 cm/sec^2 and a velocity of 13.72 cm/sec on the N29°W component, the particle velocity for FFD is much less than the Melendy Ranch record. This difference is probably caused by the predominant frequency content, 11 Hz for FFD and 5 Hz for the Melendy Ranch.

Table 1 indicates that the maximum acceleration recorded on the crest of the FFD did not amplify due to the height of the 45-m earth dam. Actually, the peak ground acceleration recorded at the downstream site was somewhat higher than that on the crest.

Table 1

Results of CE Accelerograph Records Obtained from New Hampshire Earthquake of 18 January 1982

Station	Site Location	Azimuth of Component	Azimuth* deg	Uncorrected Accelerations cm/sec²	Corrected: Maximum Acceleration (a), cm/sec²	Corrected: Maximum Velocity (v) cm/sec	Corrected: Maximum Displacement (d) cm	Velocity Spectrum Intensity 5%, ζ	$\frac{a \cdot d}{v^2}$ Hori.	$\frac{a \cdot d}{v^2}$ Vert.	$\frac{v}{a}$ Hori.	$\frac{v}{a}$ Vert.	$\frac{(v/a)\ vert.}{(v/a)\ hori.}$	$\frac{a_{vert}}{a_{hori}}$
Franklin Falls Dam	Downstream	L-225°	234.5	111.68 (21 Hz)	140.70 (0.143 g)	2.03	0.16	9.53	5.464		0.0144		0.443	1.926
Epicenter Distance =		Up		208.34 (21 Hz)	271.00 (0.276 g)	1.73	0.08	7.29		7.251		0.0064		
8 km		T-135°		267.94 (16 Hz)	377.86 (0.385 g)	2.87	0.17	13.23	7.798		0.0076		0.842	0.717
	Right Abutment	L-45°		282.52 (14 Hz)	287.70 (0.293 g)	2.68	0.25	13.08	10.017		0.0093		1.150	0.601
		Up		171.89 (20 Hz)	172.89 (0.176 g)	1.86	0.41	11.61		20.487		0.0107		
		T-315°		565.05 (14 Hz)	539.96 (0.550 g)	5.59	0.43	22.39	7.432		0.0103		1.039	0.320
	Crest	L-45°		102.79 (11.4 Hz)	123.96 (0.126 g)	2.67	0.36	12.09	6.259		0.0215		1.176	0.922
		Up		111.38 (11.4 Hz)	114.31 (0.116 g)	2.89	0.47	13.15		6.432		0.0253		
		T-315°		243.46 (14 Hz)	306.83 (0.312 g)	4.06	0.33	17.12	6.143		0.0132		1.916	0.372
Union Village Dam	Crest	L-245°	300.0	24.08	22.46	0.46	0.04	2.32	4.246		0.0205		0.883	1.031
Epicenter Distance =		Up		23.31	23.17	0.42	0.04	2.19		5.254		0.0181		
60 km		T-155°		25.73	25.07	0.50	0.005	2.67	0.501		0.0199		0.909	0.924
	Left Abutment	L-245°		9.05	9.49	0.15	0.03	0.95	12.653		0.0158		1.727	0.654
		Up		6.00	6.21	0.17	0.05	1.04		10.744		0.0273		
		T-155°		7.17	6.73	0.23	0.06	1.39	7.633		0.0341		0.801	0.922
	Downstream	L-245°		38.15	37.01	0.82	0.08	3.54	4.403		0.0221		0.706	0.781
		Up		27.02	28.90	0.45	0.07	2.37		9.990		0.0156		
		T-155°		22.96	22.58	0.47	0.05	2.45	5.111		0.0208		0.750	1.279
North Hartland Dam	Left Abutment	L-15°	178.5	6.66	11.08	0.20	0.05	1.24	13.850		0.0180		2.072	0.338
Epicenter Distance =		Up		3.56	3.75	0.14	0.04	0.95		7.653		0.0373		
61 km		T-285°		6.35	6.84	0.22	0.06	1.45	8.479		0.0321		1.162	0.548
	Crest	L-15°		33.57	37.34	0.76	0.12	3.74	7.757		0.0203		1.354	0.448
		Up		17.12	16.73	0.46	0.09	2.40		7.116		0.0275		
		T-285°		29.39	38.19	0.86	0.13	3.86	6.712		0.0225		1.222	0.438
.North Springfield	Crest	L-275°	255.5	26.05	24.38	0.56	0.06	2.38	4.664		0.0229		0.659	0.921
Dam, Epicenter		Up		22.61	22.45	0.34	0.06	1.91		11.652		0.0151		
Distance = 76 km		T-185°		21.55	21.54	0.41	0.09	2.59	11.532		0.0190		0.795	1.042
	Downstream	L-275°		24.88	31.08	0.41	0.07	1.74	12.942		0.0132		1.159	0.439
		Up		14.20	13.66	0.21	0.05	1.39		15.487		0.0153		
		T-185°		20.72	22.59	0.29	0.06	1.76	16.116		0.0128		1.195	0.605
Ball Mountain Dam	Crest	L-30°	245.6	8.75	8.80	0.37	0.08	2.15	5.142		0.0420		0.676	1.360
Epicenter Distance =		Up		11.97	11.97	0.34	0.07	1.92		7.248		0.0284		
103 km		T-300°		10.38	10.03	0.37	0.07	2.27	5.128		0.0369		0.769	1.193
White River Junction	Basement	L-270°	285.0	14.80	15.00	0.33	0.06	2.04	8.264		0.0220		0.791	1.454
(VA Hospital)		Up		21.34	21.81	0.38	0.08	2.40		12.083		0.0174		
Epicenter Distance = 60 km		T-180°		29.04	31.00	0.57	0.12	3.23	11.449		0.0184		0.946	0.703
								Data No.:	24	12	24	12	24	24
								Mean:	7.903	10.116	0.0204	0.0203	1.047	0.830
								SD:	3.678	4.387	0.0086	0.0088	0.400	0.403
								Mean & SD:	11.581	14.403	0.0290	0.0291	1.447	1.233

* Azimuth is from epicenter to the recording site. Azimuth is also related to geographical north.

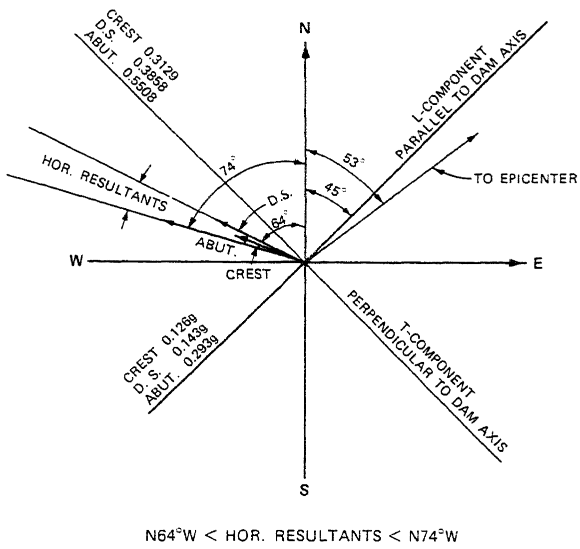

Figure 3. Resultant force direction of horizontal peak ground acceleration of crest, downstream, and abutment at Franklin Falls Dam and the direction from dam to epicenter.

Because of the lack of the strong-motion data in the eastern United States, the rate of attenuation of ground motion has always been uncertain. Even though the data are not sufficient or not evenly distributed with distance and it would be better to make an analysis for the attenuation of ground motion using data for different site conditions, the analysis was performed because this is the first set of data from this region.

All five earth dams were located in different valleys and their geometrical boundaries were critical to the ground motion. Generally, the two horizontal components of an accelerograph on the crest of a dam are oriented parallel to the dam axis (longitudinal component) and perpendicular to the dam axis (transverse component). For the purpose of comparison, the accelerographs located on the abutment and downstream are oriented the same as on the crest. Thus, in terms of site topography, the longitudinal component is approximately the motion perpendicular to the valley axis, and the transverse component the motion parallel to the valley axis. Figure 1 shows the direction of the longitudinal axis of each earth dam and the orientation is also given in Table 1. If desired, the transverse and longitudinal components can be resolved into the radial and tangential components with respect to the ray path from the source.

Figures 4a, b, c, and d show the attenuation curves of the three orthogonal components for peak ground accelerations (PGA), peak ground velocity (PGV), peak ground displacement (PGD), and velocity spectrum intensity (VSI) on the crest, abutment, and downstream sites for the five CE earth dams.

The general attenuation characteristics of the ground motion are shown as follows. The attenuation rate of PGA, PGV, and VSI on the crest are shown as the same as on the downstream sites. Attenuation is naturally faster on the abutment (rock) than on the crest and downstream sites. The energy or amplitude of the transverse components at FFD is higher than the other two components. However, the rate of attenuation for the transverse component is faster

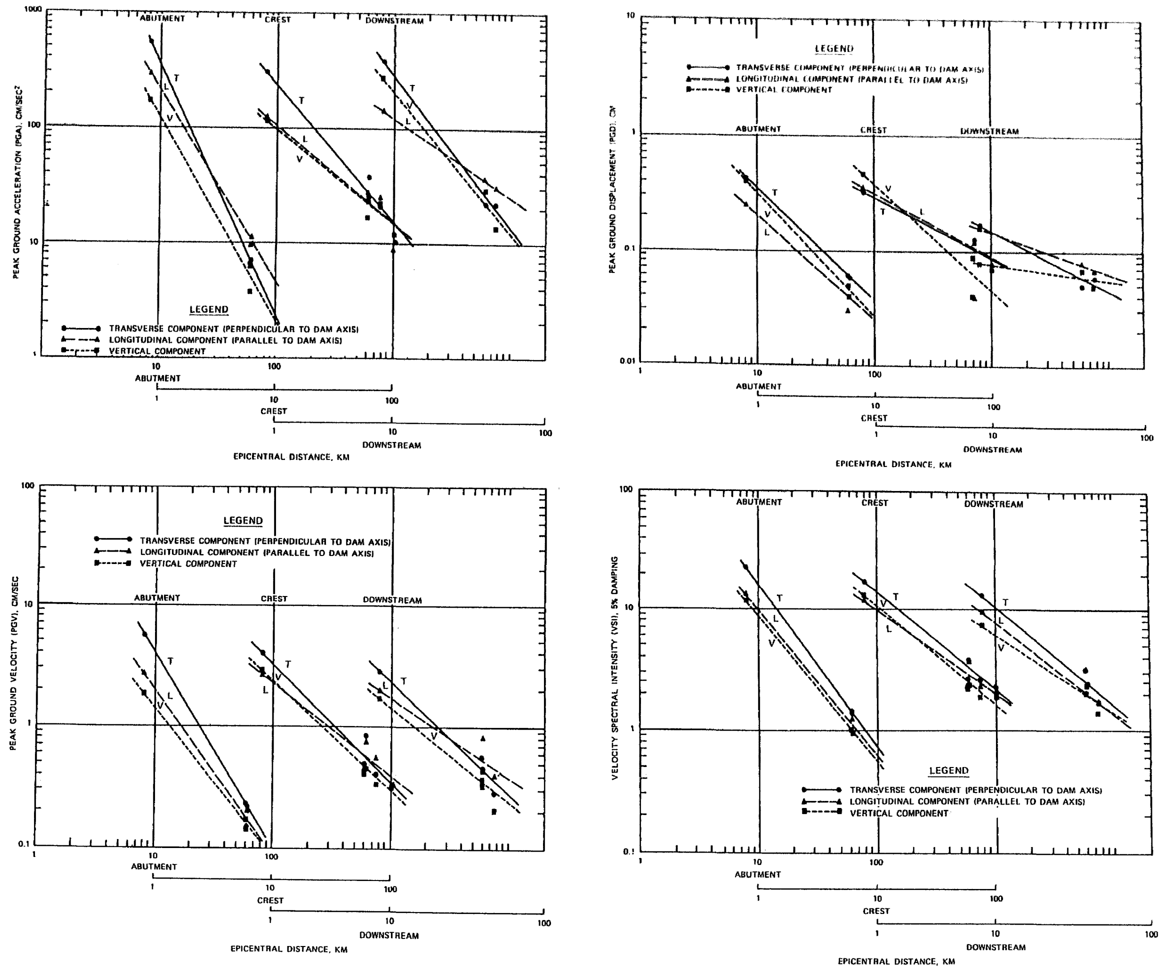

Figure 4. Attenuation of PGA, PGV, and VSI versus distance at abutment, crest, and downstream of the earth dam.

than for the longitudinal and vertical components. The attenuation trend of PGV and VSI is similar, because both are based on the same concept of energy. The PGD's for the downstream sites are somewhat lower than the crest sites and overall the presentation is not as unique as PGA, PGV, and VSI curves due to the double integration of the long-period waves.

Based on the statistical analysis of the peak ground motions, a, v, and d, it has been found that the average ratio of v/a for the 36 components of this earthquake is 0.0204 sec. The average ratio of v/a for the 110 components of the western United States is about 5 times higher than for this New Hampshire earthquake. The average ratio a_v/a_h (vertical maximum acceleration to horizontal maximum acceleration) for this earthquake is 0.83. Uwabe and others (Ref. 2) found the average ratios of a_v/a_h for Japan and the western United States are 0.33 and 0.48, respectively. The cause of this difference needs further investigation.

The average ratio of ad/v^2 for 189 vertical components of the strong-motion earthquake records in the western United States is 6.62 ± 4.30 and for 382 horizontal components is 5.30 ± 3.84. The former is about 25 percent higher than the latter. However, the average ratio of ad/v^2 for the 12 vertical components of this New Hampshire earthquake is 10.116 ± 4.387 and for the 24 horizontal components is 7.903 ± 3.678. The former is about 28 percent higher than the latter. For most earthquakes of practical interest, Newmark and Rosenbluth (Ref. 3) give $ad/v^2 = 5$ to 15. This agrees with the present study.

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