

Polarization of Near-fault Long-period Ground Motion

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Abstract. Through the analysis of typical near-fault ground motion, the inhomogeneity of the spatial distribution of long-period ground motion intensity on the fault parallel component (FP) and normal component (FN) is revealed. The study shows that the intensity of long-period ground motion on the fault parallel component is higher than that of on the fault normal component. This may be due to the fact that the velocity pulse is more easily formed on the fault parallel component higher than that of on the fault normal component, and the velocity pulse is more intense. The study is of great significance to the establishment of the attenuation relationship of near-fault ground motion and the seismic fortification of near fault structures.

1. Introduction

The most obvious feature of near-fault ground motion is that it is easy to form velocity pulses. Near-fault ground motions can be broadly classified into two categories. One is directivity pulse, and the other is the pulse associated with permanent displacement. Generally speaking, forward directivity and permanent displacement in near-fault ground are the two main reason causing near-fault velocity pulses [1]. The forward directional pulse occurs in the direction perpendicular to the fault strike. The impulses associated with permanent displacement are in the form of step (fling step) and unilateral velocity pulses in the direction parallel to the strike of the fault (for the strike-slip fault), or in the direction perpendicular to the strike of the fault (for the dip-slip fault). In the latter case, the directional effect and the permanent displacement effect appear in the same direction. There is no pulse in the dip-slip movement parallel to the strike of faults.

The forward directivity pulse occurs in the process when rupture propagates forward, and the propagation velocity of the rupture is approximately equal to the shear wave velocity. In this case, most of the energy emitted during the rupture process almost reaches the site ahead, causing strong long period pulses in the time history of ground motion (usually in front of the time history). This represents almost all accumulation effects of seismic radiation from seismogenic structures. This phenomenon is more obvious if the slip direction of fault surface is also toward the site.

Permanent displacement rises from permanent deformation (fault movement) caused by tectonic movement during earthquakes. The velocity pulse occurs near the surface rupture, away from the source, and has nothing to do with the epicentre. Table 1 summarizes the formation conditions of different types of velocity pulses.



Table 1. Formation conditions of different types of velocity pulses

Type of fault	Directivity pulse	Permanent displacement
Strike slip fault	Perpendicular to strike of fault	Parallel to strike of fault
Dip-slip fault	Perpendicular to strike of fault	Perpendicular to strike of fault

Pulse-type ground motion has a strong contribution to the long-period response spectrum. Because of the complex genesis of pulse-type ground motion, the spatial distribution of pulse-type ground motion is not uniform. In Table 1, we can see that there is a higher probability of pulse-type ground motion in the direction perpendicular to the strike of faults. There are many researches on near-fault long period ground motion [2-5], but there is a lack of research on polarization phenomenon of near-fault long-period ground motion. Based on the above reasons, some typical near-fault strong ground motion records are selected to analyze the intensity variation characteristics of long-period ground motions perpendicular to the direction of fault strike and parallel to the direction of fault strike.

2. Selection of typical pulse-type ground motion records

Table 2 is the classification of mechanical properties of faults based on the size of the rake of fault. It is divided into strike-slip fault, normal fault, reverse fault, reverse-oblique fault and normal-oblique fault.

Table 2. Fault classification

Mechanical property	Rake
Strike-Slip	$-180^\circ < \text{Rake} < -150^\circ$ $-30^\circ < \text{Rake} < 30^\circ$ $150^\circ < \text{Rake} < 180^\circ$
Normal	$-120^\circ < \text{Rake} < -60^\circ$
Reverse	$60^\circ < \text{Rake} < 120^\circ$
Reverse-Oblique	$30^\circ < \text{Rake} < 60^\circ$ $120^\circ < \text{Rake} < 150^\circ$
Normal-Oblique	$-150^\circ < \text{Rake} < -120^\circ$ $-60^\circ < \text{Rake} < -30^\circ$

Table 3 lists eight strong earthquake records used in this work to study the difference (polarization phenomenon) of long-period ground motion characteristics that may be caused by the effects of forward directivity or permanent displacement in two directions of vertical fault direction and parallel to the strike of fault. Among them, San Fernando and Northridge earthquakes belong to reverse fault mechanism; Loma Prieta and CHI-CHI (records of two earthquake stations) earthquakes belong to reverse-oblique mechanism; Kocaeli, Kobe and Landers earthquakes belong to strike-slip mechanisms. These are near-fault strong motion records with magnitudes above 6.5. Their average fault distance is 2.86km. The fault distance mentioned here refers to the minimum distance between the seismic station and the fault.

Table 3. Seismological catalogue

Time	Earthquake	Station	Mw	Fault distance(km)	Seismogenic structures	Rake(Dip)
1971-02-09	San Fernando	Pacoima	6.61	1.81	Reverse	$83^\circ (7^\circ)$

1994-01-17	Northridge	RRS	6.69	6.50	Reverse	103°(13°)
1989-10-18	Loma Prieta	LGPC	6.93	3.88	Reverse-oblique	140°(50°)
1999-09-21	CHI-CHI	TCU068	7.6	3.01	Reverse-oblique	55°(35°)
1999-09-21	CHI-CHI	TCU075	7.6	3.38	Reverse-oblique	55°(35°)
1999-08-17	Kocaeli	Yarimca	7.4	2.6	Strike-slip	180°(0°)
1995-01-16	Kobe	KJMA	6.9	0.6	Strike-slip	180°(0°)
1992-06-28	Landers	Lucerne	7.3	1.1	Strike-slip	180°(0°)

In order to analyze the forward directivity effect and permanent displacement effect, we transfer the seismic components of two horizontal directions to the direction of vertical and parallel faults by proper rotation, thus obtaining the ground motion records of the two components. It can be seen from table 2 that the probability of a pulse in the direction perpendicular to the strike of the fault is higher than that in the direction parallel to the strike of fault. In the strike-slip mechanism, the directional effect and the permanent displacement effect can occur at the same time in the direction perpendicular to the strike of the fault. The combined effect of the two kinds of effects may further enhance the impulsive effect. The combined action of the two pulses may further enhance the pulse action. It can be seen from table 3 that any kind of mechanism can have both strike-slip and dip-slip components at the same time, and just because of the different rakes, the strength is large or small. From the analysis of the above two tables, it is easy to see that there is more probability of occurrence of velocity pulses in the direction perpendicular to the strike of faults, and the amplitude may be greater.

Let's first look at the long-period characteristics of the two sets of strong motion records of reverse mechanism. Figure 1 shows the strong motion records of the 1971 San Fernando earthquake. The rake of the earthquake is 83°, mainly showing the characteristics of Strike-Slip. From the time history of acceleration, we can see that the PGA of FN direction is greater than that of FP direction.

It can be seen from the velocity time history that although the FP component also has certain pulse characteristics, the FN component's pulse characteristics are more significant and the PGV is greater. The PGA and PGD of the FN component are respectively about twice as large as that of the FP component. Since the maximum reliability period of the record is only 2 seconds, we can only calculate the reliable absolute acceleration response spectrum, the relative velocity response spectrum and the relative displacement response spectrum of 5% damping ratio in 2 seconds. It can be seen from the diagram that the absolute acceleration response spectrum, the relative velocity response spectrum or the relative displacement response spectrum have the higher spectral values of the long-period response spectra of the FN component than those the FP component. In the absolute acceleration response spectrum, the spectral shape of the FN component is wider than that of FP.

Figure 2 shows the time history and response spectrum of the 1994 Northridge earthquake. The rake of the earthquake is 103°. So the mechanism shows a certain slip component (but smaller). There seems to be velocity pulse on both the FN and the FP components, but the pulse of the FN component is more significant. The PGV of FN component is more than two times higher than that of FP component. It is noteworthy that the fault distance (1.81km) of San Fernando is smaller than that (6.50km) of Northridge, but the peak speed is 45cm/s smaller than the other. We wonder if it is related to the different magnitudes, and it may also be related to the characteristics of different directivities. The maximum reliable period of Northridge record is 8 seconds, so we can only give 8 seconds of the response spectrum. It can be seen from the diagram that the spectral values of the absolute acceleration response spectrum, the relative velocity response spectrum, and the relative displacement response spectrum of the FN component are all larger than those of the FP components.

In summary, from the two ground strong records of reverse earthquake, the spectral values of the long-period ground motion of the FN component (with a significant velocity pulse) are obviously higher than that of the FP component, and this is especially evident in the relative velocity response spectra.

Next, three reverse-oblique strong motion records will be discussed. It is worth noting that in this mechanism, there is a stronger strike-slip component than in reverse mechanism. Therefore, permanent displacement may occur in the direction perpendicular to and parallel to the strike of faults, while the directivity appears only in the direction perpendicular to the direction of the strike of faults.

Figure 3 shows the time history and response spectrum of the 1989 Loma Prieta earthquake. The rake of the Loma earthquake is 140° . Therefore, there are large strike-slip components in the strong ground motion records of Loma earthquake. There is a high chance of significant pulse in the vertical direction of fault strike, but permanent displacement may also occur in the direction parallel to the strike of the fault. The velocity pulse of Loma earthquake is not as typical as that of San Fernando earthquake and Northridge earthquake. Velocity pulses occur on both FN and FP components, but the PGA of FN components is much higher than that of FP components. It can be seen that the spectral values of the absolute acceleration response spectrum, the relative velocity response spectrum and the relative displacement response spectrum of the FN component are obviously higher than those of the FP component in the long-period part.

Figure 4 shows the record of the 1999 CHI-CHI earthquake in TCU068 station. The rake of Chi-Chi earthquakes is 55° . Therefore, Chi-Chi earthquake has a large strike-slip component. There are obvious pulses in both the FN and the FP components. There are obvious pulses in the acceleration time history. A very typical velocity pulse appears in the speed history. In the time history of the displacement, the two components have a very typical permanent displacement. The absolute value of the PGA of the FN component is 15.3 cm/s^2 larger than that of the PGA of the FP component, and the corresponding difference the absolute values of PGV and PGD is 1.1 m/s and 1.52 m respectively. It can be seen from the response spectra that the spectral values of the long-period ground motion of the FN component are obviously higher than those of the FP component. In the time history of the 1999 Chi-Chi earthquake recorded in TCU075 station (Figure 5), a very significant velocity pulse appears in the FN component, and the PGV is larger. In the FP component, the velocity pulse is not very obvious and the PGV is small. In the displacement time history, the permanent displacement of the FN component is very significant, but the permanent displacement of the FP component is very small. The absolute value of the PGA of the FN component is 67 cm/s^2 , the absolute value of the PGV of the FN component is 79 cm/s larger than that of the FP component, and the absolute value of the PGD of the FN component is 1.1 m greater than that of the FP component. The absolute acceleration response spectrum, relative velocity response spectrum and relative displacement response spectrum of FN and FP of TCU075 are similar to those of TCU068. According to the records of TCU068 and TCU075, the near fault pulse-type ground motion of Chi-Chi earthquakes may be mainly permanent displacement effect, not the forward directivity effect.

Next, the records of three strike-slip type mechanisms will be analyzed. Figure 6 shows the time history and response spectra of the 1999 Kocaeli earthquake. The rake of the Kocaeli earthquake is 55° . There is no dip-slip component in the earthquake. But it is worth noticing that velocity pulses can appear in the direction perpendicular to the strike of the fault, and permanent displacement effect can occur in the direction parallel to the strike of faults. There seems to be the characteristics of pulse in the velocity history of FN and FP components, but the FN component is more obvious. The PGA of the FN component is 45 cm/s^2 larger than that of the FP component, but the difference between the PGVs of the two components is very small. Although the spectral values of the long-period ground motion in the FN component are higher than those in the FP component, the difference is not significant.

Figure 7 shows the time history and response spectrum of the Kobe earthquake. The rake of the Kobe earthquake is 180° . Both the FN component and the FP component show the characteristics of pulse, but the velocity pulse of the FN component is more obvious and the PGV is greater. From the characteristics of the response spectra, the long-period spectral values in the FN component are also much higher than that in the FP component.

Unlike all the above examples, the PGA of the FN component of the Landers earthquake is about 100 cm/s^2 lower than that of the FP component, but the PGV is 48.35 cm/s higher than that in the FP

component, and a significant velocity pulse appears in the velocity time history in the FN component (Figure 8). Although there is also obvious pulse in the FP component, the PGV is much smaller. From the response spectra, the spectral values in the FN component are much higher than those in the FP component. This may indicate that the size of the PGV of pulse (rather than the PGA) plays a more important role in the spectral size of the long-period response spectrum.

In the previous part, the influence of pulse-like ground motion of reverse type, strike-slip type and reverse-oblique type on the response spectrum of long-period ground motion is compared. It is found that pulse-like ground motion caused by the effects of directivity or permanent displacement have shown distinct differences in the direction perpendicular to the fault direction and the direction parallel to the fault direction. The peak ground motion in the FN component is generally higher than that in the FP component (except the Landers earthquake), and the spectral values of the long-period ground motion in the FN component are generally higher than those in the FP component.

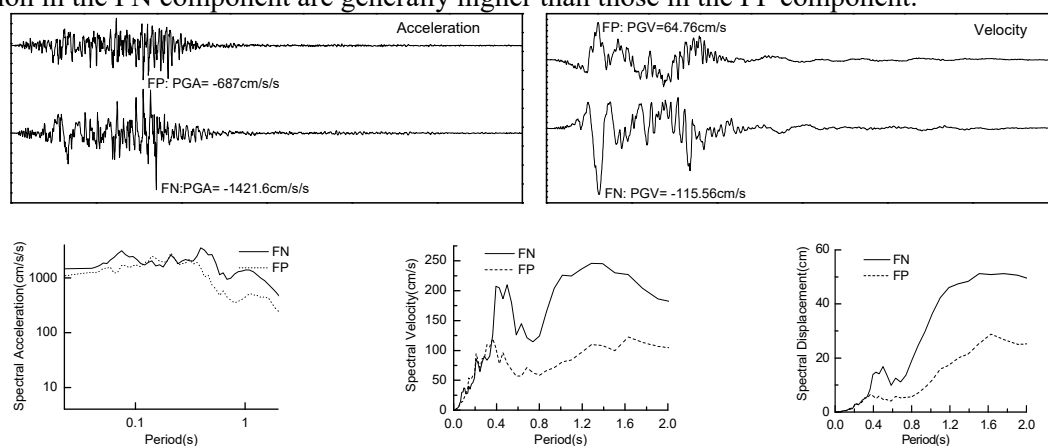


Figure 1. Ground motion time history and response spectrum of San Fernando earthquake.

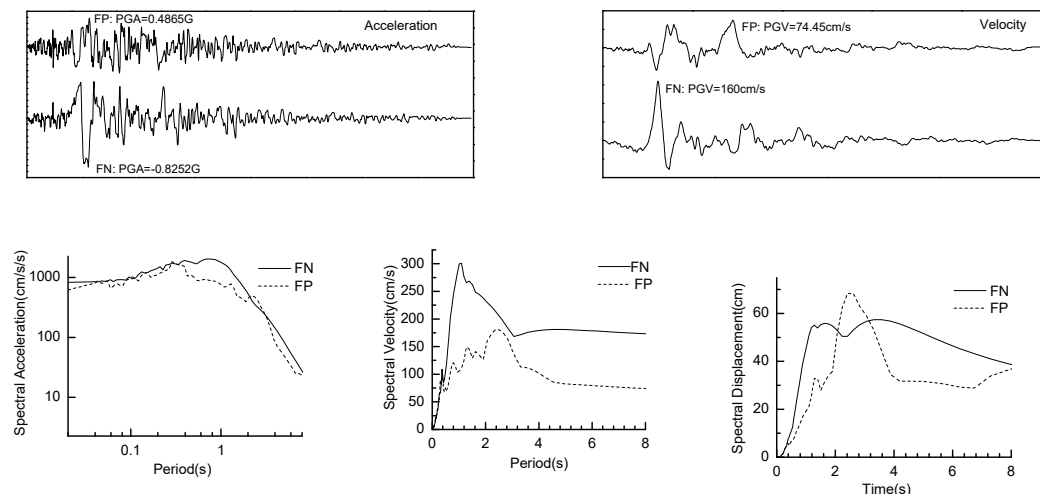


Figure 2. Time history and response spectrum of ground motion for Northridge earthquake.

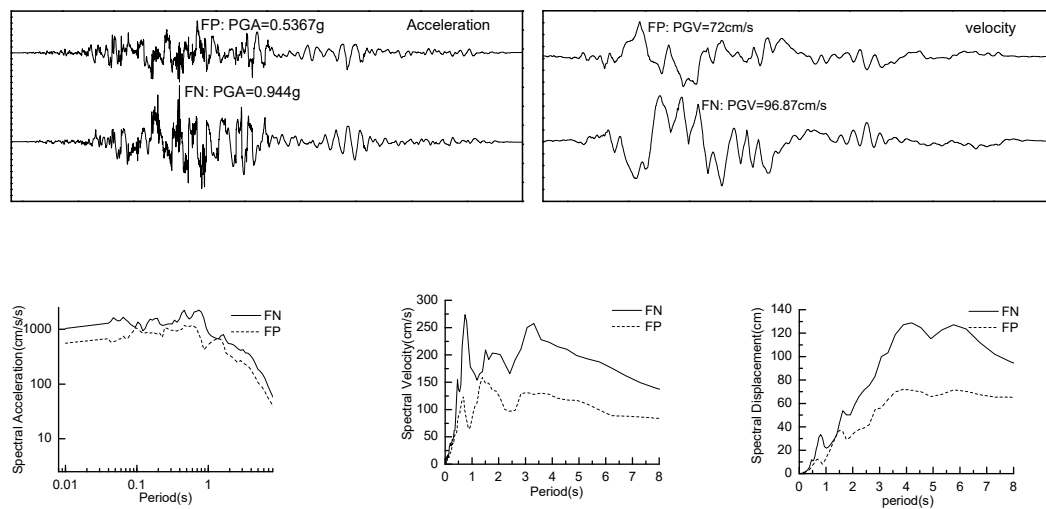


Figure 3. Time history and response spectrum of ground motion for Loma Prieta earthquake.

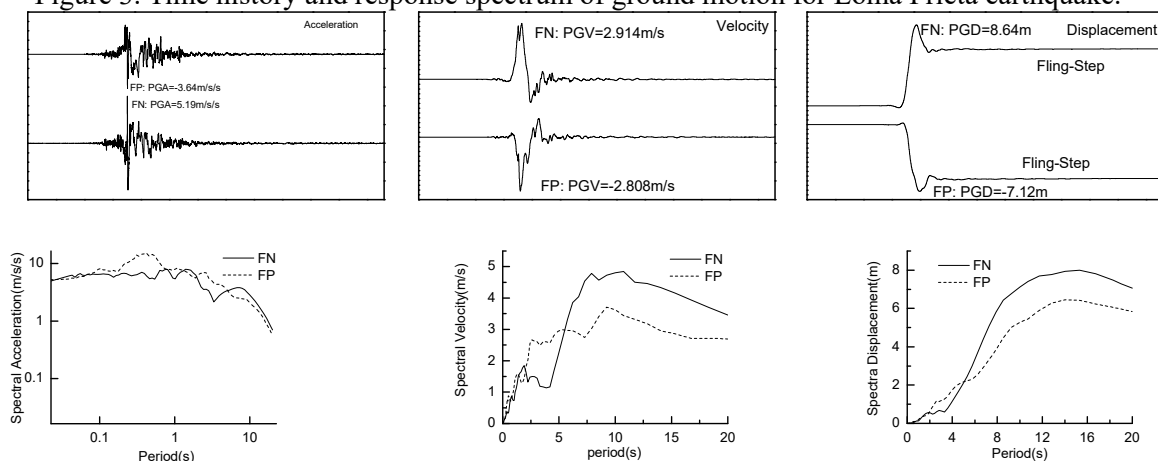


Figure 4. Time history and response spectrum of ground motion for Chi-Chi earthquake (TCU068).

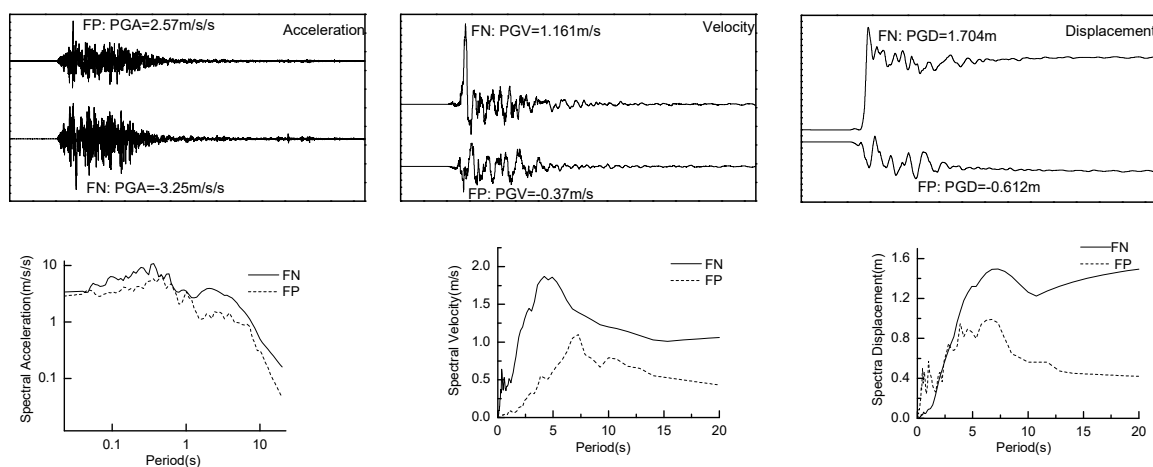


Figure 5. Time history and response spectrum of ground motion for Chi-Chi earthquake (TCU075).

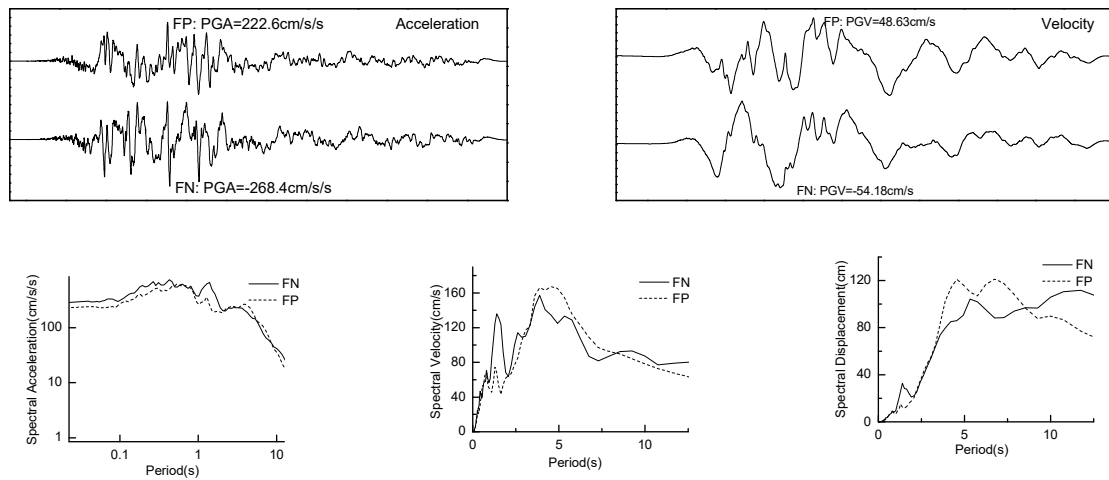


Figure 6. Time history and response spectrum of ground motion for Kocaeli (Izmit) earthquake.

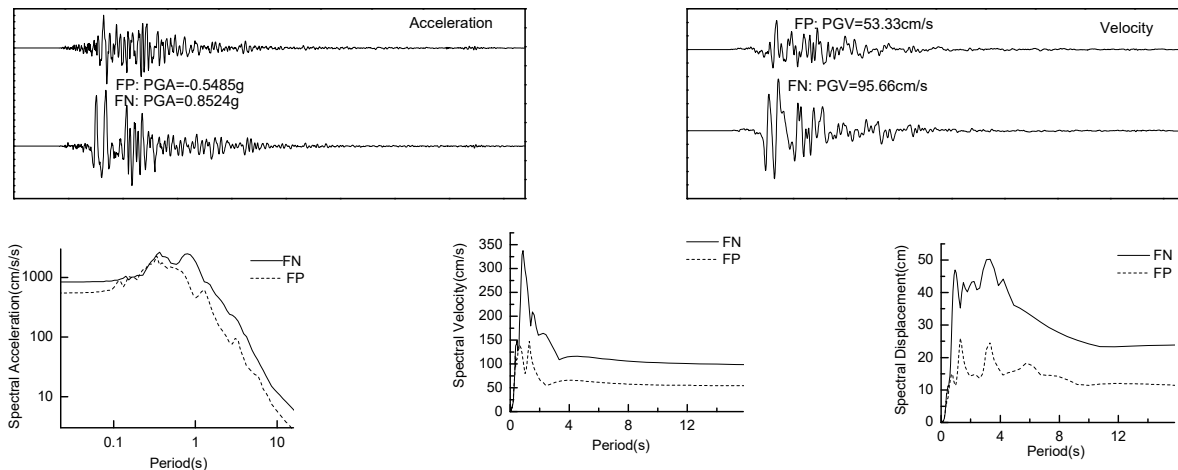


Figure 7. Time history and response spectrum of ground motion for Kobe earthquake.

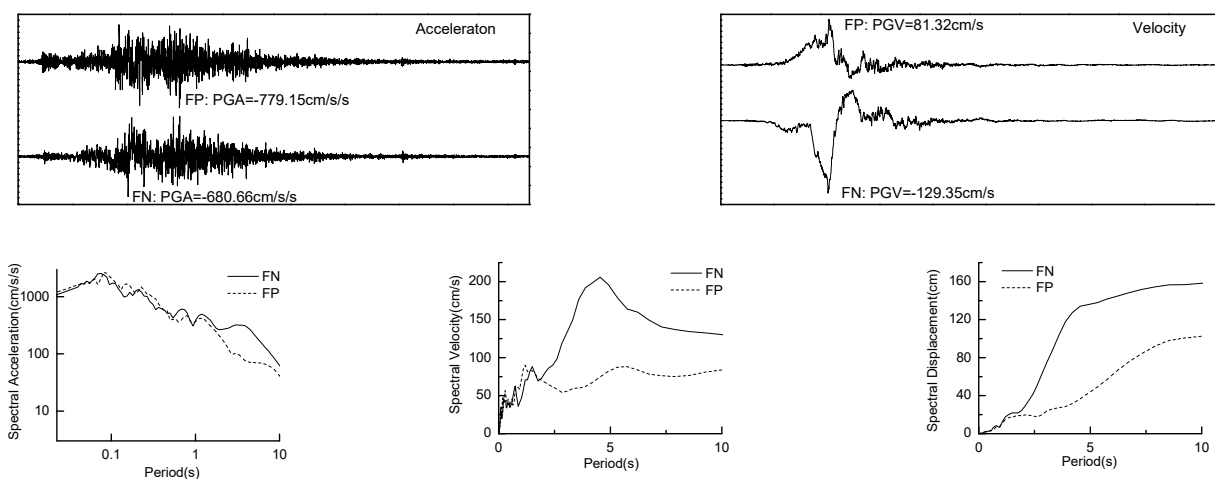


Figure 8. Time history and response spectrum of ground motion for Landers earthquake.

3. Conclusion

In the analysis of typical pulse-like ground motion, it is found that the pulse-like ground motions generated by directivity or the permanent displacement effect, whether they are about reverse type,

strike-slip type or reverse-oblique type mechanism, show obvious difference in the direction perpendicular to the fault strike and the direction parallel to the fault strike. The peak ground motion in the FN component is generally higher than that in the FP component (except the Landers earthquake), and the spectral values of the long-period ground motion in the FN component are generally higher than those in the FP component. Based on the above analysis, it is thought that the near-fault pulse-like ground motion has obvious polarization phenomenon.

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