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Review Article

Review on Baseline Correction of Strong-Motion Accelerogram

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Abstract: Because of various reasons, the baseline drift in the strong motion accelerogram was often founded, especially in the near-fault accelerogram. The baseline drift could lead to the unreliable velocity and displacement obtained by the accelerogram integration without or with improper specialized baseline correction. For dealing with the problem, in the study, the various reasons causing the baseline drift in accelerogram were analyzed, the baseline correction principle and the different baseline correction methods were discussed, and the problems in the methods were pointed out.

Keywords: Strong Motion Accelerogram, Baseline Drift, Baseline Correction, Baseline Correction Principle, Permanent Displacement

1. Introduction

In 1923, the great Kanto earthquake of M_L7.9 occurred, causing a lot of death and economic losses. After the earthquake, Japanese earthquake researchers thought to develop an instrument used to directly record the real strong ground motion and building structure earthquake response for aseismic design for building structure. In 1931, Maihiro Kyoji was invited to visit America by the American Civil Engineering Association (ASCE), where he emphasized that measuring the acceleration response of the structure under earthquake load for aseismic design was very important. In 1932, the first accelerometer on the world was successfully developed in the United States. On March 10, 1933, the first strong motion accelerogram was recorded in Long Bench Earthquake, California, which was the birth of strong motion observation [1, 2].

Strong motion observation is an important work in earthquake engineering study. The main purpose of this work is to obtain credible ground motion record and engineering structures response record under earthquake load, which is the basic data for building structural aseismic design code. In this work, the data processing of strong motion accelerogram is an important task.

However, the researchers in processing the accelerogram (especially near-fault strong motion accelerogram) found the velocity and displacement time history obtained by acceleration integration showed the obvious baseline drift phenomenon (Fig. 1). The phenomenon showed in directly mathematical results is not matched by actual situation. The reason leading to the problem is baseline drift in the accelerogram caused by the various factors.

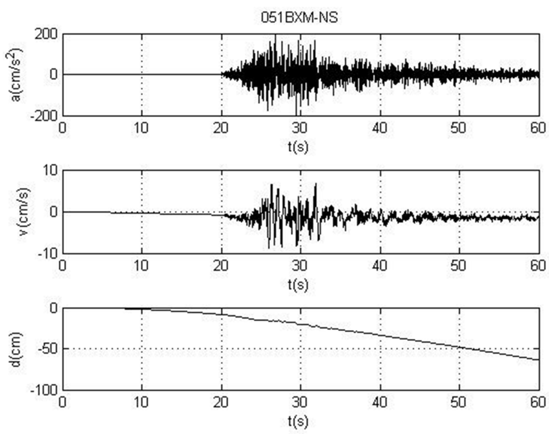

Figure 1. NS direction accelerogram recorded at 051BXM station in Lushan earthquake 2013, and velocity and displacement time history obtained by directly integration without the baseline correction.

In order to solve this problem, many researchers have proposed some methods for baseline correction from different perspectives studies, such as the baseline correction principle, the effects of field conditions, background noise, and the accelerometer hysteresis effect and so on. But majority proposed methods were only the mathematical solution, lacking the strict solution proved in physics, and none of methods could deal with the baseline drift of all near-fault accelerogram perfectly.

2. The Reasons Causing the Baseline Drift in Strong Motion Accelerogram

In contrast with the analog instrument, the digital instrument for strong motion observation has the advantages of lower noise level, higher dynamic range, wider frequency bandwidth, higher sampling rate, longer pre-event recording and so on [1,3]. But the baseline drift in the accelerogram is still the problem had to face. The present studies showed that the problem is the result caused various factors, including the following internal factors and external factors.

2.1. The Internal Factors

The internal factors mainly include instrument noise, background noise and initial value processing error. These factors are mainly relevant with the performance or parameter settings of digital strong motion observation instruments.

(1) The noise of the instrument mainly includes electronic noise, errors caused by insufficient sampling rate and resolution ratio, the micro magnetic hysteresis effect of the sensor material and the circuit, and the noise caused by other unknown reasons. The present study shows that the magnetic hysteresis effect of the sensor is mainly due to material fatigue [3].

(2) The main background noise is caused by the random wave including various frequencies energy, which is affected by the surrounding environment, such as tide, wind, human activities, etc. It also relates closely to the site conditions. The low frequency noise can cause the baseline drift shown in acceleration time history [4-6].

(3) The initial value error is determined by pre-event record. The current digital instrument can record enough long pre-event record, the baseline-drift caused by zero-drift of instrument and long period environmental noise could be deal with easily in general accelerogram by high-pass filter. But the way is not fit for dealing with some near-fault accelerogram, because the low frequency energy component in such accelerogram includes the permanent displacement information, simply high-pass filtering could lead to the information lost. [7-9].

(4) There are some internal factors worth being studied, such as magnetic hysteresis effect of the sensor material and the circuit and so on. How and how deeply to influence on the baseline drift is still s problem.

2.2. The External Factors

Pier moving is the clear external reason. The base pier movement mainly occurs at the near-fault region. When the earthquakes happened, the ground deformation (rupture, horizontal displacement, uplift) was often found at near fault regions. So such strong motion acceleration time history value mixed with the base pier movement value (tilt, rotation, uplift). The pier moving effect is not shown obviously strong motion acceleration time history generally, but the velocity and displacement obtained by the acceleration integration is sensitive to it [7, 10, 11].

3. Commonly Used Baseline Correction Methods

Generally, the accelerogram recorded in near fault site, and the velocity and displacement obtained by the acceleration integration, but they are unacceptable without or with improper specialized baseline correction. For obtaining the credible acceleration, velocity, displacement, some methods were proposed in the many studies, the commonly used baseline correction methods are mentioned below.

3.1. Baseline Initialization

When the strong motion instrument records seismic data, the records unitary skewing may occur by the effect of the background noise. In order to ensure strong motion records starting from zero, records should be processed by baseline initialization. At present, almost all of the baseline correction processing used in the baseline correction method is subtract the mean values of the prior part. Boore [7], Yu Haiying [10], Wang Decai [12] ect. in their studies suggest adopting the baseline initialization that subtract the mean values between 0~20s. Zheng Shuiming [9], Wang Guoquan [13] and other scholars have just said in general to subtract the average value of the prior part of earthquake records. Rong Mianshui [14] used least square method to eliminate linear trend that were brought in by acceleration background baseline drift. In the study of Peng Xiaobo [8], he pointed out the idea that the work of the strong motion instrument is triggered. Under the trigger threshold, there has been a motion caused by the earthquake, and this motion value is far larger than the value of the background noise.The value of these motions is much larger than the background noise, and the distribution is not uniform. Simply subtracting the mean value of the pre-event records cannot guarantee that everything subtracted is background noise. It is likely to subtract the ground motion records under the threshold, which will cause a bigger subtractive average, affecting the following correction results.

3.2. Low Frequency Filtering Method

Low frequency noise is one of the main reasons causing the baseline drift. So the most direct way is to use the low frequency filtering method, which can effectively eliminate the low frequency noise impact on the acceleration baseline. Trifunac [15] first proposed using the low frequency filtering method to correct the acceleration baseline drift caused by low frequency signals. Brady and Converse [16] made a further improvement by joining a long enough period of zero sequence in one record.

3.3. Iwan Baseline Correction Method

Iwan [3, 17] based on the Kinematrics company production FBA-13 and PRD-1 type digital strong motion instrument test found that when acceleration is bigger than 50gal, a tiny baseline jump phenomenon will happen, it's usually called the bouncing acceleration value "acceleration threshold". Although the effect of acceleration records is very small, but it will lead to obvious baseline drift in velocity and displacement obtained by integral method. In order to deal with this problem, Iwan divided acceleration time histories into three parts, the middle part represents the strong motion record. He thought that the drift which happens in the middle part is caused by the magnetic hysteresis. It is generally considered that the excursion is constant in each period. By linear fitting velocity time history baseline, the slope of every part we get can be represented as an excursion of the acceleration baseline. Using the least square method fitting the third part get slope of fitting line exactly is the excursion of acceleration baseline drift, and then subtracts the excursion from the corresponding period in the acceleration time history. According to the request that the ending of velocity time history obtained after integrate acceleration time history is zero to determine the slope of the second velocity stage, then subtracts slope obtained above from the corresponding acceleration time history period. This method is called Iwan-1 method, Iwan in practice also found the first time beyond the threshold to the acceleration time history ends, there are a lot of points can be satisfied to make the end of velocity time history is zero. Iwan further proposed to select the point that can make the final displacement of displacement time history obtained through integration is minimal as the second cut-off point, which is the Iwan-2 method.

3.4. Boore Method

When Boore [18-21] et al. used the Iwan method processing Chi-chi earthquake acceleration records to choose cut-off points to correct the baseline, he found the second cut-off points has greater impact on the correction results. So he pointed out that it is not appropriate to make acceleration amplitude threshold as the time boundaries. Boore made a further simplification, choosing the moment the first wave reached as the first cut-off point, and the moment can make the final velocity that via velocity integration is zero as the second cut-off point. So the method is also called V_0 correction method.

3.5. Wang-Zhou Baseline Correction Method

Wang Guoquan, Zhou Xiyuan [13] in the process of correcting Taiwan Chi-chi near-fault seismic records baseline, consider that the slope is stable after the baseline drift of displacement time history happen. So it only needs one straight line to fit. Wang Guoquan used baseline initialization process original acceleration time history, then chose a straight line fitting the records between 65~90s, thus he can got the slope of the fitting line and intersection of this line and the time axis. In acceleration time history, subtracting the fitting line slope from intersection moment, integrating this to get velocity time history, then do following process using baseline initialization, the displacement time history can be obtained by the once integrate.

3.6. Wu and Wu Baseline Correction Method

Wu and Wu [22] processing the near-fault seismic records of Taiwan considered that if the permanent displacement is generated, the recorded displacement after correction is similar to the shape of a slope function. So Wu uses one similar thought to the Iwan method, but he put forward a new way when select time cut-off point. He selected the moment the displacement time history started excursion as the first point. If the acceleration at corresponding time is less than the acceleration amplitude threshold, the moment of acceleration amplitude threshold was ensured as first point. When the permanent displacement of the ground occurs, it will not change in a short time. The displacement value is approximately same as the value of the permanent displacement in theory [23-25]. Therefore, selecting the moment the displacement time history tends to be a permanent displacement as auxiliary point. However, since the process of data processing is constrained by methods, the displacement time history does not necessarily run parallel to the timeline. And it is difficult to determine the time point when there is lack of reference of the near field GPS station data. So it is necessary to constantly choose moments from the start time cut-off point to end by recursive method so that the displacement time history after the auxiliary time points are approximately parallel with the time axis. The second time points should be selected between the moment selected above and the end moment. Therefore, Wu introduced into the concept of flatness selects multiple second points, through iteration and the least square method to calculate the permanent displacement values of every site and to calculate the flatness of displacement time history after auxiliary point. In the end, select the corresponding second point of the maximum flatness. Then using the Iwan method correct displacement time history baseline get excursion value of displacement time history between auxiliary point to the end, and this is the permanent displacement value.

3.7. Hermite Interpolation

When Zhou Baofeng [26, 27] correct the baseline, he put forward base on the process of earthquake and baseline drift in a straight line trend these two points. The data of baseline drift need to be piecewise fitting, and it's not suitable for higher order curve fitting. To avoid generating node and rough phenomena in the process of interpolation, Zhou Baofeng used piecewise two point three times Hermite interpolation constructing a connecting interpolation curve between two piecewise line to make the piecewise point not only meet the function value but also ensure the first derivative continuous, achieving smooth transition curve.

4. Principles for Baseline Correction

Although the different method was proposed in the different studies, the researchers have consensus on the principles for baseline correction. All people in the field thought, after one earthquake, the ground motion is stopped, the acceleration becomes small, the velocity tends to zero with time, and the displacement tends to a steady value (zero or permanent displacement value) with time. Therefore, the result of correct baseline need to meet the following two points: (1) The end of velocity time history value is zero (2) The displacement time history curve runs nearly parallel to the abscissa.

Some people proposed that the baseline correction results can also refer to the ground deformation measured by GPS at the same time [28, 29]. Then through comparison with the displacement time history curve ending value determine whether there is permanent displacement, and the difference between the baseline correction results and the actual permanent displacement. But the principle is not fit to every case, because not all station's ground deformation is recorded in real time accurately by GPS system.

Generally we should consider all three points above. If the baseline correction results conform to all these judgment principles, we can consider that baseline correction results credible.

5. Discussion on Commonly Used Baseline Correction Methods

At present, all the methods are based on the following two assumptions: (1) Strong earthquake records can be divided into three periods: the pre-event part, the earthquake part and the post-event part, and assuming that the slope of each period is stable; (2) Permanent displacement formed in a very short moment.

Baseline initialization is the first step towards eliminating the impact of the overall bias in the baseline. The method proposed by Iwan is a basic method, his method mainly focusing on several specific types of accelerogram, according to the earthquake record jump point ensuring the threshold point then processing every period based on the least square method. Boore proposed his method based on the Iwan method. Boore's method takes the last period fitting velocity result as zero as a requirement to select the second discontinuity point. Wang-Zhou's method is only for the characteristics of the Chi-chi earthquake, selecting the fixed period to correct the strong motion records. Wu and Wu's method is applied to the iteration to choose time points and uses displacement flatness to evaluate the correct effect. The baseline correction method of Hermit interpolation is focused on solving the jump of discontinuity point from the perspective of numerical processing. The low frequency filter method is mainly aimed at the low frequency signal which leads to the baseline drift shown in the acceleration time history.

None of these methods above were widely applied to correct all strong motion accelerogram with baseline drift. There are many main problems such as the following:

(1) The selected method is not valid for all cases. One reason is the parameters used in baseline correction are related to special instrument or sensor. Iwan proposed his method just based on the test of FBA-13 and PRD-1 type instrument produced by Kinematrics company, but it is necessary to be proved whether the parameters in his method are valid to other type of instruments or not. The other reason is how to determine the parameters in selected method relied on the subjective thoughts and experiences of the users in practical application. Even in the case of selecting the same method, different strong motion data may led to different selected parameters. For instance, Huang Bei [30] selected 90s as the starting time adopt the method of Wang Guoquan. The method Yu Haiying[31] used to correct near fault records of the Wenchuan earthquake and the method Zhou Baofeng applied to correct the Japanese "311" earthquake are both only for specific earthquake acceleration records.

(2) In some studies, a number of new evaluation criteria were added to make further corrections. For example, Chen Yong [32] used the least square method to fit the integral acceleration to select the inflect point time repeatedly by means of a half step method, and eventually to get the most stable displacement, Rong Mianshui used mathematical method to make an analysis, introducing some parameters such as "Time shifting slope ratio", " Standard deviation of fitting segment ", "displacement tail variance" for optimizing the baseline correction method, but its essence is still the selection of fitting time, and just using mathematical method to judge the rationality. Including the Wu and Wu baseline correction method, the introduction of the concept of flatness was also used to evaluate the baseline correction. Although these methods meet the standard of the baseline correction method, there are some differences between the co-seismic GPS data record. Considering the error of GPS itself and the influence of distance between the strong motion station and GPS station, the way's validity has to be proved. The displacement time history directly recorded and obtained by acceleration time history recorded integration in the same station could be used to be proved the methods, but the suitable data are scarce in reality.

(3) Different baseline correction methods may bring new errors or lose some important information contained in seismic wave records [33, 34]. In the filtering process, the acceleration information may introduce new noise signals, and the long period wave information or the permanent displacement information of the ground may be filtered out. But the long period seismic information is very important for the seismic calculation of large span bridges, pipeline engineering and so on.

(4) In the near-fault region, the ground motion is strong, and the foundation pier of the instruments often moves, such as tilt, torsion and vertical lifting. The movement effects on the accelerogram have not been discussed overall [35, 36]. And the present studies focused on mathematical method correction, the credible experiment study on the baseline drift

is still lack under the condition matching the actual situation of ground motion in near fault region.

6. Conclusion

According to the discussion above, the baseline drift included in the accelerogram is still a problem that could not be ignored. The reasons leading to the problem have not been clear. In order to solve the problem at last, the further studies have to be done. The three aspects of work blows are worth doing. The first work is the numerical simulation in physics on the effect of the known factors to the baseline drift; the second work is the known factors' sensitivity analysis in the baseline correction; the last work is the experiment study on the baseline drift under the condition matching the actual situation of ground motion in near fault region, such as with the permanent displacement. After the studies, the problem will be explained clearly, the validity and rationality of the commonly used baseline correction methods will be proved, and the better method will be proposed. At last, the problem will be solved perfectly.

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