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PRELIMINARY ANALYSIS ON BIZARRE WAVEFORMS IN STRONG MOTION RECORDS

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ABSTRACT

One of the key questions in strong motion record processing is to identify bizarre waveforms and make suitable adjustments. Some typical strong motion records with strange waveforms in earthquakes of China were collected and analyzed in this paper. Five kinds of abnormal acceleration waveforms were revealed, including regular noise, spike, asymmetric waveform, obvious baseline drift and strong motion records packets separation. Firstly, the generation mechanism was analyzed preliminarily. It's found that the mechanism of spikes was rather complicated and mechanism of the asymmetric waveforms was of diversity. Secondly, reasonable processing approaches were offered. Regular noise can be reduced or even eliminated by filtering methods; spikes can be identified by 'jerk' method, ratio method and the consistency of the corresponding time of three-component PGA; the Butterworth low-pass filter can be applied to correct asymmetric waveforms; two pieces of strong motion record packets can be connected by searching for continuous and repeated data; accumulation can be used to find the clear baseline drift. Finally, the effects on time history, Fourier amplitude spectrum and response spectrum were studied before and after correction of strong motion records, and result shows that the abnormal waveform directly affects the characteristics of time history and frequency spectrum.

Keywords: bizarre waveforms; spike; asymmetric waveform; splice; baseline drift

1. INTRODUCTION

Strong motion records are of great significance for earthquake disaster prevention and earthquake emergency in China, high-quality strong motion records can reflect the field or structure objectively, simple processing can be used to study seismic engineering and engineering earthquake. However, there are some abnormal data in a few strong motion records, which reduces the application confidence of the observed data. If they are not corrected, these records could hardly reveal the vibration information of the structure or field under the action of earthquakes correctly, which affects following scientific research conclusions such as instruments seismic intensity, emergency rescue, disaster evaluation and so on. Therefore, the quality of observation data is attracting much attention of researchers increasingly. The research on singular waveforms is a good breakthrough and its fundamental objective is to eliminate the false information therein, warns the researchers against the distorted waves in the strong ground motion input selection and provides reference for improvement of strong motion instrumentation, construction and maintenance of strong motion system. Besides, the research of singular waveforms is helpful to excavate the special phenomenon in seismic

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engineering and engineering earthquake. At present, the special geological structure, topography and field ground motion characteristics are still lack of further research, especially the large amplitude acceleration records have always been the focus of seismic engineering and engineering earthquake. Strong motion records can be used to evaluate the extremum of any extreme strong motion records, analyze the impact of factors, including tectonic and geological background, focal mechanism, the stiffness and stress drop on the rupture and asperity, and site conditions of high variability, as a result, the environment which most likely leads to great amplitude of strong motion records is given.

Generally speaking, regular noise, spike, asymmetric waveform, obvious baseline drift and strong motion records packets separation can be regarded as abnormal records. The generation of the singular waveform comes from the local terrain influence, the monitoring environment mutation, the collision between the instrument base pier and the vibration isolation trough, the strong motion instrument, etc.Some scholars at home and abroad have carried on related research. Boore & Bommer gives the "jerk" method for identifying spikes (Boore and Bommer,2005).The high frequency "spike" may be caused by brittle failure of the rock near the ground beneath the station (Bommer and Douglas,2004). Luis Fabia´n Bonilla thinks that "spike" may be directly related with pore pressure of soil, and has relatively close relation with tight sandstone sedimentary cycle flow (Bonilla et al.2005). Wen Kuo-Liang et al. (2001) conducted a study on the reasons for the abnormal waves of PGA (peak ground acceleration) over 1g in the east-west direction of acceleration record belonging to the station coded TCU129 in ‘9.21 Chi-Chi’ earthquake. Zhou et al. (2010) studied the abnormal record caused by the base pillar in Yibin Gaochang station in Wenchuan earthquake. The Science journal attributed the asymmetry waves to ‘trampoline effect’ (Shin Aoi et al. 2008). Research on regular noise, obvious baseline drift and records packets separation, however, there is less consideration.

Considering that the strong motion data is of great significance for the earthquake engineering, the research on the mechanism of abnormal records, therefore, appears particularly important. This study summarized five kinds of abnormal records as follows: regular noise, ‘spike’, ‘asymmetric waveforms’, strong motion record separation and obvious baseline translation. Moreover, the generation mechanism of abnormal records is analyzed. Finally, processing methods to correct abnormal records are proposed.

2. ON THE REGULAR NOISE

A piece of strong motion record coded by 0M1002130423035303 (Li Shanyou et al.2014) in the Lushan earthquake mobile station presents such a phenomenon as regular noise, however, the obvious regular noise disappears when the Butterworth causal filter is applied with the 4th order and band-pass filter for 0.01-25Hz.

As the chart shows, the peak ground acceleration decreases to the original peak of -34.1%, which shows that the regular noise locates in low frequency less than 0.01Hz. The acceleration time history, the absolute acceleration response spectrum, the relative velocity response spectrum, the relative displacement response spectrum and the Fourier amplitude spectrum before and after filtering are shown in Figure 1-5.

Although the overall trend of response spectrum and Fourier spectrum before and after filtering did not change, the absolute peak acceleration response spectrum is reduced by 29.9% and the peak relative velocity response spectrum is reduced by 33.3%, the peak displacement response spectrum increased by 1.4 times, the peak Fourier amplitude spectrum is reduced by 65.9%, and the predominant frequency is changed from 25.04Hz to 12.94Hz. Obviously, the regular noise has great influence on the time history, response spectrum and Fourier amplitude spectrum, so, we have to get rid of the regular noise to avoid the adverse effects of the related research. The most probable cause for the phenomenon is attributed to certain frequency power source near to the strong motion instrumentation during earthquakes.

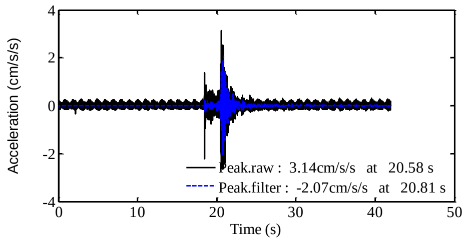


Figure 1. Acceleration time history

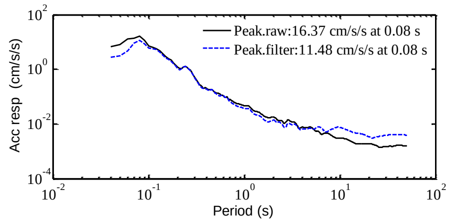


Figure 2. Absolute acceleration response spectrum

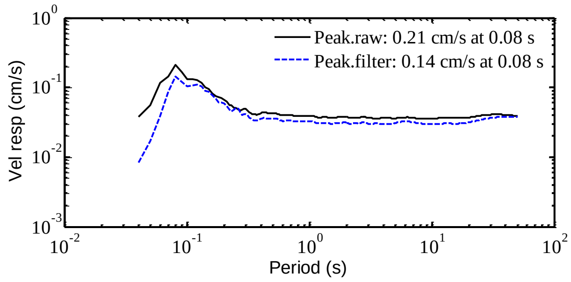


Figure 3. Relative velocity response spectrum

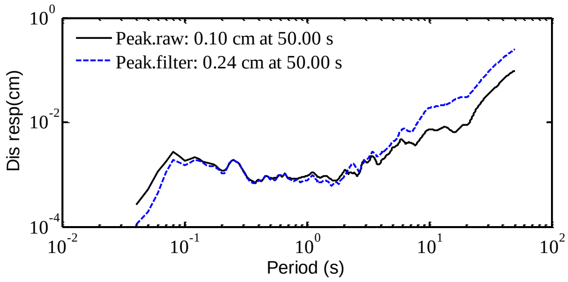


Figure 4. Relative displacement response spectrum

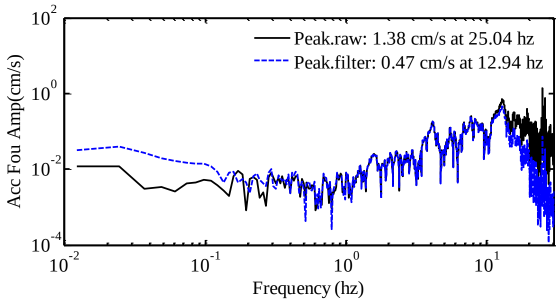


Figure 5. Fourier amplitude spectrum

3. ON THE 'SPIKE'

In recent several important earthquakes, there are some strong motion records puzzling researchers. As shown in Figure 6 (Li Xiaojun et al.2009), there is an extremely big PGA called high-frequency 'spike', which usually pops up in the acceleration time history and is an isolated data point incompatible with the neighboring data points.

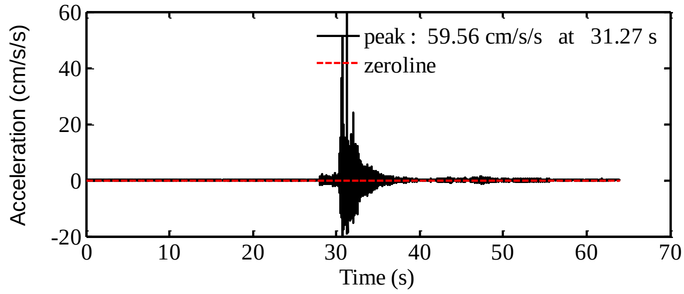


Figure 6. Acceleration time history
(080805003436L0009c.smc, M3.1, ratl= 3.6, ratr=21.1)

We think that obvious ‘spike’ is attributed to the unreasonable peak value in the acceleration time history. According to its English explanation, spike is something long and thin with a sharp point. If the record with spike is used in the seismic engineering and engineering earthquake research, the objectiveness of research findings will be endangered. As for the cause for ‘spike’, we think that strong motion instruments, the surrounding environment, unsuitable operation and the brittle failure of rock beneath the earth's surface closer to the station should be responsible for the ‘spike’. However, no enough evidence has been provided to prove its mechanism. Therefore, necessary experiment should be carried out to survey the cause for ‘spike’ so as to further study the unclear nature of ground motion or avoid another unreasonable strong motion record in the future earthquake. In general, the simple ‘spike’ can be detected visually at both ends of a piece of strong motion record easily. However, if the ‘spike’ is hidden in the peak of ground motion, effective measures should be taken to identify it. According to Boore & Bommer (Boore and Bommer, 2005), when a spike appears in the acceleration time history, a ‘jerk’ time history will produce bilateral pulse with the differential of acceleration. As shown in Figure 7, the acceleration time history named by 032XPX080512142802 proves the effectiveness of the method (Lu Shoude et al.2008). However, there are still some records with spike which can't be identified.

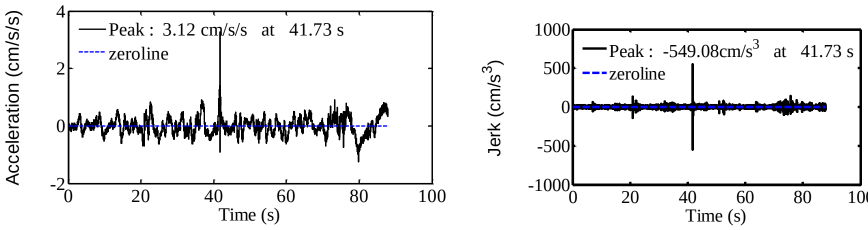


Figure 7. Acceleration time history and Jerk time history（032XPX080512142802）

As we know, when an earthquake occurs, reasonable strong motion record is in continuous and dynamic change, which will not become incompatible with the neighboring data. So, spike can be recognized by calculating the ratio of PGA to adjacent data.

Strong motion records from Taiwan ‘9.21 Chi-Chi’ earthquake are famous for high-quality data (Lee et al.1999). There are 1269 pieces of records selected to make statistical ratio of the PGA to adjacent sampling value. We find that the proportion of the ratio of more than 1.1 is less than 1% in horizontal components and less than 5% in the vertical component, which indicates that the ratio of more than 1.1 or less than 0 is a smaller probability event.

For Wenchuan aftershocks strong motion records from fixed stations, a total of 501pieces are selected to calculate the ratio of PGA to adjacent data including149 in E-W direction, 227 in N-S direction and 125 in UD direction(Li Xiaojun et al.2009).It can be found that the horizontal ratio greater than 2.0 are not more than 1%, the vertical ratio is no more than 8%, according to the relevant number shown in Table 1, it can be found that the ratio is almost greater than 0, as shown in Figure 8, the acceleration record named by 051LXM080517042903 is of obvious ‘spike’ and the ratio of PGA to the right data is -9.7, which generally does not happen, and the peak of ground motion appears at 20s.

Besides, the ‘spike’ in strong motion records can be identified according to the corresponding moment of PGA. As shown in Figure 9, for example, the corresponding time of PGA is 12.08s,13.70s and 13.66s respectively for three-component strong motion records from Rushan Ms4.3 earthquake in 2014. In the vertical direction, it is not reasonable for the time of PGA ahead of more than 1.5s compared with the horizontal component. Not only, but the ratio of PGA to adjacent data reaches 29.5. So, the PGA of UD direction can be deemed as ‘spike’.

Table 1. Case for Wenchuan aftershocks strong motion records with the ratio of greater than 2.0

Serial Number	Filename	PGA (cm/s/s)	Time (s)	LPGA (cm/s/s)	Left rate	RPGA (cm/s/s)	Right rate
1	051LXT080514122201	-39.19	23.36	-29.69	1.32	-19.14	2.05
2	062WIX080525162101	20.36	33.06	17.31	1.18	9.77	2.09
3	051LXT080515085002	-26.09	22.87	-24.72	1.06	-11.22	2.33
4	051LXM080513075403	-46.32	24.36	-9.89	4.68	-42.08	1.10
5	051LXM080514233303	25.63	20.71	25.25	1.02	12.39	2.07
6	051LXM080517042903	52.65	20.00	30.86	1.71	-5.43	-9.70

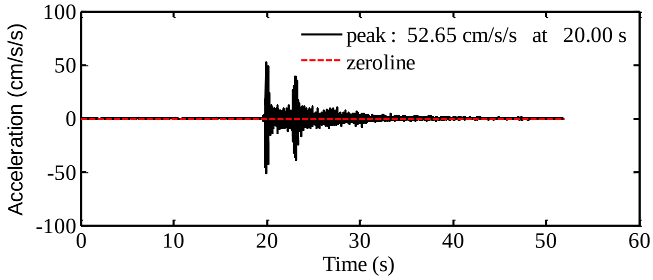
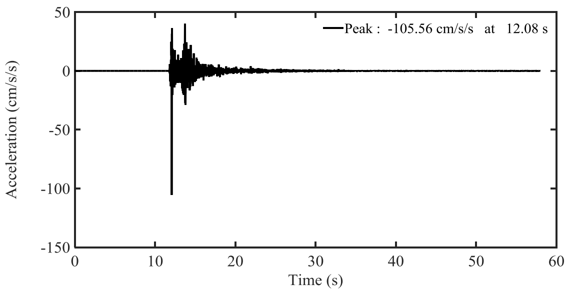
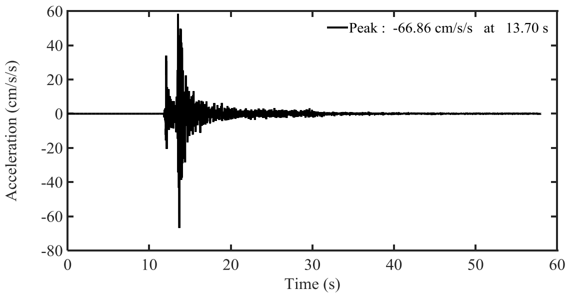


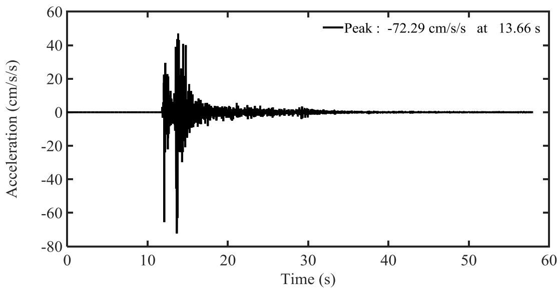
Figure 8. Acceleration time history (051LXM080517042903, ratl=1.7062 , ratr= -9.7)



(a) UD direction



(b) EW direction



(c) NS direction

Figure 9. Acceleration time history

3.1 Processing and analysis of 'spikes' in strong motion records

Currently, two approaches in dealing with such spurious 'spikes' are to either remove the 'spike' completely or reduce its amplitude to a certain level in coordination with adjacent data points, generally it is adjusted to the average of two adjacent data points (Simpson,1996). Take the strong motion record named by 032XPX08051214280 as an example, two methods are provided to adjust the 'spike', the solid line stands for the raw data, the dashed means that this point is set to zero, the dotted line belongs to the case of the average of the two adjacent data points (see Figure 11). Figure 10 shows that it is rich in the long-period components, little change has happened in the velocity and displacement waveforms, however, the maximum amplitude corresponding to the time history decreases accompanied with the reduction of ‘spike’, the position of PGV (peak ground velocity) stays unchanged at 88.000s, and the position of PGD (peak ground displacement) varies from 41.825s to 41.810s. Fourier amplitude spectrum changes greatly from 2s to 6s with the predomination period of 0.208s, however, the peak has changed little. Great changes have happened between 0.04s and 0.2s in absolute acceleration response spectrum, and the maximum amplitude is 4.060 cm/s^2, 4.129 cm/s^2 and 4.930 cm/s^2 respectively. It indicates that the ‘spike’ has little effect on the velocity, displacement and Fourier amplitude spectrum but for absolute acceleration response spectrum at periods of 0.04-0.2s. From the example illustrated, the adjustment of the PGA can be used to study the impact on relevant parameters, if there is little for the effect, it can be used safely, otherwise, necessary calculations should be carried out to reduce the degree of distortion of data. If it is difficult to identify the ‘spike’, what you should do is to choose other more reasonable data other than the abnormal record in order to ensure the quality of the data, which provides some reference for selecting strong motion records in earthquake engineering research.

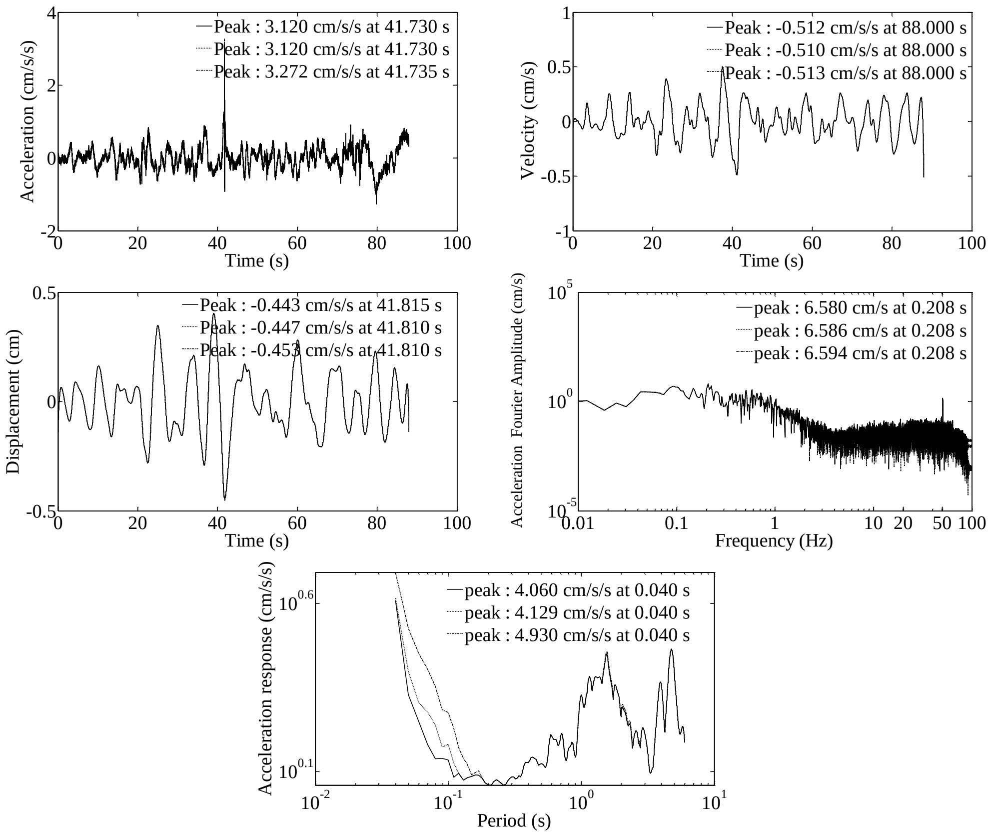


Figure 10. Spikes effect on the time history, the acceleration Fourier amplitude spectrum and the absolute acceleration response spectrum (032XPX080512142803)

4. ON ASYMMETRIC WAVEFORM

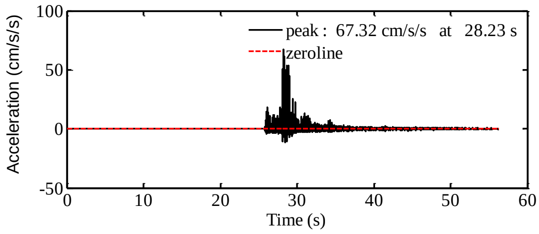
‘Asymmetric waveform’ is another abnormal waveform in strong motion records. This phenomenon occurred in the mobile strong motion station named by L2018 in aftershocks of ‘5.12’ Wenchuan earthquake (Li Xiaojun et al.2009), as shown in Figure 12, the waveform in the east-west component of the strong motion record become asymmetric.

In strong motion records from ‘5.12’ Wenchuan earthquake aftershocks, as shown in Figure 15, six acceleration time histories from the Lixian mobile strong motion station coded by L2008 are asymmetry in the waveform, the velocity and displacement time history is similar respectively despite of different magnitude and epicenter shown in Table 2, however, asymmetry waveform only appears in the direction of east-west other than north-south and the vertical direction shown in Figure 11, which indicates that the most likely thing is to be stuck in instrument failing to record the right strong motion waveform.

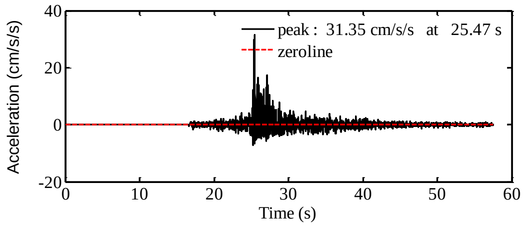
In summary, such asymmetric waveform mechanism is of diversity, which is consisted of instrument, instrument pier and trampoline effect. We think certain number of tests should be carried out to retrieve the abnormal waveforms in order to figure out the exact mechanism. If it is the instrument or the instrument pier that caused the asymmetric waveform, low-pass filtering can be applied to make correction for the asymmetry acceleration time history. However, if asymmetric waveform is produced by trampoline effect, we believe that it is reasonable to be applied to earthquake engineering research.

Table 2. Earthquake information corresponding to strong motion records

Record Number	Magnitude	Longitude (E°)	Latitude (N°)	Depth (km)	Epicentral distance (km)
080815010639L2018a	Ms4.2	103.50	30.98	16	59.6
080801163241L2018a	Ms6.0	104.85	32.02	14	172.8
080804174001L2018a	Ms3.3	103.36	31.37	13	20.1
080609152836L2018a	Ms4.5	103.93	31.31	13	74.3
080628022054L2018a	Ms4.2	103.45	31.43	13	27.5
080714001315L2018a	M_L4.0	103.37	31.41	19	20.1



(1) 080514211625L2018a.smc (M3.6)



(2) 080609152836L2018a.smc (M4.5)

Figure 11. Acceleration time history

5. ON THE OBVIOUS ACCELERATION BASELINE DRIFT

Generally speaking, it is not easy to find the obvious acceleration time history baseline drift, however, the record coded by 51QLY20130420O9370001.XMR shows clear baseline drift, which comes from the fixed station in '4.20' Lushan earthquake mainshock (Li Shanyou et al.2014). As shown in Figure 12, the PGA only reaches 7.72cm/s^2, but there appears significant baseline drift in the vicinity of 47.785s in raw acceleration records. The apparent baseline translational position can be determined by the accumulate of acceleration. The acceleration time history and response spectrum before and after correction are shown in figure 13-16. Before and after translation, the peak ground acceleration and the peak moment does not change, the peak of absolute acceleration response spectrum decreases from 25.82 cm/s^2 to 25.00 cm/s^2, the decline range is only 3.2% from 0.2s to 10s, spectrum value is on the decline after translation and reaches the largest decline amplitude in 10s.The peak of relative velocity response spectrum is reduced from 1.84cm/s to 0.59cm/s with a decline amplitude of 67.9% between 1s and 10s, and the peak corresponding period changes from 10s to 0.2s.The peak of relative displacement response spectrum decreased from 5.60 cm to 0.43cm with the rate of 92.3%, where the peak position has not changed. The spectrum value stays in the decline stage from 0.4s to10s after translation. Therefore, the effect of the translational motion on the time history and spectral characteristics of the ground motion is relatively large. Adverse effects will be brought to related research if no necessary correction is offered to such records. The reason for this phenomenon may be due to the offset of the sensor caused by the "tilt pendulum" or the tilt of the instrument pier during the earthquake.

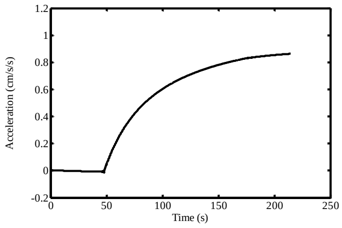


Figure 12. Identification for acceleration record baseline drift

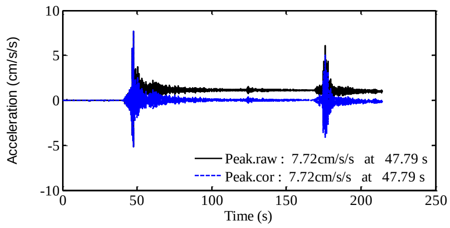


Figure 13. Acceleration time history

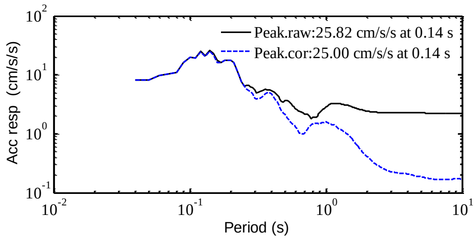


Figure 14. Absolute acceleration response spectrum

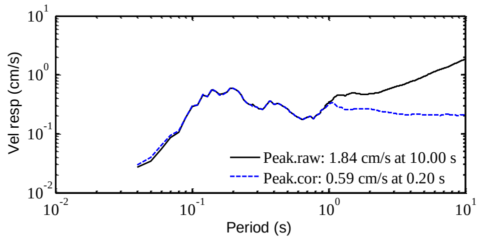


Figure 15. Relative velocity response spectrum

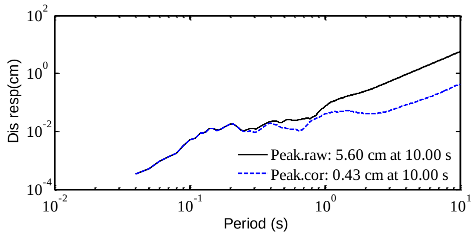


Figure 16. Relative displacement response spectrum

6. ON RECORD SEPARATION

There are some separated strong motion records with data in the Lushan earthquake mainshock ground motions (Li Shanyou et al.2014). It shows that a number of data points at the end of the first data packet are same as the initial part of the second packet data. Therefore, taking strong motion records in Figures 17-18 as an example, program codes are wrote to find two packets continuously repeated points(Zhou Baofeng et al.2014). When the tail and head data of data packet consecutive coincides, as shown in Figure 19, there are 2000 data points with the ratio of 1,then the two parts of record are connected together as Figure 20. As shown in Table 3, 9 pieces of Lushan earthquake strong motion records were spliced in the method successfully. We think that too short pre-event time is the cause for separated records phenomenon. Therefore, sufficient post-event time with 30 seconds should be provided so as to ensure the integrity of the strong motion records.

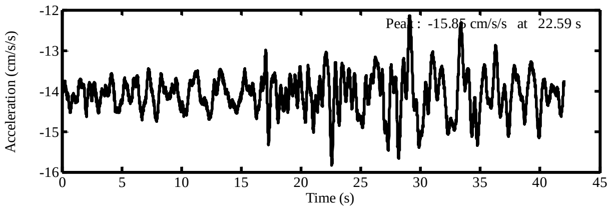


Figure 17. acceleration time history(1)

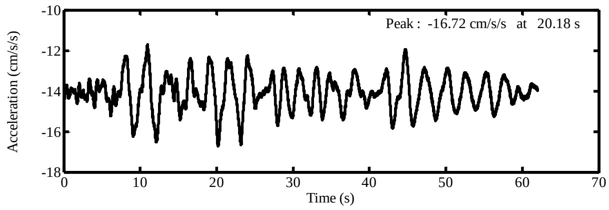


Figure 18. acceleration time history (2)

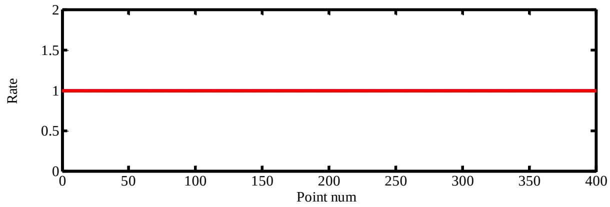


Figure 19. continuous coincidence points

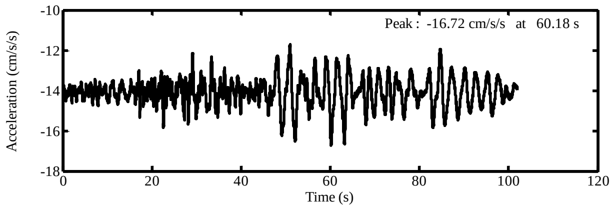


Figure 20. acceleration time history (after splice)

Table 3. cases for strong motion record splice(53KXRD20130420080249)

Serial number	record 1	record 2	Continuous coincidence points
1	53YSSZ20130420080249-1.001	53YSSZ20130420080249-2.001	3400
2	53YSSZ20130420080249-1.002	53YSSZ20130420080249-2.002	3400
3	53YSSZ20130420080249-1.003	53YSSZ20130420080249-2.003	3400
4	53KXRD20130420080249-1.001	53KXRD20130420080249-2.001	400
5	53KXRD20130420080249-1.002	53KXRD20130420080249-2.002	400
6	53KXRD20130420080249-1.003	53KXRD20130420080249-2.003	400
7	53KXEL20130420080249-1.001	53KXEL20130420080249-2.001	2000
8	53KXEL20130420080249-1.002	53KXEL20130420080249-2.002	2000
9	53KXEL20130420080249-1.003	53KXEL20130420080249-2.003	2000

7.DISCUSSION AND CONCLUSIONS

Such five kinds of abnormal strong motion records are offered as regular noise, spike, asymmetric waveform, obvious baseline drift and strong motion records packets separation, which offer us challenges on how to identify the false information and further study the ground motion characteristic. Filter can be applied to reduce or eliminate the regular noise. Methods for Jerk, ratio and the three-component PGA time consistency can be used to identify the spike comprehensively. Furthermore, the mechanism of spike was preliminary analyzed and necessary methods were presented to adjust strong motion records with spike. A comparative study was made before and after adjustment on time histories, Fourier amplitude spectrum and acceleration response spectrum. Some representative strong motion records with the feature of asymmetric waveform are analyzed and different mechanisms were summarized preliminarily. Separated strong motion records from Lushan earthquake were spliced by searching for continuous repeat points. Finally, the clear baseline drift can be removed by accumulation. In addition, the related mechanism on abnormal waveform has yet been studied based on the theory and experiment, and more objective approach will be given, which provides more reliable data to support earthquake engineering research.

8.ACKNOWLEDGEMENTS

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