2. STRONG GROUND MOTIONS

2.1 INTRODUCTION

This chapter describes the results of strong motion analysis. Signal to noise ratios, corrected accelerations, velocities and displacements of the intense ground motions recorded in this earthquake are presented. In order to illustrate different characteristics of these records, different spectra such as power spectral densities, response spectra and H/V spectra are also provided and a discussion on each spectrum is presented in a nutshell.

2.2 RECORDED ACCELEROGRAMS

On 22 June 2002, at 7:28:20 local time, a destructive earthquake struck some vast regions in Hamadan, Qazvin and Zanjan provinces in Iran. This earthquake was also felt in Tehran, Kermanshah, Qom, Central, Ardebil and Gilan provinces as well. The magnitude of this earthquake as announced by the Earthquake Information Center of The US Geological Survey, was Mw=6.5 (See **Chapter 1**).

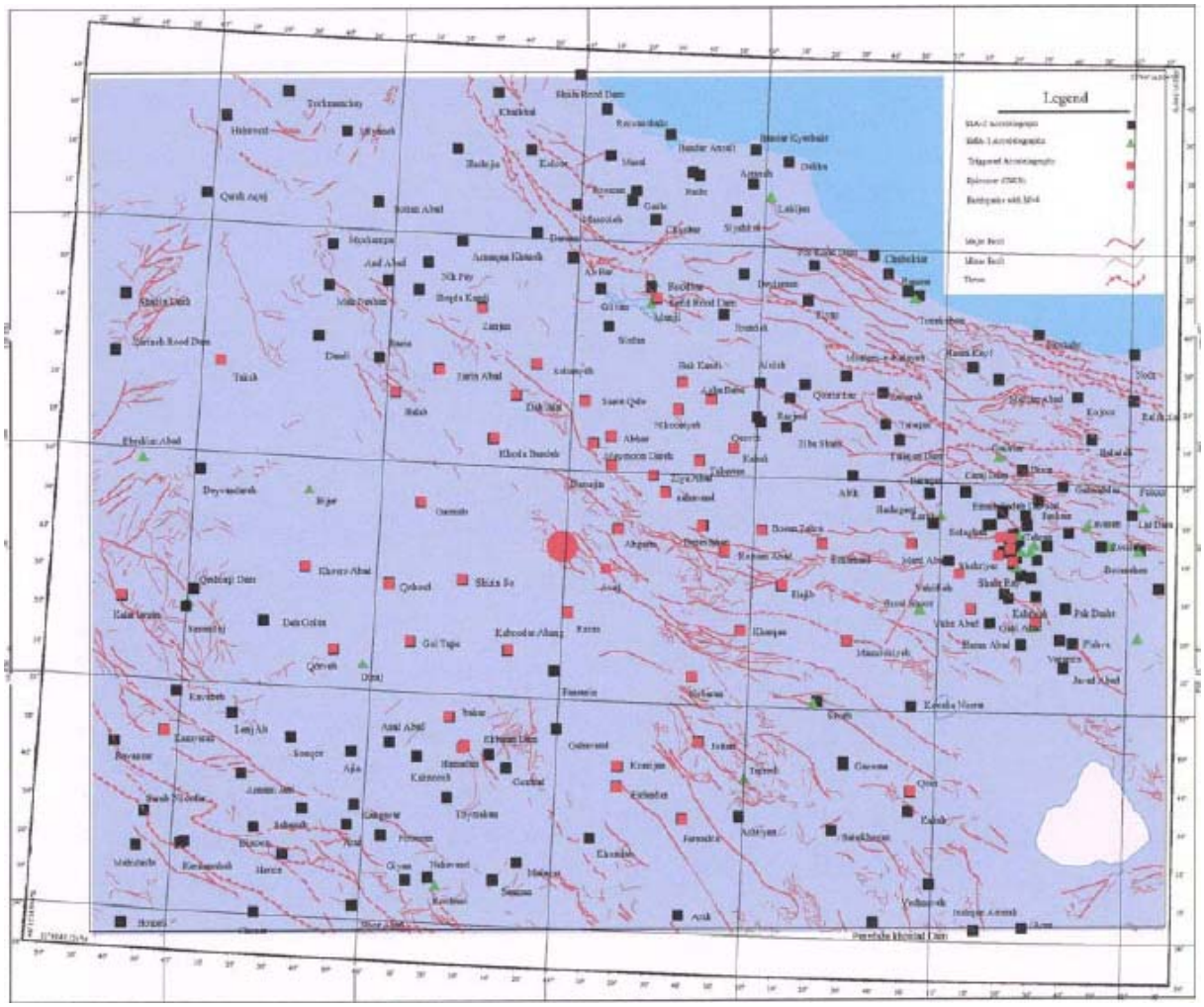


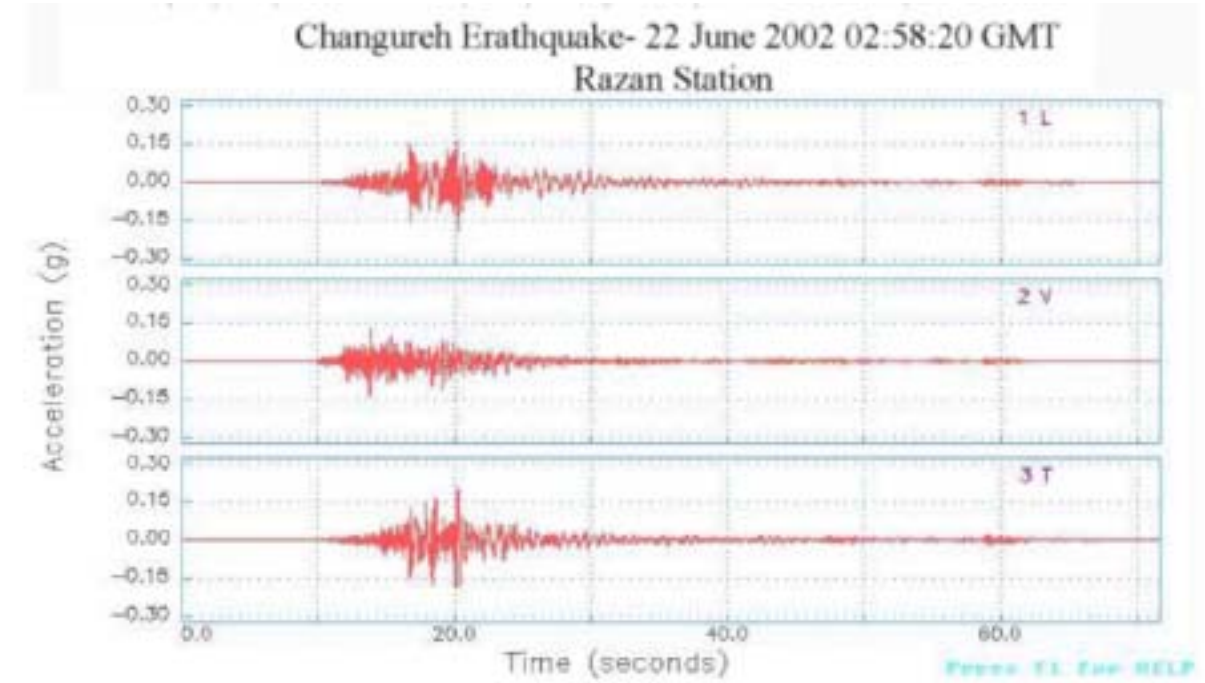
Figure 2.1. Map of accelerometer stations: Stations where the main event of the Changureh Earthquake was recorded are marked with red (BHRC).

According to the report of Building and Housing Research Center (BHRC), the earthquake was recorded by more than 50 digital accelerometers. The maximum acceleration of about 0.5g was reached at Avaj station, 26km away from the hypocenter. **Table 2.1** shows the recorded PGA values, their locations, times and azimuths. The locations of the stations are also shown in **Figure 2.1**. Accelerometers at red squares among the other stations were all triggered by the main event, and are found in an area of about 250 Km in radius.

Table 2.1. List of the stations that record Changureh Earthquake (BHRC).

No	STATION	Record No.	Geog. Coord. E	N	P.G.A (cm/s/s) L	V	T	Altitude m	Azimuth L	T
1	AVAJ	2749-1	49.22	35.58	498.78	271.67	484.12	1970	105	195
2	RAZAN	2756-1	49.03	35.38	183.53	134.99	200.58	1840	5	95
3	SHRINSO	2781	48.46	35.5	179.78	92.54	128.07	1810	170	260
4	KABODARAHANG	2754-1	48.72	35.2	87.5	70.91	166.19	1675	150	240
5	ABEGARM	2748-1	49.28	35.75	119.68	60.99	130.37	1660	312	42
6	GHOHORD	2778	48.07	35.47	51.83	23.39	85.09	1900	168	258
7	DARSCHIN	2769-2	49.23	36.03	55.67	42.32	77.6	1675	230	320
8	ABHAR	2763	49.22	36.15	39.43	28.92	74.29	1504	310	20
9	KHARAGHAN	2824	49.95	35.33	36.89	20.93	46.12	1900	90	99
10	BACKKANDI	2797-3	49.69	36.4	42.32	14.26	24.19	1320	192	282
11	BAHAR	2750	48.43	34.9	34.02	17.3	40.18	1730	142	232
12	SAEINQALEH	2772	49.07	36.3	39.16	22.5	34.31	1679	40	130
13	ZIYAABAD	2760-2	49.45	35.99	34.48	18.34	37.1	1400	230	320
14	GOLTAPEH	2777	48.2	35.22	32.92	26.33	32.48	2120	240	330
15	MAYMONDAREH	2771	49.13	36.12	32.66	22.37	23.26	1790	232	322
16	BOEINZAHRA	2759	50.05	35.77	19.21	10.98	31.39	1210	272	2
17	DAMESFAHAN	2751-1	49.73	35.79	27.3	15.75	25.18	1460	116	206
18	NAHAVAND	2761	49.52	35.92	26.67	18.05	27.26	1380	322	52
19	KHOSROABAD	2955	47.62	35.52	23.17	10.5	23.31	1840	304	34
20	KHODABANDEH	2753	48.69	36.12	23.2	13.84	17.12	2000	10	100
21	TEHRAN2	2766	51.4	35.72	22.86	5.02	17.34	-	50	140
22	KAHAK	2790	49.88	36.12	22.86	6.56	18.92	-	229	318
23	GARMAB	2752	48.22	35.83	18.98	19.87	22.49	1690	140	230
24	HAMEDAN	2780	48.52	34.79	22.06	7.86	12.17	1800	145	235
25	ROSTAMABAD	2792	49.86	36.67	21.69	11.55	20.05	1470	126	216
26	DEHJALAL	2768	48.7	36.31	18.12	20.49	20.65	2040	82	172
27	MARDABAD	2774	50.86	35.73	12.05	5.31	20.64	1216	0	90
28	MAMONIEH	2796	50.62	35.3	20.09	5.77	15.93	1270	115	205
29	TALEGHAN	2816	50.77	36.18	13.44	12.77	19.23	-	173	263
30	ESHTEHARD	2773	50.37	35.72	19.12	6.82	17.15	1186	350	94
31	FARMAHIN	2826	49.68	34.5	19.05	10.66	18.35	1786	257	17
32	KOMIJAN	2821	49.33	34.72	18.65	8.64	18.34	1760	312	42
33	SOLTANIYEH	2757	48.8	36.45	14.91	8.6	18.43	1786	100	190
34	HALAB	2770	48.05	36.3	17.82	6.01	11.6	1990	70	160
35	GHORVEH	2953	47.8	35.17	9.15	8.19	17.72	1916	30	120
36	TAKAB	2952	47.1	36.41	15.66	4.27	16.74	1822	250	340
37	TEHRAN-SHC	2944	51.13	35.7	16.4	6.74	13.25	-	20	110
38	SEFIDROUD	2795-3	49.39	36.75	16.89	3.73	7.68	-	28	118
39	NOBARAN	2822	49.7	35.12	15.4	9.35	15.48	1654	160	250
40	VAHDIYEH	2803-2	51.01	35.6	14.32	5.76	15.4	-	40	130
41	ESFANDAN	2794	49.33	34.63	12.7	8.95	14.95	1750	160	25
42	ZARINABAD	2758	48.28	36.41	14.86	6.11	11.77	1740	334	34
43	AGHABABA	2786-2	49.75	36.33	14.44	6.28	12.7	-	184	274
44	NIKOYEH	2791	49.57	36.28	14.43	9.43	10.13	1520	268	358
45	TEHRAN1	2765	51.4	35.72	9.84	5.02	14.32	-	280	10
46	FARDIS	2839	-	-	13.93	6.52	9.57	-	265	355
47	KAVANEH	2956	46.98	34.96	9.3	3.28	13.92	1620	270	360
48	KALATELARZAN	2954	46.66	35.35	11.64	2.62	13.14	1530	300	30
49	KAHRIZAK	2820	51.37	35.5	13.09	4.22	10.88	1024	350	80
50	VAHNABAD	2819	51.17	35.45	12.62	6.12	10.84	1037	35	125
51	JOFTAN	2823	49.75	34.84	12.74	7.17	11.75	1540	265	355
52	TAKESTAN	2793	49.7	36.06	12.42	11.73	11.92	1270	283	13
53	GARMDAREH	2832	51.06	35.7	11.7	5.66	9.48	-	194	284
54	QOM	2755	50.89	34.66	8.24	4.51	11.57	969	135	225
55	HAMEDAN-ABBASABAD	2779	48.52	34.78	6.16	4.62	11.56	-	90	210
56	ZANJAN	2795	48.48	36.67	11.06	5.18	10.12	1650	34	124
57	HAJIB	2789	50.19	35.54	9.28	6.72	11.05	1613	10	100
58	TEHRAN3	2767	51.4	35.72	4.35	2.11	5.23	-	82	162

In **Figure 2.2**, three uncorrected components of the 4 strongest accelerograms are shown (excluding Avaj station). Features in common for the records are (1) spiky peaks and (2) short duration times.



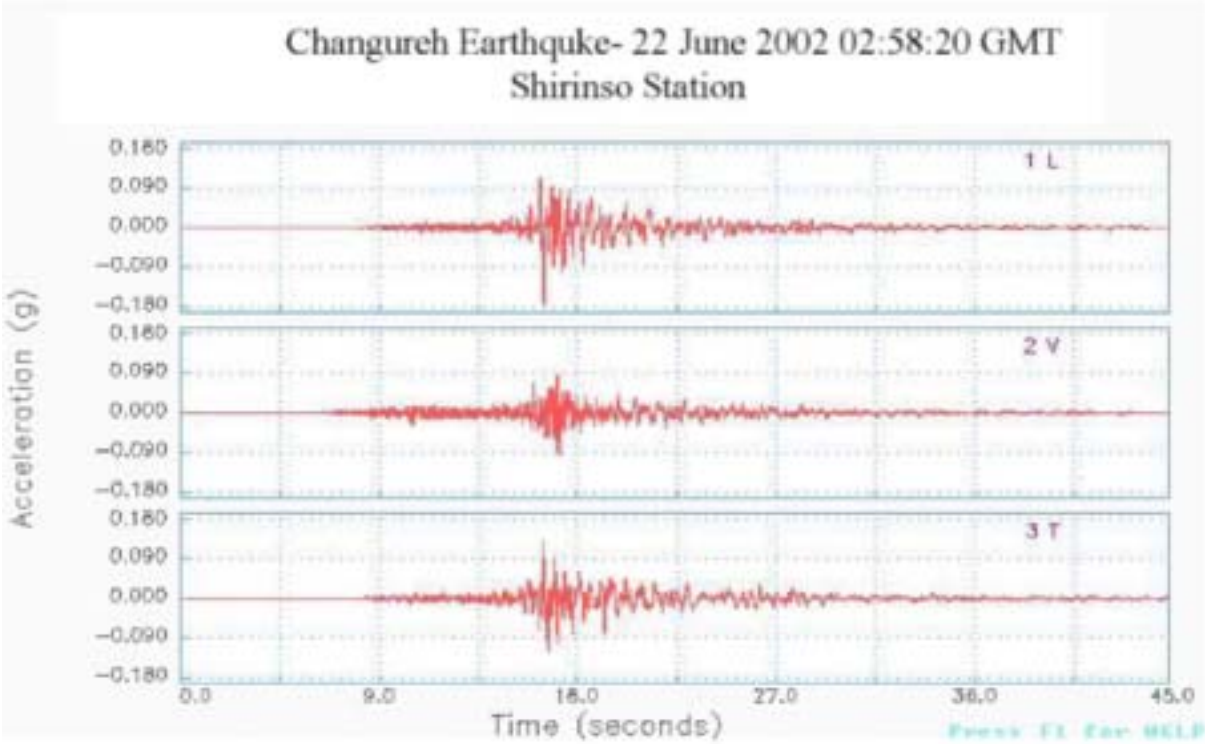
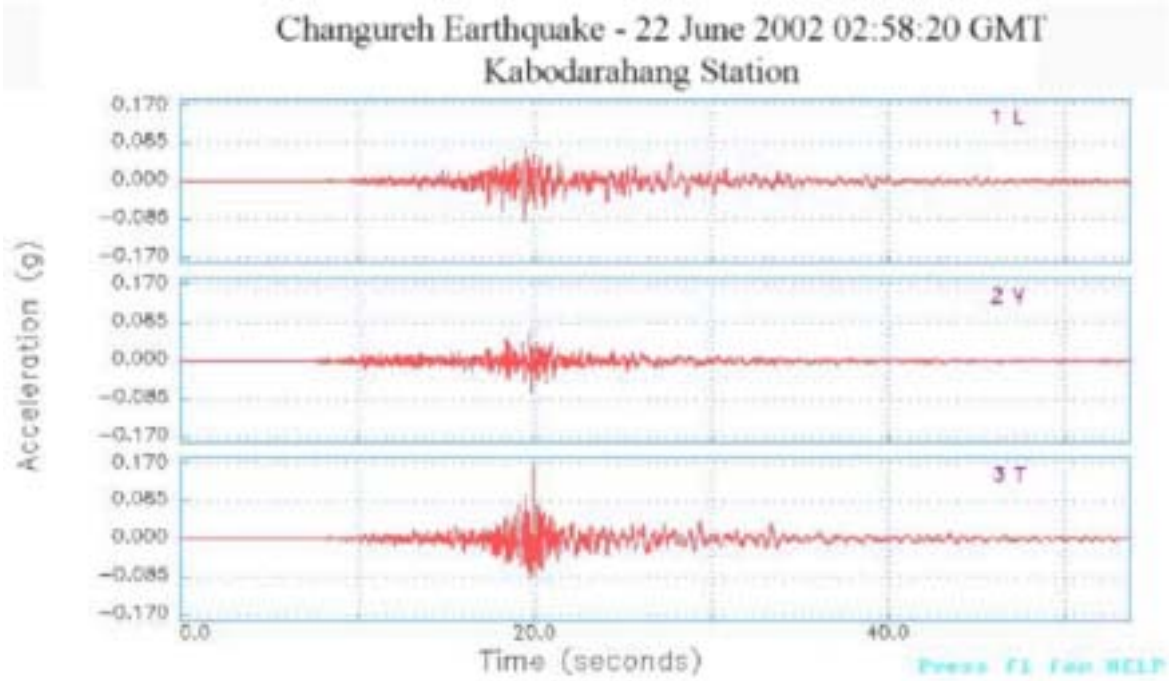


Figure 2.2. Four strongest motions recorded at Razan, Shirinso, Kabodarahang and Abegarm



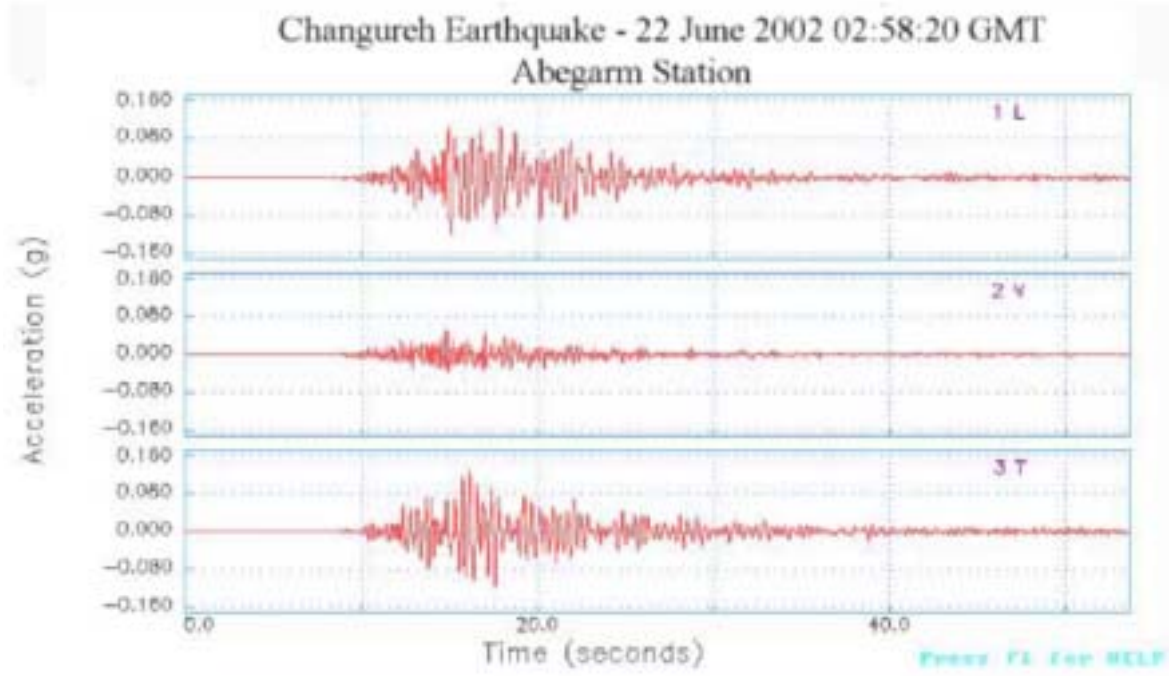


Figure 2.2 (cont). Four strongest motions recorded at Razan, Shirinso, Kabodarahang and Abegarm

At a glance over the planar locations of the stations with recorded PGA values, the bigger PGA values are mostly found on the western side of the Avaj fault that was activated in the earthquake. This fact may prove that there was a directivity effect.

As shown in **Table 2.1**, there are only two horizontal PGA values larger than 0.2g. For this reason, discussion will be narrowed to these two components. They include Avaj and Razan records with the maximum uncorrected PGA values of 0.51g and 0.2g reached.

An earthquake accelerogram generally contains all accelerations from the time that the earthquake begins until the time that the motion has returned to the level of background “noise”. For engineering purpose, only the strong motion part must be extracted. For this, both the pre-event parts and tail parts of the accelerograms were examined. Though there is no guarantee that the tail parts contain only pure noises, the reference noise signal was taken from the tails because there were some forshocks effects appearing in the pre-event parts. **Figures 2.3** and **2.4** show the signal to noise (S/N) spectra of three components of Avaj and Razan records, respectively. From these figures, the lower and higher cutoff frequencies for a band-pass filter were set at 0.15 Hz and 25 Hz, respectively, and all records were conditioned so that the noise amplitudes were minimized. The corrected accelerations together with velocities and displacements at Avaj and Razan stations are shown in **Figures 2.5** and **2.6**, respectively.

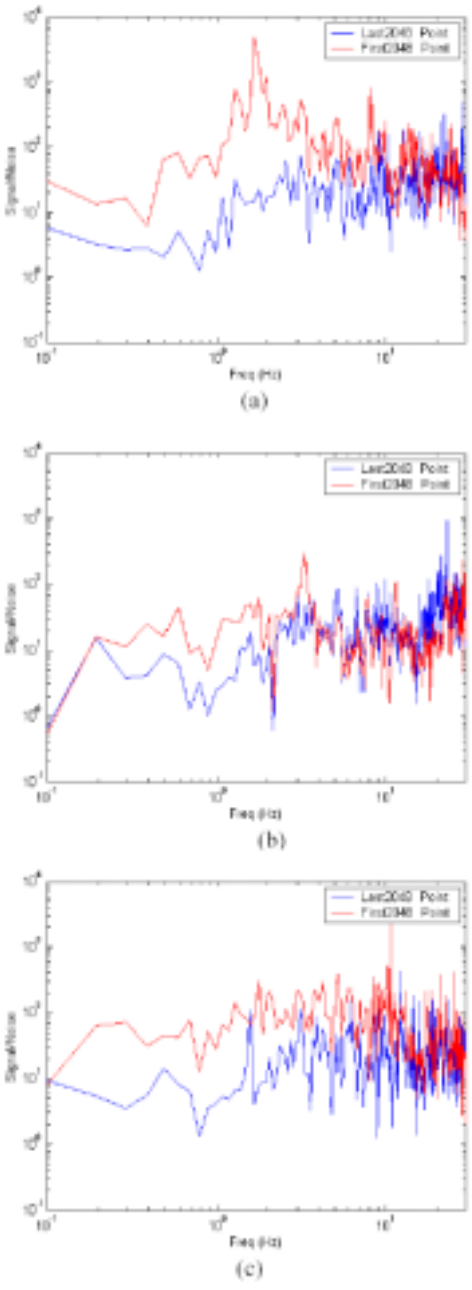


Figure 2.3. Avaj S/N ratio spectrum
(a) Horizontal 1 (b) Vertical (c) Horizontal 2

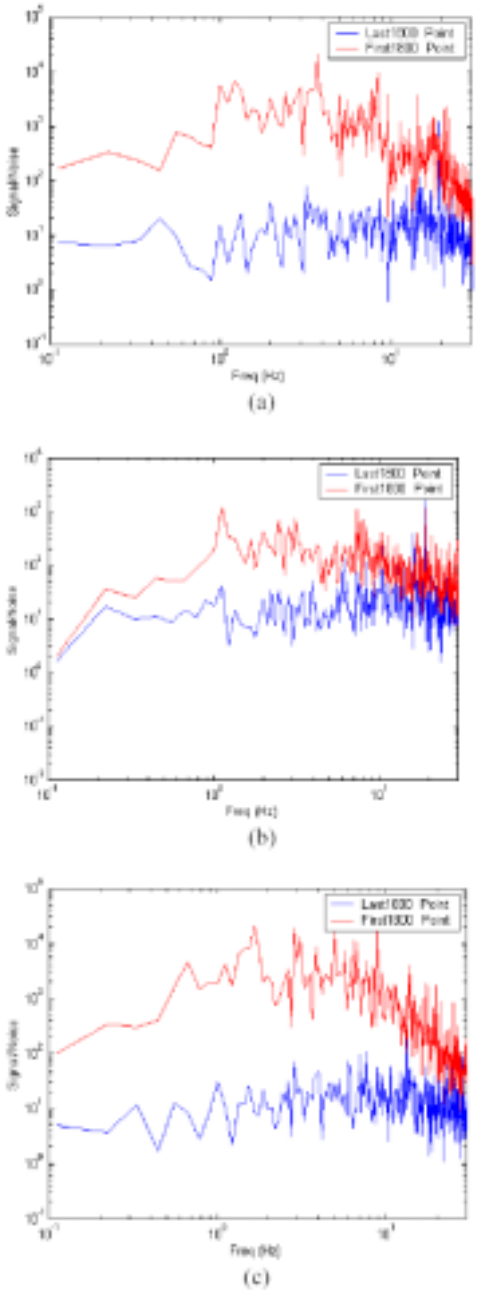


Figure 2.4. Razan S/N ratio spectrum
(a) Horizontal 1 (b) Vertical (c) Horizontal 2

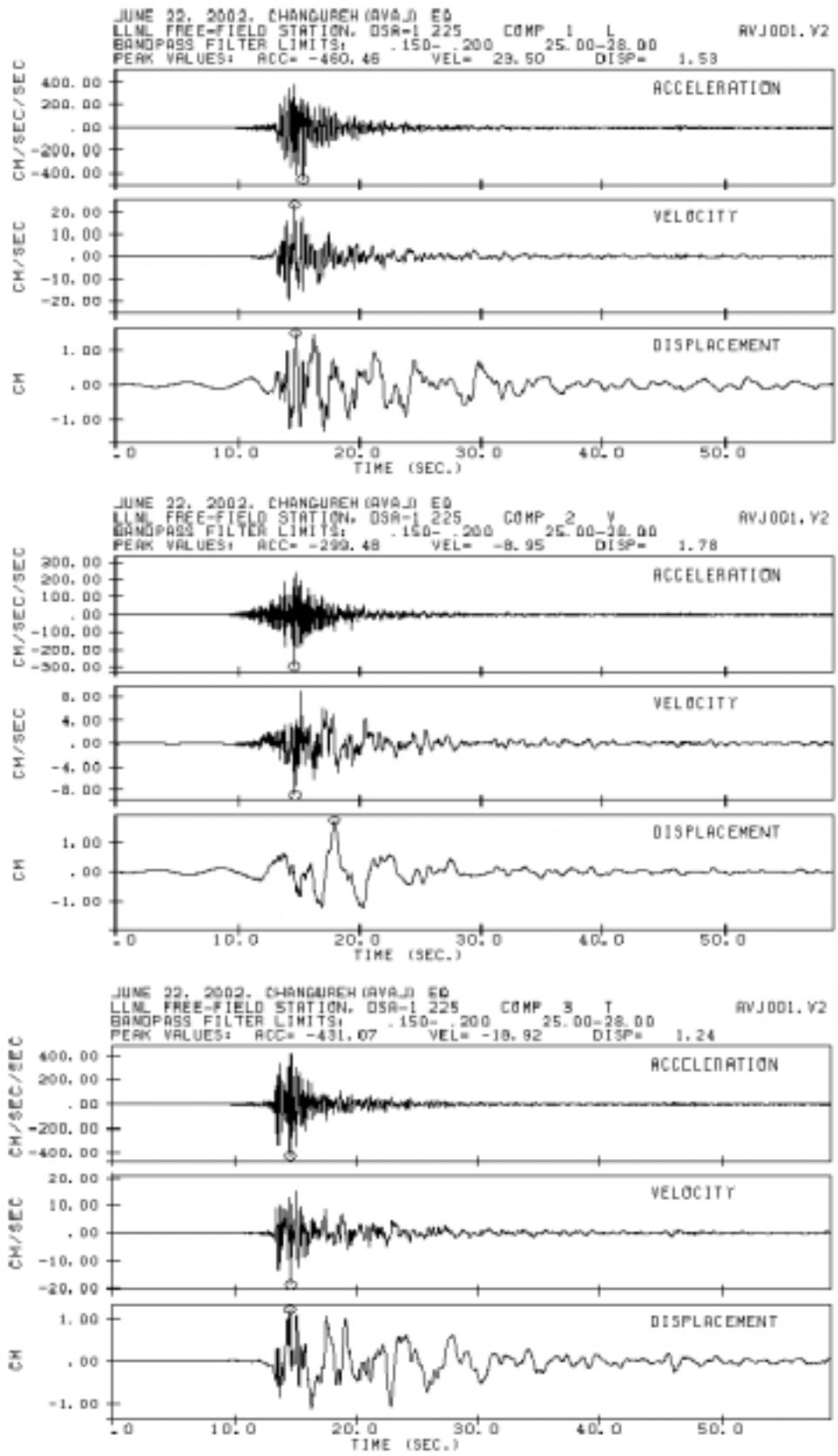


Figure 2.5. Corrected acceleration, velocity and displacement at Avaj station

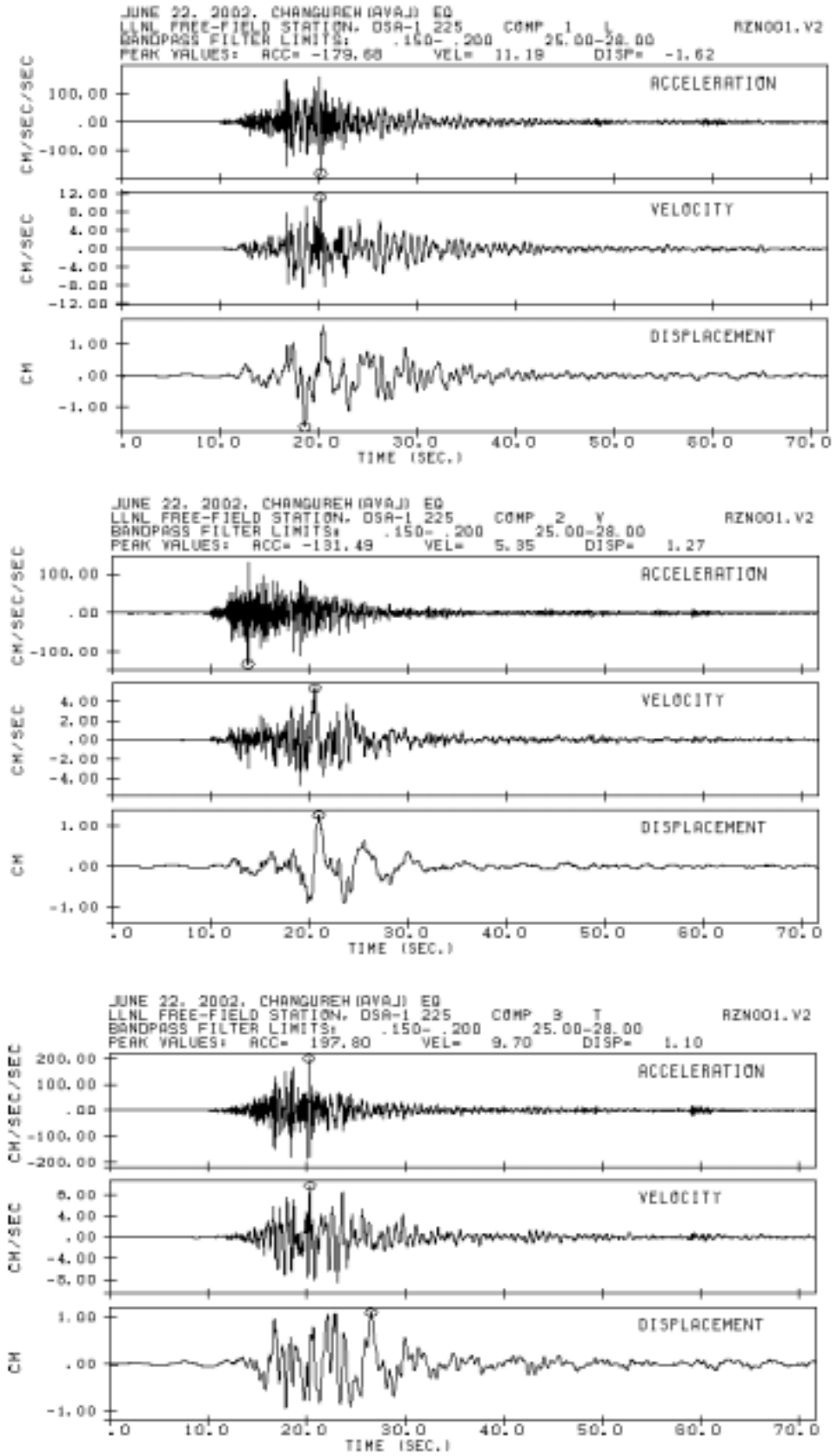


Figure 2.6. Corrected acceleration, velocity and displacement at Razan station

2.3 PSD AND RESPONSE SPECTRA

In conventional strong motion analyses, it is common to describe frequency characteristics of a motion in terms of Fourier Spectrum. On the other hand, power spectral density (PSD) of the motion is useful in characterizing an earthquake as a random process.

Power spectra of Avaj and Razan records are shown in **Figures 2.7** and **2.8**.

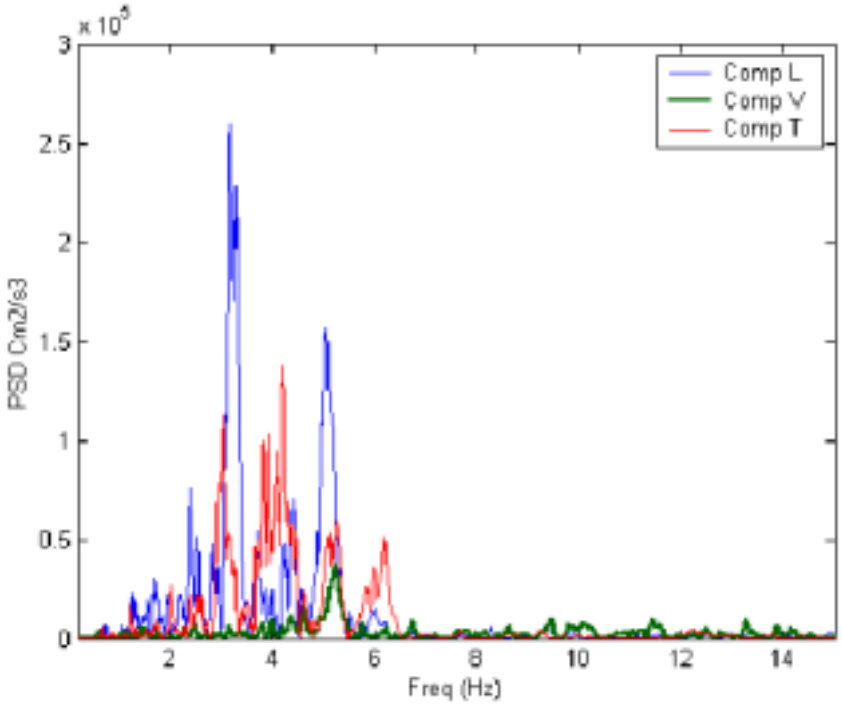


Figure 2.7. PSD at Avaj station.

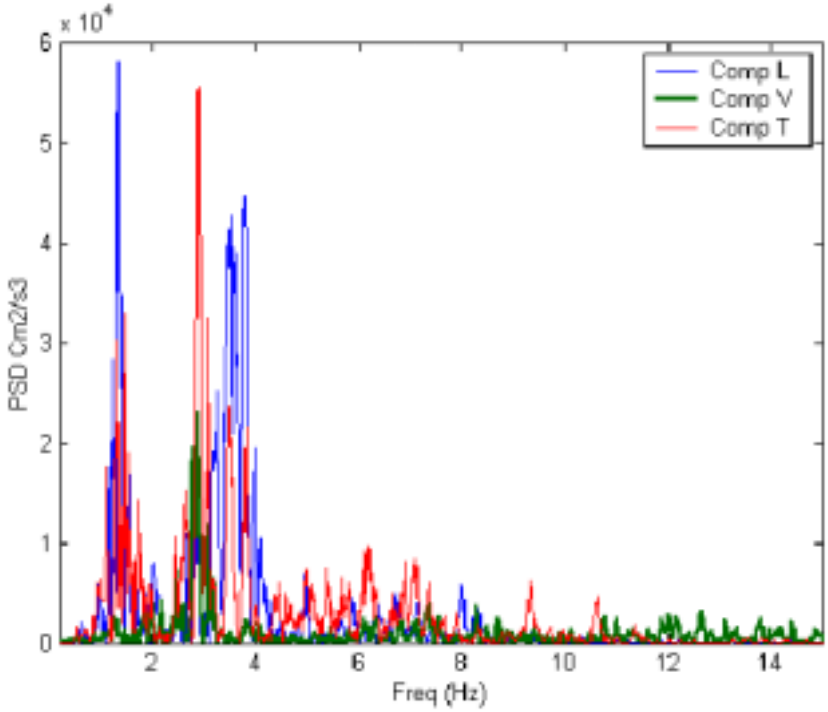


Figure 2.8. PSD at Razan station.

Response spectra were also calculated for these records, and plotted in a four-way logarithmic plot (tripartite plot) in **Figures 2.9** and **2.10**. As is clear from Avaj PSDs and response spectra, two distinct dominant frequencies at about 3 Hz and 5 Hz are recognized for the longitudinal horizontal component, one at about 4 Hz for the transverse component and one at about 5 Hz for vertical component. As for Razan, there are two distinct peaks at around 1.2 Hz and 4 Hz for the longitudinal component and 3 Hz for both the transverse and vertical components.

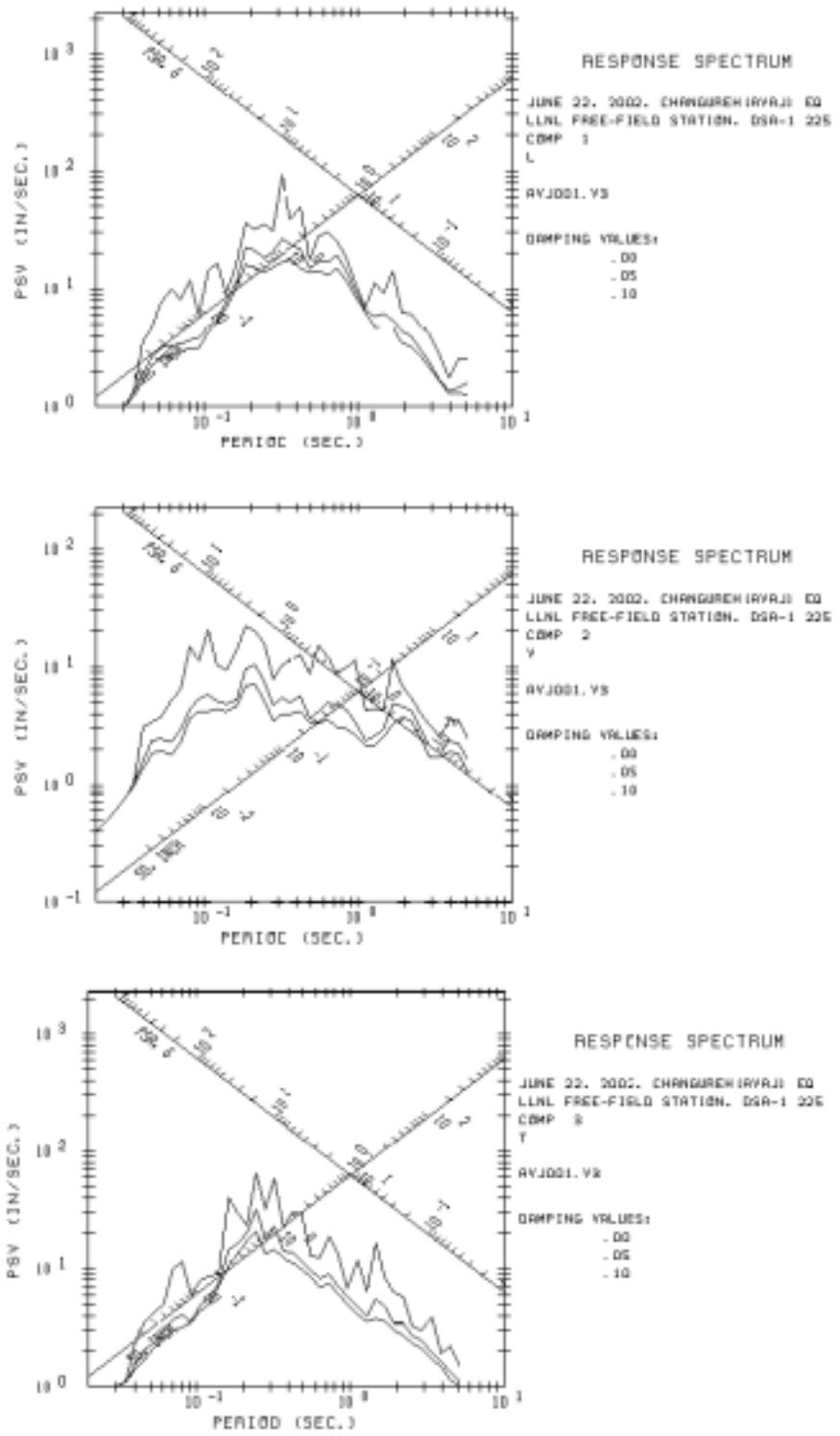


Figure 2.9. Response spectra at Avaj station

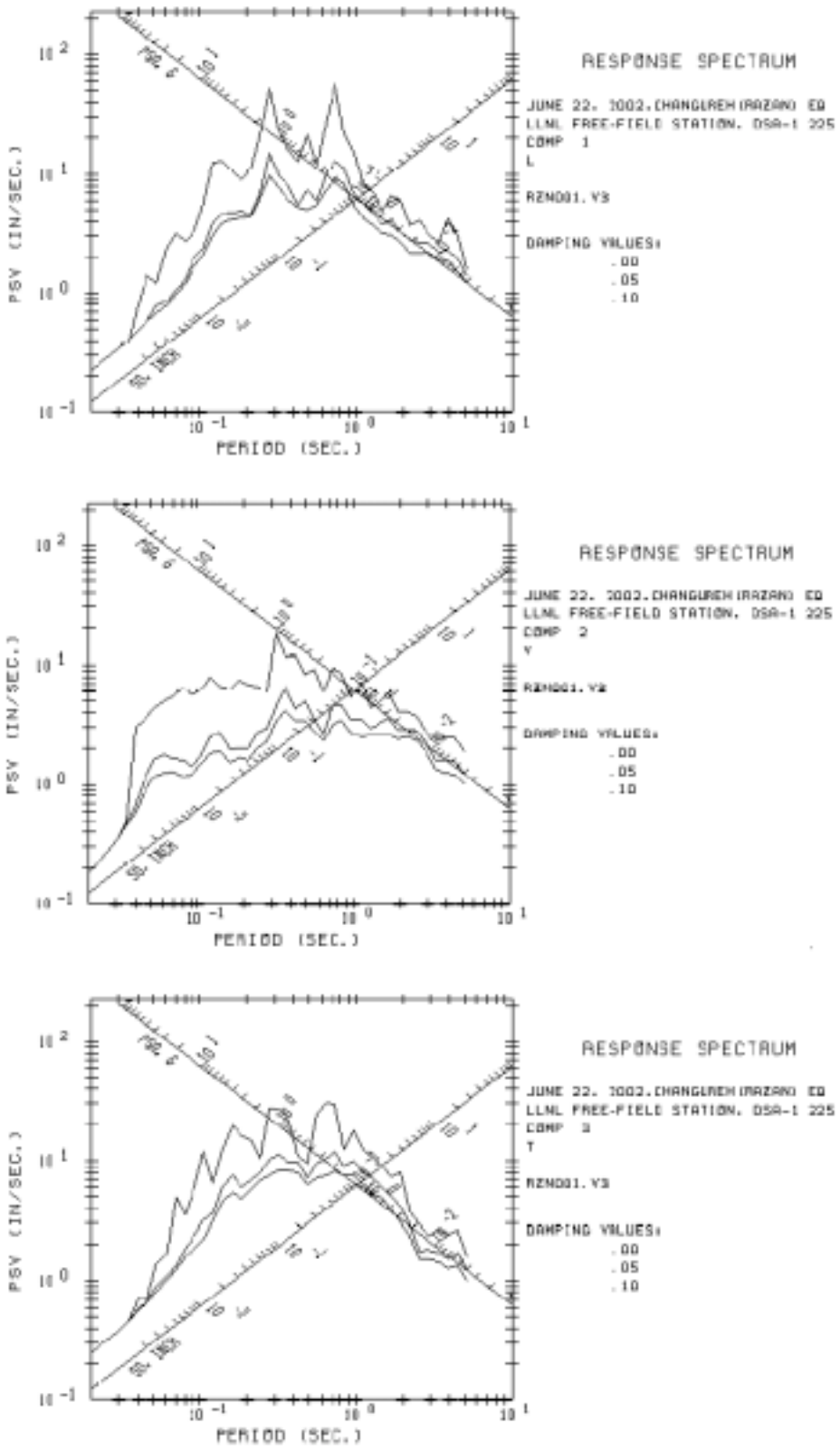


Figure 2.10. Response spectra at Razan station

2.4 HORIZONTAL TO VERTICAL SPECTRAL RATIOS

Local site conditions can profoundly influence all the important characteristics of strong ground motion. If an accelerometer is installed on a rock outcrop, it can be used as a reference and the local site effects at the other sites nearby can be recognized by comparing them with the reference record.

In the area of Changureh Earthquake, due to the lack of such a reference station, the HVSR (Horizontal to Vertical Spectral Ratio) technique (Nakamura, 1989) was utilized. This technique has received due attention recently because of its potential for identifying predominant periods of soft soil deposits as well as amplification factors. The applicability of HVSR technique to obtain site effect using both weak and strong motion records in the frequency domain was examined by Lermo and Chavez-Garcia [4] and Zare and Bard [3].

HVSRs were calculated for both Avaj and Razan records, and are shown in **Figures 11** and **12**, respectively. HVSR for Avaj record has a peak at about 2.2 Hz, while a peak at around 1.5 Hz is seen in Razan. From this, Avaj and Razan sites are classified into Types 3 and 4, respectively (Type 1 = rock site, Type 2 = hard soil, Type 3 = medium soil and Type 4 = soft soil, See [3]).

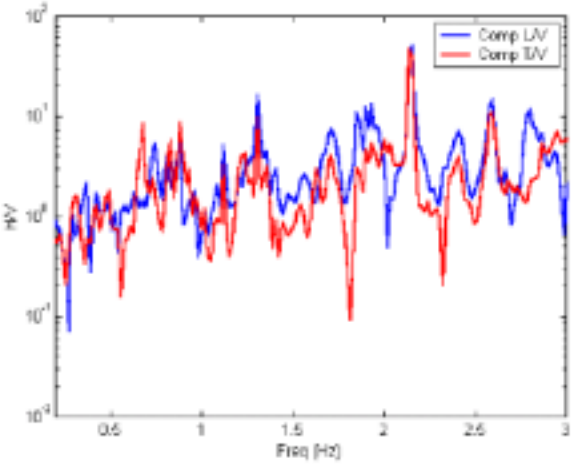


Figure 2.11. HVSR at Avaj

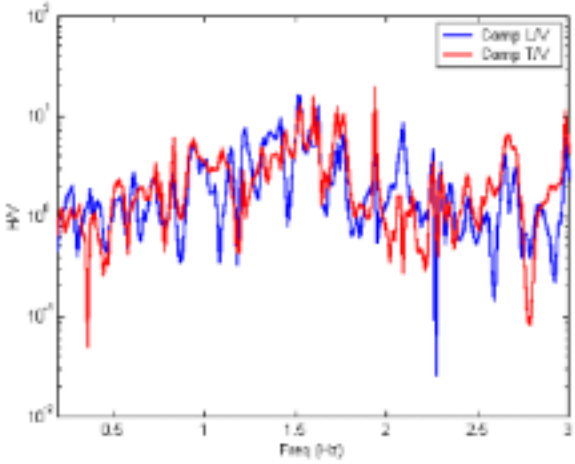


Figure 2.12. HVSR at Razan

2.5 AFTERSHOCKS

Aftershocks of the Changureh earthquake were recorded at BHRC stations as well as temporary stations set by International Institute of Earthquake Engineering and Seismology (IIEES). The list of BHRC aftershocks is given in **Table 2.2**. The greatest aftershock with the peak PGA value of 0.15g was recorded at Changureh.

As for IIEES aftershocks, Zare[2] reported that about 37 aftershocks in the first day were recorded in Hesar village. **Figures 2.13**, **2.14**, **2.15** and **2.16** show respectively the greatest aftershock among those recorded at Hesar, its average FFTs, HVSRs and response spectra for total 37 seismometers. These figures show that the fundamental frequency of the record was about 20 Hz indicating that the site is stiff.

Table 2.2 Aftershocks (BHRC)

			Geog. Cord.		Epicenter			UPGA (Cm/s/s)			Origin Time	
No	Station	Record No	E	N	E	N	M	L	V	T	h:m:s	D-M-Y
1	CHANGUREH	2841-5	48.96	35.77				56.67	88.88	150.28	13:29:58	25/07/2002
2	CHANGUREH	2827-2	48.96	35.77				146	30.8	87.85	20:26:09	06/07/2002
3	CHANGUREH	2827-5	48.96	35.77				81.12	60.55	133.2	22:58:01	10/07/2002
4	ABEGARM	2748-3	49.28	35.75	48.91	35.64	5.1	54.32	20.96	72.67	06:45:33	22/06/2002
5	CHANGUREH	2764-2	48.96	35.77				55.56	23.88	27.83	18:58:03	26/06/2002
6	CHANGUREH	2816	48.96	35.77	48.9	35.69	4.3	52.54	23.12	41.98	19:24:51	03/07/2002
7	AVAJ	2749-5	49.22	35.58	48.91	35.64	5.1	39.13	29.28	44.5	06:45:33	22/06/2002
8	CHANGUREH	2827-13	48.96	35.77				25.45	31.95	36.1	08:13:50	22/07/2002
9	CHANGUREH	2827-6	48.96	35.77				16.14	20.5	35.97	02:26:53	11/07/2002
10	AVAJ	2749-2	49.22	35.58				35.8	12.52	25.45	03:03:21	22/06/2002
11	CHANGUREH	2827-12	48.96	35.77				24.48	29.04	34.62	08:04:26	22/07/2002
12	CHANGUREH	2827-1	48.96	35.77				18.62	21.9	33.58	22:43:13	04/07/2002
13	CHANGUREH	2841-2	48.96	35.77				18.62	21.9	33.58	22:43:02	04/07/2002
14	AVAJ	2783	49.22	35.58	48.86	35.49	4.6	32.92	14.04	26.3	18:18:46	26/06/2002
15	CHANGUREH	2788	48.96	35.77				19.05	31.31	29.22	09:40:21	01/07/2002
16	CHANGUREH	2841-3	48.96	35.77				25.77	19.9	30.23	17:35:46	12/07/2002
17	CHANGUREH	2861	48.96	35.77				25.77	19.9	30.23	17:35:56	12/07/2002
18	CHANGUREH	2784	48.96	35.77				26.91	21.48	29.76	16:20:27	28/06/2002
19	ABEGARM	2748-2	49.28	35.75				19.07	5.74	29.38	03:00:42	22/06/2002
20	CHANGUREH	2827-10	48.96	35.77				18.12	12.21	25.96	20:18:06	20/07/2002
21	CHANGUREH	2827-7	48.96	35.77				23.46	15.61	23.63	03:06:02	11/07/2002
22	CHANGUREH	2827-11	48.96	35.77				23.06	14.52	18.49	22:08:43	21/07/2002
23	CHANGUREH	2827-9	48.96	35.77				19.17	13.56	21.94	15:22:26	20/07/2002
24	CHANGUREH	2764-1	48.96	35.77				21.37	21.92	19.52	18:51:17	26/06/2002
25	CHANGUREH	2775	48.96	35.77				19.91	12.79	18.02	18:19:58	27/06/2002
26	AVAJ	2749-4	49.22	35.58	48.68	33.9	4.1	19.12	7.6	13.37	04:41:48	22/06/2002
27	CHANGUREH	2827-3	48.96	35.77				13.72	7.81	18.09	21:47:19	08/07/2002
28	RAZAN	2766-2	49.03	35.38	49.01	35.51	4.4	17.07	8.06	17.67	03:32:00	22/06/2002
29	ABEGARM	2782	49.28	35.75	48.86	35.49	4.6	14.22	7.94	16.08	18:18:46	26/06/2002
30	RAZAN	2776	49.03	35.38	48.91	35.64	5.1	13.24	10.57	15.88	06:45:33	22/06/2002
31	CHANGUREH	2841-6	48.96	35.77				8.79	14.64	11.04	15:03:53	25/07/2002
32	KABODARAHANG	2754-2	48.72	35.2				10.01	6.67	14.63	02:58:51	22/06/2002
33	CHANGUREH	2841-4	48.96	35.77				11.62	8.55	14.63	04:33:58	25/07/2002
34	CHANGUREH	2841-1	48.96	35.77				9.74	14.59	10.13	18:01:20	29/06/2002
35	ZIYAABAD	2760-3	49.45	35.99	48.91	35.64	5.1	14.41	3.88	9.01	06:45:33	22/06/2002
36	CHANGUREH	2827-4	48.96	35.77				9.87	3.93	13.93	03:19:42	10/07/2002
37	AVAJ	2749-3	49.22	35.58	49.01	35.51	4.4	13.7	6.59	13.76	03:32:00	22/06/2002
38	DANESFAHAN	2751-2	49.22	35.58	48.91	35.64	5.1	12.87	5.98	4.84	06:45:33	22/06/2002
39	CHANGUREH	2827-8	48.96	35.77				12.23	5.34	12.51	04:39:51	11/07/2002

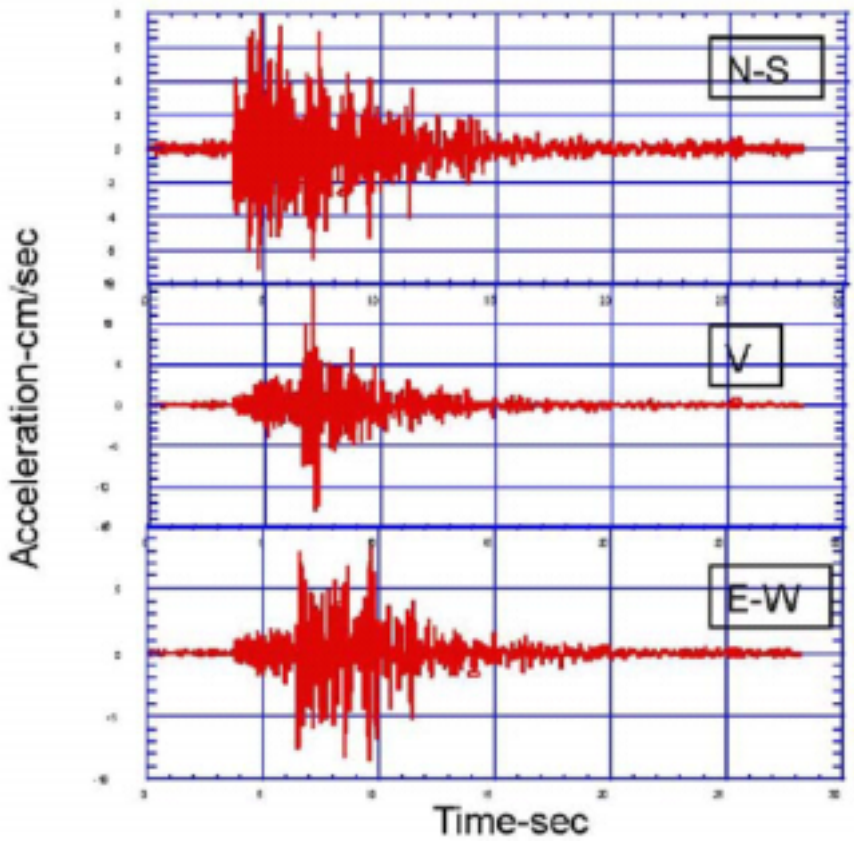


Figure 2.13. The most intense aftershock at Hesar (IIEES, Zare, 2002)

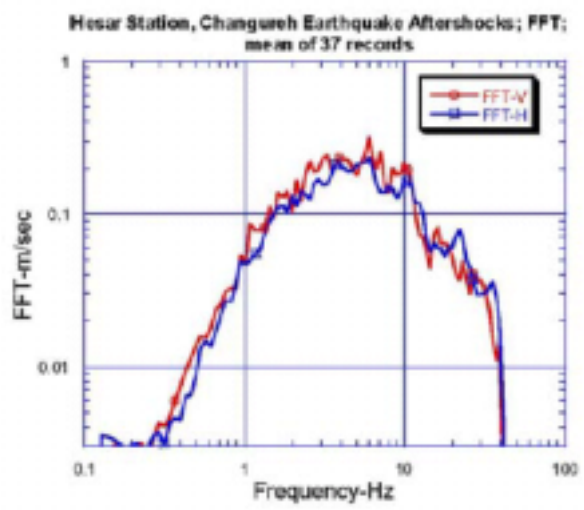


Figure 2.14 Average FFT spectra for 37 aftershocks recorded during June 22, 2002 at Hesar. (Zare, 2002)

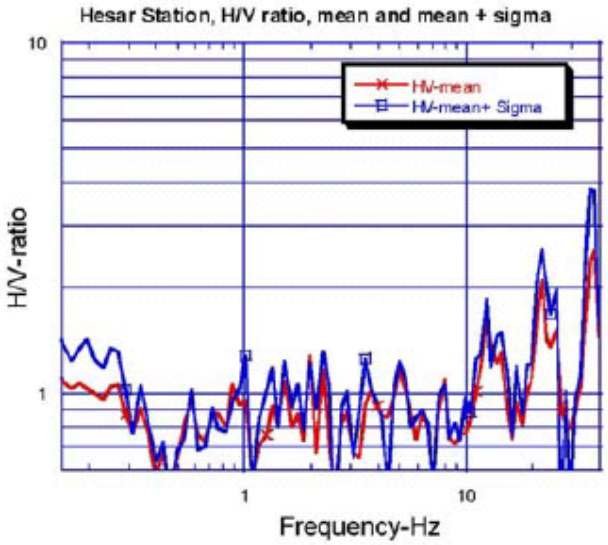
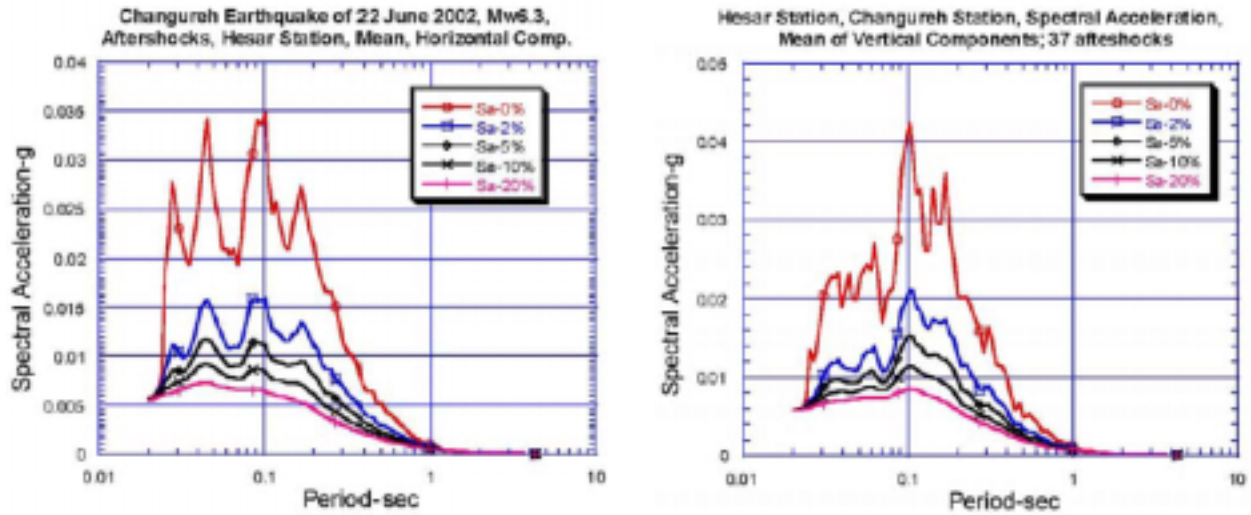


Figure 2.15 Average and Average+1 standard deviation HVSRs for 37 aftershocks recorded during June 22, 2002 at Hesar. (Zare, 2002)



(a) **(b)**

Figure 2.16. Average response spectra for 37 aftershocks recorded during June 22, 2002 at Hesar: **(a)** Horizontal componets. **(b)** Vertical components (Zare, 2002)

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