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Related Study on Strong Motion Records Quality

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Abstract

Strong motion records provide us with the first-hand vibration information on the free field or engineering structure, which are valuable and significant for research on the earthquake disaster mitigation and earthquake emergency. Thus, strong motion records have to be ensured with high quality so as to reflect the free field or structure information objectively and can be used in earthquake engineering after general processing. However, due to some reasons, there may be some abnormal strong motion records, which reduces the application of the observed data. Therefore, it's necessary to classify strong motion records according to the quality and give some advice for records applications and measurements for improvement. In this paper, preliminary definition of related concepts on strong motion records are presented, including the quality of strong motion records and recording process. More than five kinds of abnormal strong motion records are summarized and analyzed on identification, processing and mechanism, including regular noise, spike, asymmetry, obvious acceleration baseline offset, incomplete accelerations, lower SNR etc. Meanwhile, some effective measures on how to avoid such bizarre waves are presented. In addition, the quality of strong motion records is divided into five levels according to baseline characteristics on acceleration, velocity, displacement time history and so on. At last, eight measures are put forward to improve the quality of strong motion records in order to ensure records integrity, consistency, accuracy and timeliness.

Keywords: strong motion observation, strong motion records quality, singular waveform, asymmetric waveform, spike

1. Introduction

China is a country suffering from serious earthquakes. In order to effectively reduce the earthquake disaster, we have taken measures such as earthquake disaster prevention, earthquake early warning and so on. Strong motion observation is the fundamental basis and the main means to understand the characteristics of ground motion and the seismic response of various engineering structures [1]. It directly provides the first-hand strong motion records for the research of seismic engineering and engineering earthquake, which requires the record to be true and reliable [2]. Strong motion records are of great significance to the study of earthquake disaster prevention, intensity quick report, earthquake alarm, earthquake early warning, etc [3-4]. High-quality strong motion records are the basis of data application and can reflect the site or structure objectively, which is convenient for eliminating the noise and reserving the truth. After simple processing, it can be used in the relevant research of seismic engineering and earthquake engineering, it can ensure the objective authenticity of the research results with reasonable research methods, prevent adverse impact on the relevant research, and even lead to the opposite conclusion. However, not all strong motion records are of high quality, and there are quality problems with some records. Therefore, before strong motion records processing, we need to study and determine the quality of the strong motion data, whether they are suitable for relevant research and need special processing or abandonment. All strong motion records are valuable and should not be discarded unless the quality is particularly poor. At present, the number of strong motion networks and early warning networks in China is increasing rapidly, and the number of strong motion records is considerable. If we neglect the supervision, evaluation and control of the quality of these data before further application, it is very likely to cause serious adverse impact or even catastrophic consequences on the relevant scientific research and engineering applications. So we need to evaluate and control the quality of strong motion records. The ultimate goal is to enhance the application value of data utilization, and ultimately win the scientific, economic and social benefits for scientific research.

In the history of strong motion observation, due to the lower density of strong motion network at home and abroad, it is a small probability event to obtain strong motion records, which is particularly precious, and the comparability of the records is not great, so it is difficult for researchers to question the quality of records. Since the increase of strong motion network density and the emergence of a large number of research achievements, the acquisition of strong motion records is no longer a small probability event. At present, the quality of strong motion records has been widely concerned by the majority of researchers, mainly reflected in the strong motion records with 'spike','asymmetric waveform', 'record separation', 'step type acceleration baseline drift' and other characteristics research of the singular waveform. Boore & Bommer gave a method named 'jerk' to identify 'spike' [5-6]. Zhou Baofeng selects strong motion records of typical earthquakes at home and abroad, and uses the ratio method based on energy and statistics to identify records with 'spike' [7]. In addition, a 'spike' can also be identified by filtering and comparing three-component PGA of the same station [8-9]. A 'spike' may be caused by the failure of accelerometers and recorders, the impact of collapsed objects, and the negligence of maintenance personnel. Large high frequency 'spike' may also be caused by brittle failure of rocks near the surface below the station [10]. Wen Guoliang et al. studied the station coded by TCU129 with the PGA of over 1G in 1999 'ChiChi' earthquake, and found that it was caused by concrete instrument pier [11]. In the 1992 Petrolia earthquake, the 'spike' of 1.8g appeared in the Cape records, while the PGA recorded nearby did not exceed 0.6g. The possible reasons include site effect, directional effect, large asperity and fault [12-15]. Anderson thought that the spike was caused by the nonlinear process near the station [16]. At present, the research on mechanism is still relatively deficient, lacking of necessary experimental means and systematic theoretical analysis.

At present, there is no clear definition of 'asymmetric waveform' in strong motion records. Zhou Zhenghua, etc. studied the phenomenon of 'asymmetric waveform' which is similar to the 'waterfall' recorded by the Yibin Gaochang during the "5.12" Wenchuan main shock. They believed that the local contact impact effect between the instrument base pier and the ground caused the generation of 'asymmetric waveform' [17-18]. In addition, this kind of asymmetrical waveform also appears in the aftershock records of Wenchuan earthquake [19]. AOI et al, A. Asaoka & Y.Sawada believed that trampoline effect caused the generation of 'asymmetric waveform' [20-21]. Yamada et al. attribute it to the properties of physical particle media, which is an asymmetric reaction to compression and tension reaction [22]. Tetsuo Tobita et al. found that the pressure stress was generated due to the disturbance of the ground material, which resulted in the acceleration of gravity and high forward pulse [23]. It is also pointed out that it may be caused by the instrument [5].

In the aftershock records of Lushan earthquake, the baseline of the original acceleration waveform of 51qly20130420o9370001.xmr shifted up near 50s. Similar phenomena were also found in the aftershock records of Wenchuan earthquake in 2008 [24]. This kind of waveform is easy to recognize. As for the separation of records, relevant research has also been carried out in the literature [8].

Considering that the strong motion data is of great significance for the earthquake engineering, the research on the quality of strong motion records, therefore, appears particularly important. This study gives us related conceptions and summarizes such abnormal records as 'spike', 'asymmetric waveform', 'record separation' and 'obvious baseline translation'. Moreover, the mechanism for the generation of abnormal records is analyzed based on the characteristics of time history. Finally, effective methods are proposed to improve the quality of strong motion records.

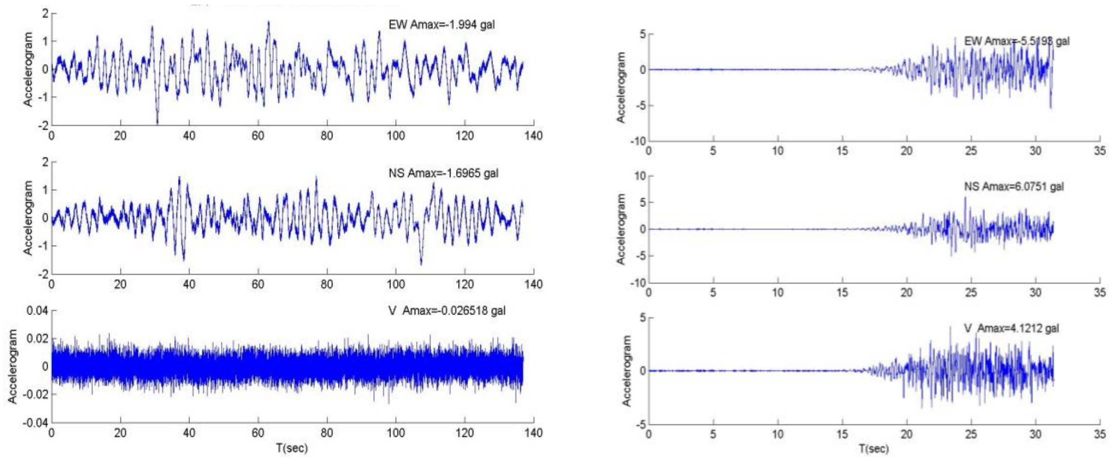
2. Related concepts on strong motion record quality

The concept of the quality of strong motion records can be understood from two aspects: the quality of the records itself and the quality of the use process [25]. The data quality of the record itself is reflected in: (1) whether the record can truly and objectively reflect the actual vibration behavior of the site or structure; (2) whether the record is complete, whether the sampling information is sufficient, and whether exists omission of any key information of the actual vibration of the site or structure; (3) the record is self-consistent, and the record does not exist isolately, and there are various constraint which describes the relationship of data. The records must satisfy the correlation among the records, but no contradict with each other; (4) the records are non-repeatable or unique, and no records with the same waveform can be found in all the strong motion records. The authenticity, completeness, self-consistency and uniqueness of records are the key properties of records, which are called the absolute quality of records and the basis of data quality assurance. The layout of strong motion network, the performance of strong motion instrument, the construction method of seismic station (array), the observation environment and the quality of operation and maintenance are the key factors to determine the absolute quality of records. In addition to the absolute quality of records, there are also the quality of records produced in the process of storage, transmission and utilization of strong motion records, which is called the quality of recording process. The storage quality of strong motion records refers to the use of appropriate programs and technologies to resist external factors, so that the data can be safely stored in the appropriate media and taken out in a timely and convenient manner without being damaged. The transmission quality of strong motion records refers to the efficiency and correctness of data transmission. In modern information society, strong motion records are transmitted among different places, so it is very important to ensure the high efficiency and correctness in the transmission process. For example, in the process of strong motion data transmission, the interference of the external environment may lead to data packet loss or data distortion. The quality of strong motion records utilization refers to the correct utilization of data. There are certain preconditions and applicable conditions for data utilization. If the correct data is used wrongly, it is difficult to draw the correct conclusion. This is particularly important for the selection of strong motion input. It is likely to draw the wrong conclusion if we select the strong motion record coming from wrong sites to make the dynamic analysis of the structure. In short, the quality of strong motion recording process is determined by the storage medium, network transmission speed and environment, and the correct use of records.

3. Quality problems on strong motion records

In general,the quality of strong motion record can be classified into five levels according to the characteristic of acceleration time history. The most ideal state is that the reasonable velocity and displacement time history can be obtained by integrating without filtering or baseline correction,which can be deemed as the first level. However, it is rare. These records should be regarded as the second level,which can be integrated to gain the ideal velocity and displacement only by filtering or baseline correction and applied in seismic engineering and engineering earthquake research. The third level belongs to records with singular waveform such as 'asymmetric waveform', 'obvious acceleration baseline shift'and 'spike', which can be applied after complicated adjustment. If the absolute time, latitude and longitude, or the polarity accuracy of the instrument is incorrect and challenges the application of records, these records can be listed as the fourth level. Incomplete records should be the worst quality strong motion data belonging to the fifth level and can't be used in seismic engineering and engineering earthquake research.

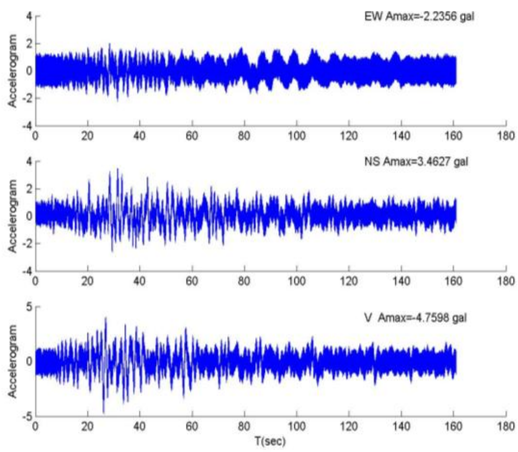
Generally, the low-quality strong motion records include incomplete records, records with lower signal-to-noise ratio, singular waveforms ('asymmetric waveform', 'obvious acceleration baseline shift'and 'spike', etc.). The incompleteness of strong motion records includes loss of head (see Fig. 1 - (a)), loss of tail (see Fig. 1 - (b)) or loss of three-channel records (see Fig. 1 - (a)). We think that the loss of head and tail of records is caused by too short time of pre-event and post-event, while the loss of three-channel records is caused by bad track of strong motion instrument. The lower signal-to-noise ratio is due to the station far away from the epicenter and excessive background noise, and the signal is submerged by noise.



(a) Records with missing head and vertical direction (b) Records with missing tails

Fig. 1 – Incomplete records

As shown in Fig. 2, in general, the research value of such records is of little significance for engineering application. There are obvious asymmetric phenomena in the north-south and vertical directions compared with the east-west direction record shown in Fig. 3 [26]. In order to correct the strong motion records with the asymmetry waveform, taking the vertical component of Yibin Gaochang strong motion records for an example, the Butterworth low-pass filtering with the second order is applied and Fig. 4 shows the time history after filtering with the corner frequency of 80Hz, 60Hz and 40Hz, respectively. Obviously, the waveform tends to become symmetry after filtering, meanwhile, the PGA reduces sharply from 120.41cm/s^2 to 35.43 cm/s^2. Therefore, we can't make sure such filtering is the best correction way for the asymmetry waveform. However, to some extent, filtering can be a correct way for the asymmetry acceleration time history [27].



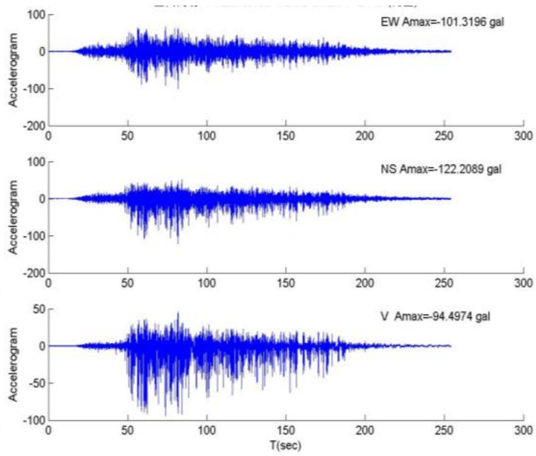
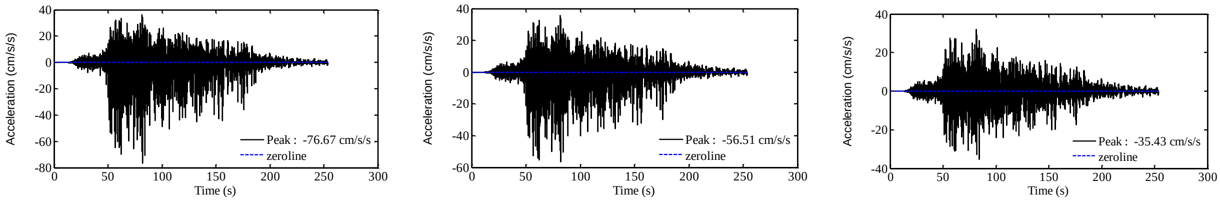


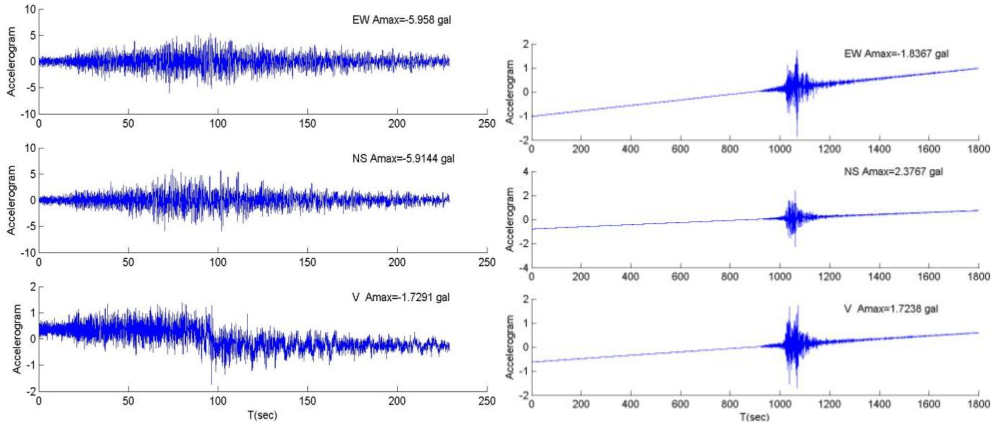
Fig. 2 – Records with lower SNR waveform Fig. 3 –Records with asymmetrical waveforms



(a) corner frequency = 80Hz (b) corner frequency = 60Hz (c) corner frequency = 40Hz

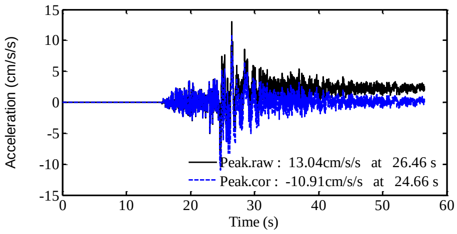
Fig. 4 –Acceleration time history (UD, after low-pass filtering)

In the "5.12" Wenchuan earthquake, although the vertical peak acceleration of Miyi Salian station is small, there is an obvious baseline drift shown in Fig. 5-(a). Remarkable rotation has taken place in all three-direction record of Liuan station shown in Fig. 5-(b) [26]. Under normal circumstances, it is difficult to find the acceleration baseline drift visually, however, there are some strong motion records with obvious baseline drift. As shown in Fig. 6, the strong motion record named 051GYQ080805174903 is triggered in "5.12" Wenchuan aftershock [24], PGA of this record only reaches 13.04cm/s^2, but there appears significant baseline shift in the vicinity of 25s in the original acceleration record. The apparent baseline translational position can be determined by the accumulate adding of acceleration and the obvious baseline translational drift begins at 24.575s. The acceleration time history and response spectra are shown in Fig. 6-9 before and after correction. It is not difficult to find that PGA shifts from 13.04cm/s^2 to -10.91cm/s^2, the position of PGA is ahead of 1.8s. And the maximum absolute acceleration response spectrum reduces from 29.81cm/s^2 to 28.09 cm/s^2, the decline is only 5.8%, however, the position of the maximum response stay unchanged. The relative velocity response spectrum increases from 4.34cm/s to 4.38 cm/s, the decline is less than 1%, and the position of the maximum response shifts from 1.3s to 1.21s.In contrast, the maximum response of displacement reduces from 10.94cm to 4.80 cm, the decline reaches 56.1% to a larger extent, however, the position of the maximum response stay fixed. Therefore, it will bring adverse effect on the time history and response spectra if such strong motion records are uncorrected. The reason for this phenomenon may be due to the stuck sensor or sensor zero offset caused by tilt of the instrument pier during an earthquake [27].



(a) Records for Miyi Salian station (b) Records for Anhui Liuan station

Fig. 5 –Records with serious baseline drift



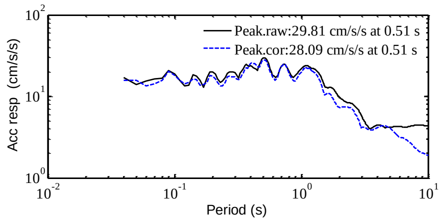
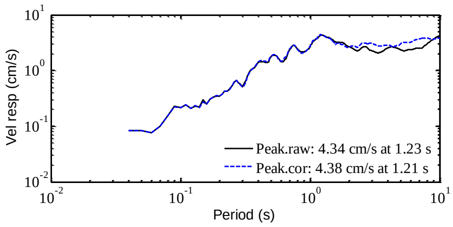


Fig. 6 – Acceleration time history Fig. 7 – Absolute acceleration response spectrum



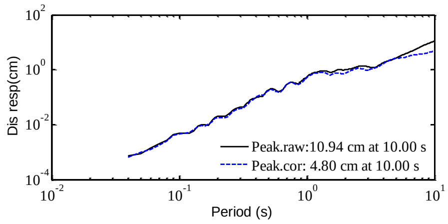
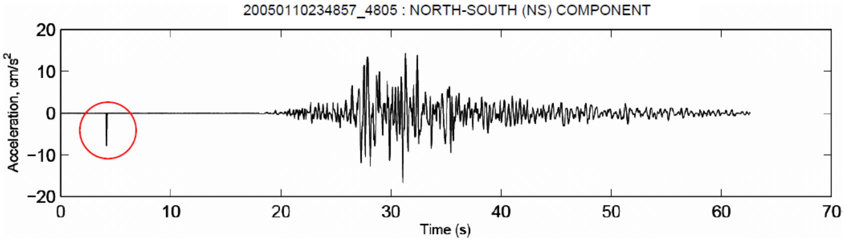


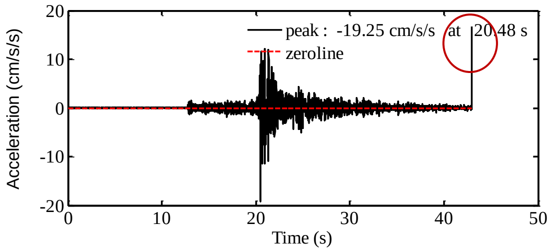
Fig. 8 – Relative velocity response spectrum Fig. 9 – Relative displacement response spectrum

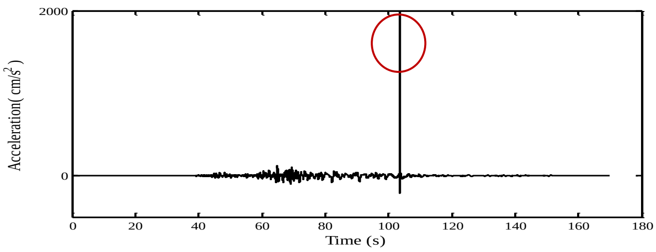
As shown in Fig. 10, there is a 'spike' in the head, tail or middle of strong motion records. Its position is changeable, and it may appear before, after or in the process of strong motion. Even the peak ground acceleration (PGA) can be a 'spike', and the effect on the response spectrum can't be ignored. The 'spike' can be identified according to the time where the three-component PGA occurs. As shown in Figure 10, taking the three-component records from Rushan Ms4.3 earthquake in 2014 as an example, the time for PGA is 12.08s,13.70s and 13.66s in UD, EW, NS direction, respectively, the time for PGA of the vertical component is ahead of more than 1.5s compared with the horizontal component. Furthermore, PGA is 29.5 times of the former sampling point value and 2.19 times of the next sampling point value [27]. Therefore, the PGA can be considered as 'spike' in the UD direction. In addition, the 'spike' can be identified according to the overall strong ground motion characterization in an earthquake [28].

Finally, the quality problems of the records are also reflected in the absolute time, latitude and longitude, and the polarity accuracy of the instrument.



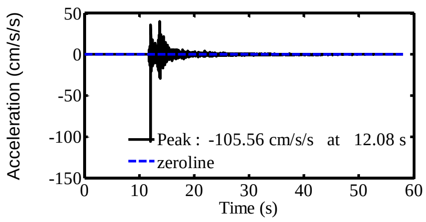
(a) A 'spike' at the beginning of the record

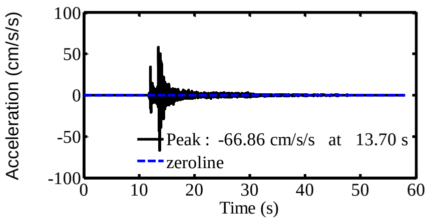


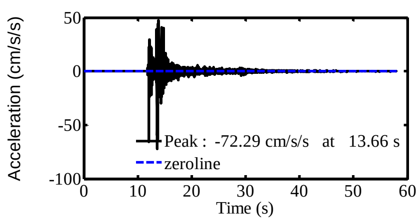


(b) A 'spike' at the end of the record (c) A 'spike' in the middle of the record

Fig. 10 – Records with the 'spike'







(a) UD direction (b) EW direction (c) NS direction

Fig. 11 – Acceleration time history

4. Measures to improve the quality of strong motion records

In order to obtain high-quality strong motion records, effective measures should be taken. A series of management activities, such as identification, measurement, monitoring and early warning, should be carried out from various data quality problems that may be caused in each stage, such as network layout, strong motion instrument research and development, nature environment,network operation and maintenance. Therefore, we need to take the following measures:

(1) The strong motion network layout should be reasonable and efficient in strict accordance with the construction specifications of strong motion stations. According to the trend of earthquake activity, population density and the possible casualties caused by future earthquakes, the status of regional economic development and the possible economic losses in the future earthquakes, the typicality and importance of the site, the strong motion network can be designed and built.In addition,the site selection of stations also needs to take into account such factors as traffic, background noise, communication, power supply, safety, etc. As shown in Fig. 3, the asymmetrical wave phenomenon may be caused by 'trampoline effect' or 'jamming' of accelerometer. It is recommended to check whether the instrument pier of the station with asymmetrical wave phenomenon meets the requirements of construction, and take back the accelerometer for testing on the low-frequency vibration platform.

(2) The stability and technical level of the strong motion instrument should be improved, following the strong motion instrument standard production instrument strictly so as to ensure high precision, durable, easy to operate. As shown in Fig. 2, there is a 'spike' in the head of the record, which may be caused by the connection error of the cache content before the recording event of the strong motion instrument or the incomplete clearing of the cache belonging to the software problem of the instrument.In addition,the burr noise may be caused by the sudden change of the internal power supply of the instrument due to the ripple of the external power supply. It is recommended that the manufacturer should improve the software and power supply unit of the strong motion instrument performance so as to avoid the fault of the system resulting from the instability of the external power supply voltage and avoid the decrease of the sensitivity of the instrument due to the aging of the instrument itself.

(3) The operation and maintenance management of strong motion network should be strengthen. Strengthen the technical training of observation personnel, refine the operation and maintenance process of the network, continuously improve the quality of automatic management and on-site inspection, and enhance the timeliness of the operation of the network. For example, the GPS clock often fails, the recorder and accelerometer fault, and the same strong motion instrument record is missing. It is recommended that the observer analyze the cause of the failure, conduct on-site inspection in time if it is necessary to solve the problem, take back the failed instrument for inspection or submit it to the manufacturer for troubleshooting.

(4) We should reduce the impact of the natural environment.Although natural conditions are often uncontrollable, necessary measures should be taken to reduce or even avoid such effects. Common interference factors include: temperature, air pressure, humidity, rainfall, wind, lightning, groundwater level and external electromagnetic field. The impact may not be as sensitive as that of seismic monitoring, but it still exsits some impact. For example, the station in the mine area may be able to avoid the risk of being hit by lightning for the induction lightning, but there is no way to escape from direct lightning strike. It is recommended to enhance the anti-interference ability of the strong motion instrument and take effective instrument grounding measures. In the desert area with large air volume, the station can only be built in the underground rock mass. In winter, especially in the place where the temperature is relatively lower, the indoor temperature must be kept within the acceptable range of instruments, otherwise instruments are difficult to work normally. In particular, metal plates inside instruments are very sensitive to the temperature and humidity of the surrounding environment, and the range of zero drift is likely to exceed the specified range.

(5) The impact of human interference should be reduced.Strong motion observation is different from seismic monitoring.Its purpose is to study the influence of ground motion on the site or civil engineering.Considering the convenience of transportation,therefore, the site is often selected in places like schools, governments, factories, mines and hydropower stations, which are relatively unchanging for a long time, and will also be subject to a certain degree of external interference. Such as human interference, vibration interference of vehicle machinery. Therefore, it is necessary to reduce human interference.

(6) The basic information of strong motion stations has to be improved continuously, such as the survey of surrounding terrain information, site classification, longitude and latitude, etc. Methods of strong motion data

processing should be improved continuously, which suppress or even eliminate the information irrelevant to the research, highlight the signal, and improve SNR.

(7) The quality of strong motion records should be evaluated scientifically. For example, the reliability and accuracy of data can be quantitatively described according to the error theory.

(8) In the application of strong motion records for scientific research and engineering applications, the scope of application of the records should be considered and should not be used blindly.

5. Conclusion and Prospect

China attaches great importance to the development of earthquake prevention and mitigation. In recent years, a large amount of funds have been invested in the construction of strong motion observation network. Its fundamental purpose is to obtain a large number of significant strong motion records and meet the purpose of earthquake prevention and mitigation in China. This paper expounds the significance of strong motion records. In order to improve the application rate of records and carry out further seismic engineering and engineering earthquake research, the quality of strong motion records must be guaranteed. First of all, the paper gives a preliminary definition of the relevant concepts of the quality of strong motion records; then, it summarizes and analyzes the incomplete waveform, the phenomenon of low signal-to-noise ratio, and the singular waveform (asymmetry, obvious baseline deviation of acceleration time history and spike, etc.) in the strong motion records; finally, in order to ensure the integrity, consistency, accuracy and timeliness of the strong motion records, eight measures and suggestions for recording quality was proposed to improve the quality of the strong motion records. It should be said that this work has a long way to go, but it is of great significance, especially for the mechanism research of various singular waveforms, which is a key point. It will provide an important reference for the construction, operation and maintenance of China's strong motion network and the generation of high-quality strong motion records.

6. Acknowledgements

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7. Copyrights

8. References

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