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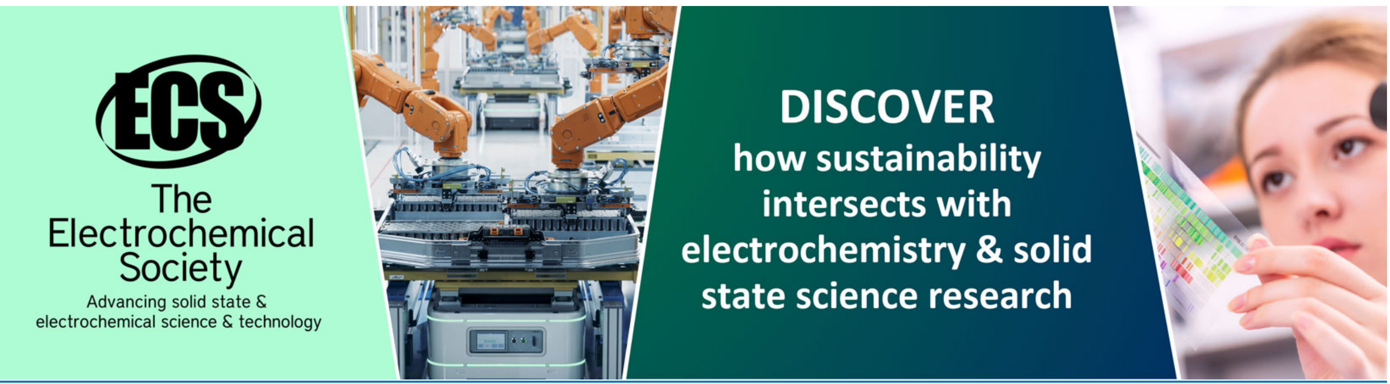

Research overview to the quality evaluation of strong-motion observation data

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Abstract. The quality of strong-motion observation data can directly influence the reliability of earthquake disaster prevention, seismic intensity rapid reporting, earthquake early warning and other results, so it's of great significance to analyse and evaluate the quality of observation data. In this paper, a detailed survey is made considering the status of domestic and overseas studies on the quality of strong-motion observation data, followed by elaborations about the method and deficiencies in the quality evaluation of strong-motion data; Meanwhile, the main factors influencing the quality of strong-motion observation data are also illustrated, and indexes of quality evaluation are summarized by combining with characteristics and application objectives of strong earthquake observation data; Furthermore, this paper also provides discussions about the development trend of data quality evaluation based on the actual strong-motion observation conditions in China, and puts forward some suggestions.

1. Introduction

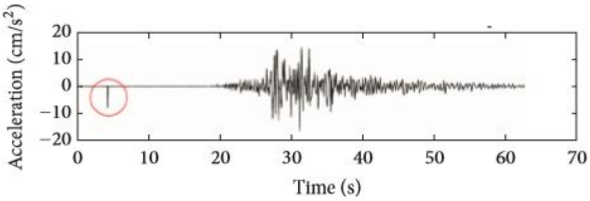
Strong-motion observation is the main approach adopted to understand the characteristics of earthquake motion and earthquake response in various engineering structures. The accumulated near-field strong-motion data are of great significance to affirm the attenuation rules of earthquake motion, study the soil reaction of fields, analyze anti-seismic properties of structures, and carry out seismic hazard analysis and seismic zoning, providing the scientific basis for the anti-seismic design of architectural structures [1-2]. The application of strong-motion observation has also been extended to the quick report of earthquake intensity, earthquake early warning, fast evaluation of earthquake damage, earthquake emergency response and intelligent control, safety diagnosis of structures, etc. Strong-motion observation has been developed into the major basis for disaster prevention, reduction and relief in our country.

Strong-motion records are the results directly observed via strong-motion observation networks, and also the basic data for various outputs afterwards. The authenticity and reliability of strong-motion records are significant to the earthquake defense, seismic intensity rapid reporting, and earthquake early warning, etc [3]. The quality of strong-motion records is the basis to ensure data application, so if the supervision, evaluation and control of data quality is neglected before promotion and use, unfavorable impacts may be incurred to relevant scientific studies and engineering applications, and even cause catastrophic effects. Therefore, quality evaluation and control should be implemented on strong-motion records, to improve the use value of observation records based on reliable data, and finally gain benefits in scientific, economic and social aspects.

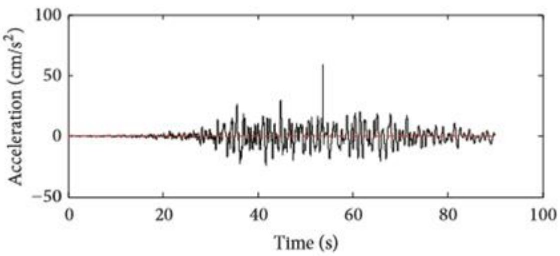
Strong-motion networks and seismic early warning networks have increased fast, providing a considerable quantity of strong-motion observation data. As the National Quick Report of Intensity and Seismic Early Warning Project is completed, all the observation data at reference stations, base stations and general stations can have strong-motion accelerogram components. According to statistics, the quantity of the strong-motion stations can reach up to above 16,000 in total in the future, marking an era of big data for strong-motion observation and studies. With such massive observation data, a new request is made for the data quality management, putting the quality problems of data on the top priority [4-6]. Strong-motion observation data are not only getting increasingly massive in quantity, but also stronger in timeliness, with various varieties, and different data application objectives, so the key point of data quality control is to design efficient and general methods for data quality evaluation. However, our country is still relatively backward in studies related to the quality management of strong-motion observation data, and is still in the initial phase to study the quality control and evaluation of strong-motion data, failing to provide effective assurance for the quality of strong-motion observation data. So problems to be urgently solved for the moment include how to study data quality of strong-motion observation system comprehensively, implement fast and effective quality evaluation of strong-motion observation data, and utilize strong-motion big data in a reasonable and effective way.

2. Review on the current status of domestic and overseas studies

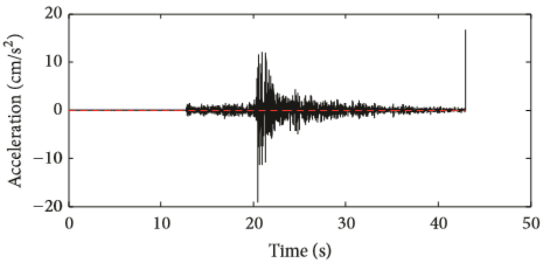
Throughout the history of strong-motion observation, it's a small probability event to obtain strong-motion records due to the excessively low density of domestic and overseas strong-motion networks, so such data are rare, with small comparability of data, posing difficulties for researchers to question the record quality. As the density of strong-motion networks increases and research results spring up in quantities, it's easier to obtain strong-motion records, and promote the comparison of various records. The quality evaluation of strong-motion data is more inclined to experience and qualitative analysis. The quality problems of strong-motion data extensively concerned by previous researchers are mainly reflected in studies on singular waveforms with "spikes" (as shown in Figure 1), "asymmetric waveform" (as shown in Figure 2), "step-type acceleration baseline shift" (as shown in Figure 3), "record separation" and other characteristics in strong-motion records. Boore & Bommer (2005) provided "jerk" method to recognize "spikes". Zhou Baofeng (2012) selected the strong-motion records of domestic and overseas typical earthquakes, to recognize a batch of records with spike phenomenon by adopting the ratio method based on energy and statistical significance. "Spikes" can also be recognized by adopting the correlation method of filter and three-component PGA at the same station (Zhou Baofeng et al., 2014). Due to big differences in earthquakes, current studies mainly focus on the conditions of PGA as "spikes", and few studies can be seen on other regular "spikes" and "spikes" at different positions [7-10]. Wen Guoliang et al. (2001) studied the reasons causing the phenomenon of over 1g at TCU129 station during "ChiChi" Earthquake in 1999, holding that it was caused by the foundation pier of the concrete instrument. 1.8g "spikes" were observed in Cape records in Petrolia Earthquake in 1992, but PGA was lower than 0.6g in all nearby records, so the possible reasons include site effect, directivity effect, huge concave and convex objects or faults (Oppenheimer et al., 1993; Ammon, 1993; Oglesby et al., 1997; Hanks, 2006). Anderson (2010) held that, "spikes" were generated in the non-linear process nearby the earthquake station. There hasn't been any clear definition about the "asymmetric waveform" shown in the strong-motion records. Zhou Zhenghua (2010), Wang Yushi (2010), Lu Dawei (2015) et al. studied the "waterfall-liked" asymmetric waveform phenomenon shown in the main earthquake area, Gaochang, Yibin during "5·12" Wenchuan Earthquake, holding that it was generated by the local contact and collision effect between the foundation pier of the instrument and the ground. Meanwhile, such asymmetric waveform was also observed in the aftershock records of Wenchuan Earthquake (Zhou Baofeng, 2012), and many other overseas records (Yamada, 2009). There are currently few methods to recognize such waveforms at home and abroad. Aoi et al. (2008), Asaoka & Sawada (2012) held that, the asymmetric waveform was caused by trampoline effect. Yamada et al. (2009) summarized it as the characteristic of the physical particle medium, and the asymmetric reaction of compression and tension reaction. According to findings of Tetsuo Tobita et al. (2010), the disturbance of ground materials generates crushing stress, and further generates gravitational acceleration and high forward pulse. Zhou Baofeng (2012) held that, such asymmetric waveform may be caused by faults of the strong-motion seismograph [11-17]. As can be seen in one of the aftershock records of Lushan Earthquake, the original acceleration waveform had its baseline shift upwards around 50s. Similar phenomena were also observed in the aftershock records of Wenchuan Earthquake in 2008. Such waveforms were easier to recognize (Li Xiaojun et al., 2009). Zhou Baofeng et al. (2014) also did relevant studies on the separation of records [18-20].



(a)



(b)



(c)

(a) "Spikes" are seen at the head of accelerograms; (b) "Spikes" are seen in the middle of accelerograms; (c) "Spikes" are seen at the end of accelerograms

Figure 1. "Spikes" Phenomenon (Baofeng Zhou, 2015).

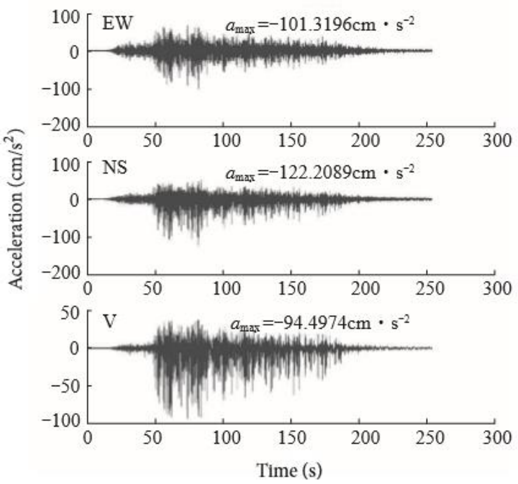


Figure 2. Asymmetric Waveform (Baofeng Zhou, 2015).

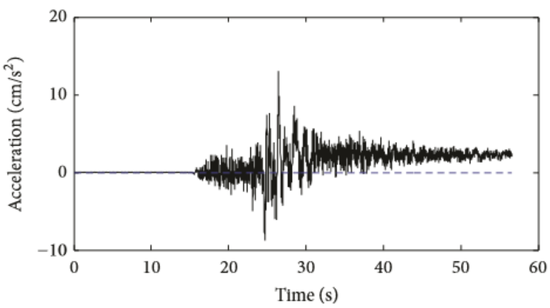


Figure 3. Baseline Shift Phenomenon (Baofeng Zhou, 2015).

The quality of observation data has been controlled and studied in the deployment and construction of partial domestic and overseas strong-motion observation system. It has been recognized that the quality control of observation data is essential to the construction of the strong-motion observation system, but we are still in the initial phase to study the quality of strong-motion observation data as a whole [20-22]. Former evaluations on the quality of strong-motion data are inclined to qualitative analysis. There are few studies on the generation mechanism and recognition methods of strong-motion singular wave, and insufficiencies can be found in necessary test approaches, systematic theoretical analysis and quantitative quality evaluation indexes and standards. The method to test data quality is relatively simple, and most tests are merely restricted to the continuous rate, record suspending rate and other single quality dimensions, and indexes to evaluate data quality haven't been fully refined yet. A unified quality evaluation standard is generally adopted for observation data at different strong-motion stations, but there haven't been any graded and classified evaluation strategies. In addition, there haven't been any intact theoretical technology system as well as intact evaluation methods of data quality, including theoretical analysis and technical methods, in terms of the quality evaluation of strong-motion observation data.

3. Factors influencing the quality of strong-motion observation data

Factors influencing the quality of strong-motion observation data should be analyzed in a deeper level during the quality evaluation of strong-motion observation data. Studies have shown that, the authenticity and reliability of strong-motion observation data can be influenced by many factors, including the strong-motion observation data entities, the setting of instrument parameters, and the observation environment at strong-motion stations.

3.1. Impact of strong-motion observation data entities

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Data entities refer to actual observation data in strong-motion observation system, and are the direct factor influencing data quality. This can be mainly reflected in the integrity and accuracy of metadata, the integrity and reliability of seismic event waveform data as well as the integrity and normalization of data formats, etc.

3.1.1. Integrity and accuracy of metadata. Metadata are major auxiliary information related to observation data in the strong-motion observation system, and are key components of data quality. Strong-motion observation metadata should include the metadata of earthquake, station, records, observation points and instruments. Earthquake metadata should include the name of earthquake, time of occurrence, longitude and latitude, earthquake magnitude, and focal depth. Station metadata should include the name of station, code, longitude and latitude, and field materials about the station address. Record metadata should include the maximum value of acceleration records, record duration, sampling rate and other information as well as record document number. Observation point metadata should include the position of observation point, the setting map of observation point, and the epicentral distance. Instrument metadata should include the model, serial number, main performance indexes and reference values of the strong-motion seismograph. The integrity and reliability of such metadata are basic conditions to ensure the quality of observation data.

3.1.2. Integrity and reliability of seismic event waveforms. Seismic event waveforms are data recorded by strong-motion observation instruments, when an earthquake happens. The integrity and reliability of seismic event waveforms mainly involve complete records without missing contents at the head or end, wave absorption, intact and clear seismic phases, and three-component correspondence of accelerograph, etc.

3.1.3. Integrity and normawlization of data format. The integrity and normalization of data format mainly involve the contents expressed by data recorded in each station. Whether such contents are complete, and whether the format is clear and accurate, whether the header file of data includes the intact information of seismic event, and whether the data format is consistent with relevant regulations and industrial standards of strong-motion observation.

3.2. Impact of strong-motion observation instruments

In order to acquire high-quality strong-motion observation data, it's essential to equip with advanced observation instrument and equipment, adopt scientific instrument installation methods, and carry out effective maintenance in the observation and operation period of the station. The strong-motion observation environment is relatively complicated, so the impact on instrument performance should be tested when such instrument is used under severe environments for a long term. Besides, electronic components and mechanical parts inside the equipment may be aged or deformed, and further influence characteristics of certain parameters, as the instrument is used continuously. If these changes cannot be timely found, the quality of observation data will be directly influenced. Therefore, strong-motion observation equipment should be tested and calibrated on a regular basis along with the adjustment and setting of instrument parameters.

Whether the parameters of observation instrument are set reasonably are directly related to whether the data recorded in the instrument are intact and reliable. Generally, there are many parameters to be set in the instrumenwt, and instrument parameters generating major impact on strong-motion observation data mainly include the threshold level of triggering, the threshold level of triggering suspension, pre-event time (s), after-event time (s), sampling rate and gains.

3.3. Impact of strong-motion observation environment

Generally, the strong-motion observation environment is complicated and diverse, and will influence the quality of strong-motion observation data. The impact of observation environment will cause severe deviation of records obtained by certain stations from surrounding earthquake damage index.

3.3.1. Impact of local field conditions. The impact of local field conditions on strong-motion observation data mainly includes two aspects: Firstly, it's the impact of uneven field medium in local, such as the weak intercalated layer, and underground holes; Secondly, it's the impact of irregular land forms of local fields, which can be mainly reflected in vertical and horizontal changes, such as river valleys, hills, scarps, and basins. Local field conditions have bigger impacts on the transmission of earthquake waves, and can be reflected in the amplification or shrinkage effect of ground motion during earthquakes.

3.3.2. Impact of instrument pier. The construction of instrument piers is not fully in strict accordance with the Construction Regulations of Strong-motion Networks among domestic and overseas strong-motion networks due to the geological environment at fields and other influencing factors. According to surveys, the instrument piers used to place seismograph are of wide varieties in sections and heights, and with different parameters of instrument piers, the impacts on strong-motion accelerogram can be quite different. Strong-motion accelerograms obtained under excessively high or loose instrument piers are no longer actual reactions on free fields, with bigger amplification or shrinkage effect than accelerograms obtained on free fields. Therefore, such data can only be used after removing the impacts of surrounding environments.

4. Quality evaluation index of strong-motion observation data

The quality evaluation index of strong-motion observation data should be selected as per the extensively recognized quality evaluation list, and then confirmed by combining with the data characteristics and quality requirements of the strong-motion observation system. Characteristics of triggered transmission data and real-time transmission data should be simultaneously considered, in terms of the strong-motion observation data [29]. Furthermore, it's also required to put factors influencing the quality of strong-motion data into comprehensive consideration, and evaluate the quality from the integrity, continuity, correctness, and accuracy of data, and define the specific evaluation index.

4.1. Data integrity

The integrity of data refers to whether the observation data are intact and as required, in terms of sampling interval, spatial distribution, time span, etc. Specific indexes to evaluate the integrity of strong-motion observation data generally include data quantity, total quantity of stations, missing channels, and incomplete accelerograms.

4.2. Data continuity

Data continuity refers to whether the observation data are continuous for a long term in time sequence. Specific indexes to evaluate the continuity of strong-motion data include the continuous rate, record suspending duration and rate, packet loss rate, and repetition rate of data.

4.3. Data correctness

Data correctness refers to no obvious errors in observation data, including the data type as required, and reasonable data value. Specific indexes to evaluate data correctness include the correctness of metadata, errors and stability of GPS clock, and data delay.

4.4. Data accuracy

Data accuracy refers to the conformity of actual observation value to the actual value, and is the quality dimension commonly concerned in data quality evaluation. The accuracy of strong-motion data is mainly specific to the seismic event waveform, and common data quality problems in current studies include excessively low signal-to-noise ratio, asymmetric waveform, spikes and other singular waveforms.

5. Discussion and suggestions

Our country is still in the initial phase to study the quality control and evaluation of strong-motion observation data, and cannot meet the future management of massive observation data of strong-motion networks. Quality evaluation and control should be carried out in different aspects, including data entities, observation instrument, and operating status, and observation environment, to ensure the quality of strong-motion observation data effectively, give full play to the strong-motion network, and further improve and build a more scientific and efficient quality evaluation system for strong-motion observation data.

The key to evaluate the quality of strong-motion observation data is to find approaches to transmit from the qualitative evaluation to quantitative evaluation, and then define and calculate all measurements in the quantitative evaluation system. In previous studies, quality problems in strong-motion accelerograms are often judged on the basis of experience and qualitative evaluation. Methods of statistical analysis, tests, numerical simulation and theoretical analysis should be adopted in future studies, to study the algorithm and quantitative criteria for quality evaluation indexes of strong-motion data. Quantitative evaluation method for strong-motion observation data should be established in accordance with the reliability and accuracy of quantitatively described data in error theories, to evaluate the quality of strong-motion accelerograms fast and objectively.

Current strong-motion instruments in our country can be divided into triggered transmission mode and real-time transmission mode, which are different in many aspects, including the transmission mode, and the setting of instrument parameters, and will also cause differences in the data quality evaluation indexes. Therefore, massive data recorded in these two kinds of instruments should be analyzed in both statistics and theories, to provide relatively comprehensive data quality evaluation indexes that can give considerations to both transmission modes. Under the precondition of evaluating the quality of continuous rate, accelerogram suspending rate, delay and other basic data quality information as well as the continuous waveform data, it's also required to further evaluate data exception based on seismic event waveform, including incomplete accelerograms, excessively low signal-to-noise ratio and singular waveforms.

Data quality analysis depends largely on the purpose of users to use such data. Graded evaluation strategies and quantitative evaluation standards should be formulated in accordance with the application objective and quality requirements of different types of strong-motion stations. According to the result of survey made among experts, system operation and maintenance personnel as well as observation data users in strong-motion observation field as per quality requirements for various strong-motion stations with different application objectives, graded evaluation strategies are formulated for observation data of various strong-motion stations respectively.

To evaluate the quality of domestic strong-motion data in a scientific and efficient way, it entails instrument management and maintenance personnel along with the strong-motion data center, and data users to make joint endeavors. Meanwhile, it's also essential to reinforce the cooperation and exchange with international organizations, and upgrade our strong-motion observation to a new level, strive to rank top of the world in observation scale, and also take a place in observation quality, and the output of achievements.

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