THE EFFECTS OF LOCAL SOIL CONDITIONS ON THE CHARACTERISTICS OF NEAR-FAULT DIRECTIVITY PULSE

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ABSTRACT

Pulse like near-fault ground motions resulting from directivity effects are a special class of ground motions that are challenging characterize for seismic performance assessment. These motions contain a pulse in the velocity and sometimes in the acceleration time histories often occurring in the direction perpendicular to the fault rupture at locations near the fault where the earthquake rupture has propagated toward the site. Near-fault recordings from recent earthquakes indicate that this pulse is a narrow band pulse whose period increases with magnitude as expected from theory. This magnitude dependence of the pulse period causes the response spectrum to have a peak whose period and amplitude increase with magnitude or size of asperity(s) on a fault. Meanwhile, the effects of local soil conditions on the near-fault directivity pulse have not yet been investigated and need to be further examined.

In this study, the relations among directivity pulse amplitude and period with local soil conditions are investigated. The strong ground motions from Chi-Chi (1999) earthquake are used here due to the large rupture length and significant number of stations in near-fault area with different soil conditions. This makes a good opportunity to investigate on the variation of forward directivity pulse parameters with the local soil properties at the sites. For this purpose, 44 accelerograms that contain forward directivity pulse are selected among 300 accelerograms recorded in near-fault area. The soil condition of recording stations is categorized into four soil types (I, II, III and IV; from very hard to loose) according to Iranian design code (standard 2800). Then, the acceleration response spectra for the accelerograms at each soil category are calculated and averaged. The amplification characteristics of directivity pulse are discussed by the mean spectral ratio of soil types II, III and IV with respect to soil type I (very hard or rock). The results show the spectral amplification up to 2.5 in the period range of 0.8 to 8 sec. Furthermore, the amplification value and period increase as the soil getting loose. Finally, the outcomes provide the field evidence on the directivity pulse amplification due to local soil conditions and their importance in design.

INTRODUCTION

In the context of quantitative seismic hazard assessment, the Earth's surface is an important boundary that totally affects the upcoming seismic energy and produces surface waves (Hartezll et al., 1994). Ground motions in the near-fault zone in addition to effect of the Earth surface, are potentially affected by wave propagation effects known as directivity. Motions affected by forward directivity contain a pulse in the velocity and sometimes in the acceleration time histories often occurring in the direction perpendicular to the fault rupture at locations near the fault (almost within 15 km from the fault) where the earthquake rupture has propagated toward the site. These motions usually exhibit the characteristics of large amplitude and long period velocity pulses (Somerville et al., 1997; Bray and Rodriguez-Marek, 2004). Near-fault recordings from recent earthquakes indicate that this pulse is a narrow band pulse whose period increases with magnitude as expected from theory. This magnitude dependence of the pulse period causes the response spectrum to have a peak whose period and amplitude increase with magnitude (Xie. et al., 2005, Xu et al., 2013), or size of asperity(s) on a fault (Somerville et al., 1999, Ghayamghamian, 2003, Ghayamghamian, 2005).To quantify the special effects of forward-directivity and develop design guidelines, much effort has been devoted to the analysis of the dynamic performance of structures subjected to idealized pulse motions (Hall et al., 1995; Alavi et al., 2000; Alavi & Krawinkle., 2004; Sasani & Bertr., 2000; Mavroeidis et al., 2003; Mavroeidis et al., 2004). Significant work has also been directed towards developing predictive relationships for parameters that characterize the velocity pulses present in forward-directivity motions (Alavi et al., 2000; Alavi & Krawinkler., 2004; Sasani & Bertr., 2000; Mavroeidis et al., 2003; Mavroeidis et al., 2004; Bray & Rodrigez-Marek., 2004). Although those interrelated studies have provided insight on several aspects of near-fault motions and their effects on structures, additional work is needed to capture not only the nature of forward-directivity motions, but also the propagation media and local soil response entirely. Meanwhile, in spite of extensive analyses have been carried out on the different aspects of the source, the effects of soil conditions on the characteristics of forward directivity pulse have not been studied well.

In this study, the effect of soil condition on the directivity pulse amplitude and period are examined using data of Chi-Chi (1999) earthquake. The large rupture length of this earthquake and the presence of many stations with different soil conditions provided a lots of recordings with directivity pulse(s) in near-fault area. This makes a unique opportunity to investigate on the variations of forward directivity pulse parameters in various soil conditions. For this purpose, more than 300 recordings of Chi-Chi earthquake are analyzed here, which among them only 40 recordings are found to contain the directivity pulse(s). Due to the relatively large number of asperities (the area with a slip larger than the mean slip on a fault), all the recordings contain multiple strong pulses over wide period range. The soil condition at each station are categorized according to Iranian design code (soil types I, II, III and IV from hard to loose). Then, the mean acceleration response spectra are calculated by averaging the acceleration response spectra at each category. The pulse amplification characteristics are explained by spectral ratio of soils (types II, III and IV) to that of soil type I.

THE SELECTED DATA AND SITE CLASSIFICATIONS

The 1999 Chi-Chi, Taiwan earthquake (M_w=7.6) caused severe damage in the near-fault region (Miyakoshi and Hayashi, 2000; Tsai et al., 2000). This earthquake began as a reverse thrust slip event along the Chelungpu fault, with significant surface breaks of approximately 85 km and vertical displacements of 1–8 m (WU et al., 2001). The surface breaks finally bent 20 degree eastward on the northern part of the fault. The epicenter (Fig. 1) was determined to be 23.85N, 120.81E, and its focal depth was 7.8 km, as ascertained by the Central Weather Bureau (CWB).

The ground motion records were obtained from motion database of the Pacific Earthquake Engineering Research Center More than 300 records were available for this earthquake. All the records are examined and among them 40 records containing forward directivity pulse with peak ground velocity (PGV) larger than 25 cm/s are selected (Table 1). These are collected in a distance of 23 km from the fault with regard to the large magnitude of Chi-Chi earthquake.

The recording stations are categorized according to their soil properties, which are collected from PEER site. This classification is on the basis of Iranian code of practice for seismic resistant design of buildings. According to Iranian code four different types of soil are defined as follow: I: rock and very stiff soil (Vs > 750 m/s); II: Stiff soil (375 < Vs< 750); III: soft soil (175 < Vs < 375); IV: very soft soil (Vs < 175 m/s). The number of records at the stations with the soil types I, II, III and IV are 1, 9, 27 and 5, respectively. The distribution of the stations according to their soil types are also shown in Figure 1 and summarized in Table 1.

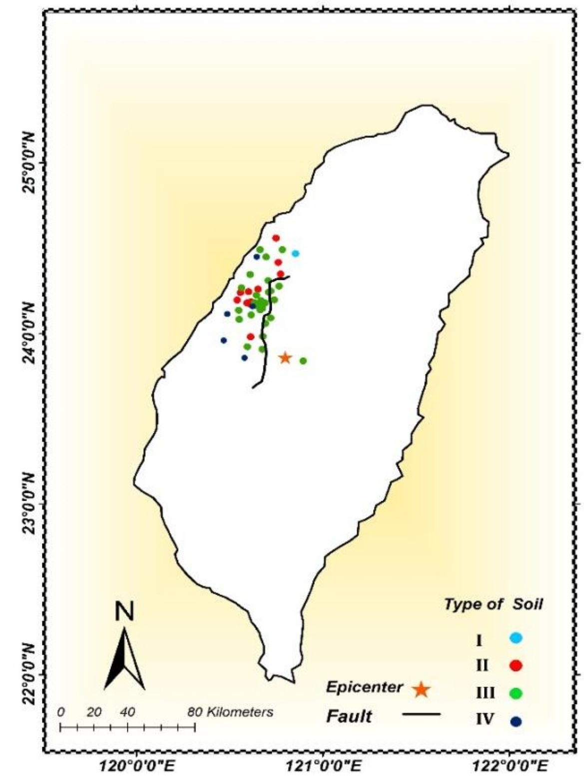

Figure 1. The Chi-Chi earthquake epicenter and fault trace on the back ground of recording stations categorized according to soil type

PULSES CHARACTERISTICS OF THE RECORDED MOTIONS

The fault parameters of Chi-Chi earthquake on the background of station locations are shown in Figure 2. Almost ten asperities (the area with the slip larger than mean slip on the fault) with different slip values and sizes can be seen in this figure. Each asperity has a capability to produce a pulse-like motion whose amplitude and period are dependent to its maximum slip and size, respectively. Therefore, from the fault model (BOI-YEE LIAO et al., 2013) given in Figure 2, one may expect to see multiple pulses with different periods and amplitudes in the recorded motions at the stations. To examine this hypothesis, three stations (TCU 128, TCU 136, TCU 120) along the fault are selected. The velocity motions are calculated from the recorded accelerations time histories as shown in Figure 3. From figure 3a, several pulses with different amplitude and periods can be recognized. The pulses amplitude and period are controlled by the station distance to the fault, rupture propagation direction and mostly their distance to the asperities.

Figure 4 Shows the Fourier spectra of the velocity motions for horizontal motions in east-west (EW) and north-south (NS) directions at the sites. Generally, the pulses show the periods larger than 0.8 sec with the peaks at 1.2, 1.6, 2.0, 2.6, 3.2, 3.9, 4.8, 7 and 8 sec, which are almost same as the number of asperities in Figure 2. This is why we see many pulses at different time and amplitudes in the velocity time histories at the sites. This also is an advantage since it makes it possible to examine the pulse response to different soil conditions in a wide period range.

Table 1. Parameters of the selected records and soil category of the stations

Station code	R_{rup} (km)*	Site	PGA(cm/s^2)	PGV(cm/s)	PGD(cm)
TCU036	16.69	III	139	38.7	43.9
TCU038	22.44	III	141	37.7	29.6
TCU039	16.70	II	145	54.5	52.8
TCU040	21.00	IV	149	39.6	40.3
TCU046	14.34	I	133	24.6	16.6
TCU049	4.48	III	293	47.9	65.3
TCU051	8.27	III	186	49.3	70.3
TCU052	0.24	III	348	159.0	184.4
TCU053	6.69	III	223	41.3	59.5
TCU054	5.92	III	148	59.4	59.4
TCU055	6.88	III	237	26.2	9.9
TCU056	11.11	IV	134	42.5	50.8
TCU057	12.57	II	118	35.2	56.7
TCU059	17.84	III	165	59.4	63.7
TCU060	9.46	III	201	36.3	51.9
TCU061	17.75	III	141	40.3	37.1
TCU063	10.39	III	172	59.0	59.2
TCU064	15.07	III	107	39.2	51.8
TCU065	0.98	III	814	126.2	92.6
TCU067	0.33	III	503	79.5	93.1
TCU068	1.09	III	566	176.6	324.1
TCU070	19.01	II	255	52.1	48.1
TCU075	1.49	III	333	88.3	86.5
TCU076	1.95	III	303	62.6	31.5
TCU078	7.50	III	444	39.2	31.2
TCU079	10.04	III	742	61.2	11.1
TCU082	5.73	III	223	58.4	71.5
TCU087	3.18	II	128	40.8	62.6
TCU100	12.14	II	117	34.6	51.9
TCU102	1.79	III	298	112.4	89.2
TCU103	4.01	III	134	61.9	87.5
TCU105	18.10	II	112	34.6	48.6
TCU106	15.22	III	157	46.6	43.3
TCU111	22.22	IV	136	57.8	55.2
TCU115	22.75	IV	96	54.0	37.8
TCU116	11.86	IV	184	48.7	49.2
TCU120	8.10	II	225	63.1	54.1
TCU128	9.70	II	139	53.9	41.8
TCU136	8.97	II	171	55.8	66.5
TCU138	10.12	III	195	40.9	36.4

* The closest distance to the fault adopted from the PEER database

THE EFFECTS OF SOIL CONDITION ON DIRECTIVITY PULSE

To examine the effects of different soil types on directivity pulse characteristics, the response spectra are calculated for the selected accelerograms in each soil category. Then, the calculated response spectra are all normalized to their peak ground accelerations, and are averaged to give the mean response spectra for the assumed soil categories as shown in Figure 5a. From this figure, the acceleration response spectral values after 1 sec show an increase with increasing period up to 8 sec Furthermore, the amplification function is calculated by using spectral ratios of soil types II, III and IV with respect to the soil type I as shown in Figure 5b. This figure clearly shows the spectral amplification up 2.5 in the period range of 0.8 to 8 sec. It is also interesting to note that as the soil becomes loose from soil type II to IV, the amplification value increases at longer periods.

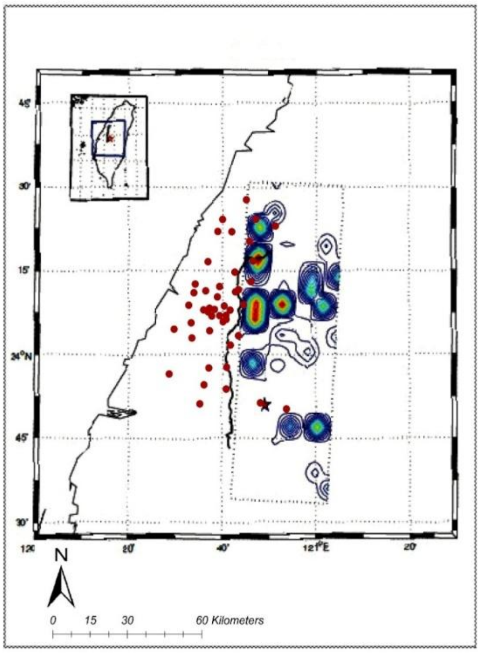

Figure 2. Chelungpu fault trace and its source model on the background of recording stations showing the locations of TCU 120, TCU136 and TCU 128 stations. The main asperities are shown by red rectangular (BOI-YEE LIAO et al 2013, with changed).

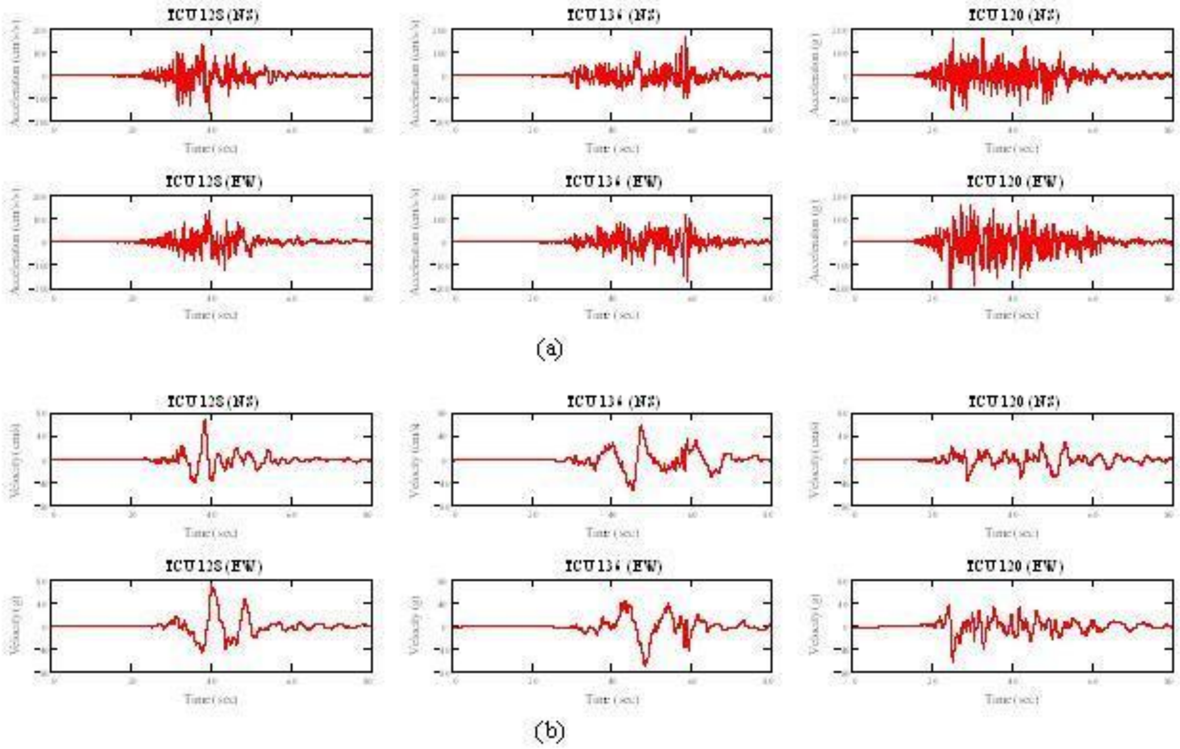

Figure 3. (a) acceleration time histories for horizontal components at TCU 120, TCU136 and TCU 128 stations, and (b) calculated velocity time histories at the stations showing several pulses with different periods and amplitudes.

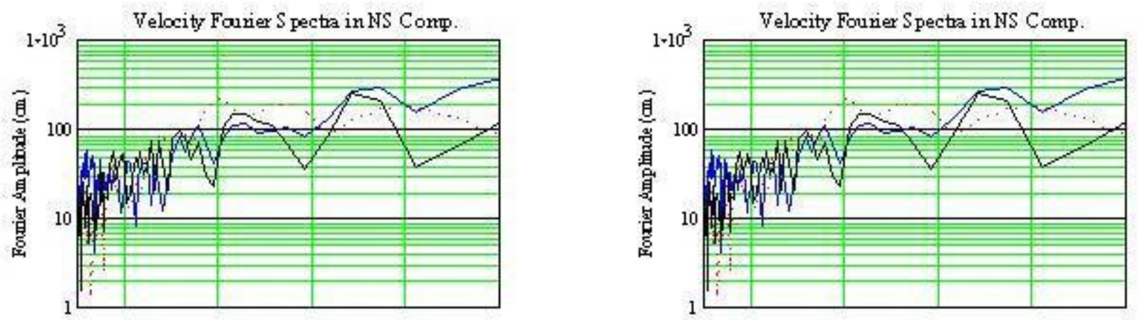

Figure 4. Velocity response spectra for horizontal components at TCU 120, TCU136 and TCU 128 stations. The peaks at 1.2, 1.6, 2.0, 2.6, 3.2, 3.9, 4.8, 7 and 8 sec seems to be corresponded with the number of asperities in source model of Chi-Chi earthquake.

CONCLUSIONS AND DISCUSSIONS

In the absence of a clear knowledge regarding soil conditions on directivity pulse characteristics, an attempt was made here to carry out an empirical analysis by using Chi- Chi earthquake (1999) data. The directivity pulse characteristics are extensively dependent to the source parameters such as asperity numbers, sizes and maximum slips, which may be largely varied earthquake by earthquake. Therefore, an increase in the number of earthquake without clear understanding of source and propagation path effects could be misled. This is why we limited our investigation to the only Chi-Chi earthquake data here. In addition to the same source parameters for all the selected stations here, large number of stations in near-fault area along with the difference in their soil conditions provide enough data to reliably analyze soil effects on directivity pulse, which could be very difficult to capture using analytical methods.

The large number of asperities with different slips and sizes generates multiple pulses in a wide range of period (0.8 to 8 sec), which is a good advantage to examine soil effects over the wide range of periods. The selected stations are categorized according to their soil properties using Iranian design code to four soil categories from very hard (soil type I) to loose (soil type IV). Then, the response spectra of selected accelerograms are calculated and averaged for each category. The amplification function is also computed by using response spectral ration of soil types II, IIII and IV to that of soil type I. The estimated amplification functions clearly show the amplitudes of pulse amplified over the period range of 0.8 to 8 with a peak value of 2.5. The amplification becomes larger as the soil gets loose. Furthermore, the soil type IV amplified the pulse in longer period range than those of types II and III. These outcomes provide a good evidence for directivity pulse amplification due to local soil properties. It also emphasize on its importance and role in design, especially for critical facilities and infrastructures.

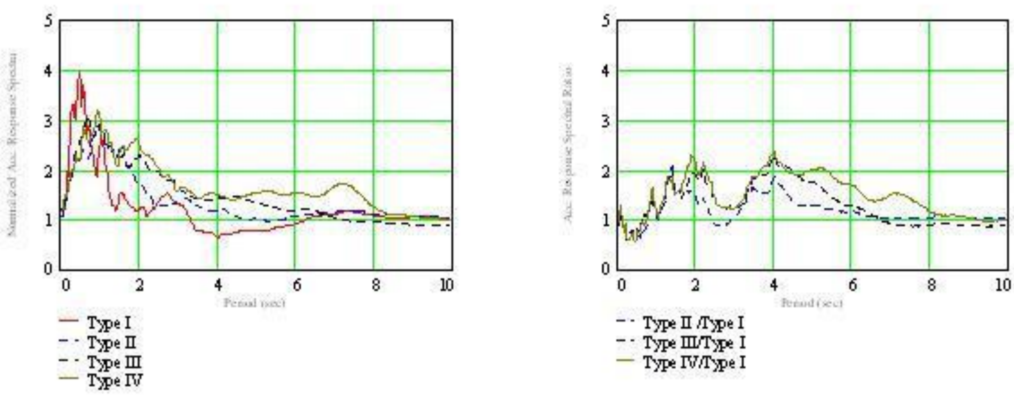

Figure 5. (a) mean acceleration response spectra for the soil catagories I, II, III and IV, and (b) amplification function calculated by using spectral ratios of soil types II, III and IV to that of type I.

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