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A new baseline correction method for near-fault strong-motion records based on the target final displacement

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ABSTRACT

Most current baseline correction methods for near-fault ground motion records focus on eliminating and minimizing baseline errors and obtaining true ground motion records that are in accordance with GPS-measured coseismic displacements. Though these methods can recover true ground motions, the single value of ground permanent displacement cannot meet the requirement of seismic response analysis of fault-crossing bridge with the consideration of various levels of relative static displacements. Besides, the corrected final displacements are often too large which will cause an extremely large pseudo-static response and a relatively small dynamic response in bridge structures. To provide across-fault seismic excitations with a reasonable series of final displacements, a new baseline correction scheme based on the target final displacement is proposed in this study, in which an additional offset displacement is introduced based on the Iwan correction scheme. The new baseline correction scheme aims at modifying the pseudo-static displacement of ground motion records to facilitate the agreement between the achieved final displacement and the target final displacement. The correction scheme is then examined in three aspects including time histories, response spectra and bridge responses. The analysis results indicate that sets of the corrected time history records with a large range of final displacements can be well achieved with a minor influence on spectral characteristics. The seismic response analysis of a cable-stayed bridge crossing a dip-slip fault-rupture zone shows that the pseudo-static response can be controlled, meanwhile, the dynamic response remains almost intact by using the new baseline correction scheme. This work can be used as a reference for input excitations of bridge crossing fault-rupture zones.

1. Introduction

The baseline correction for strong-motion records has been studied for decades in seismology to solve the problem of unphysical shifts in the velocity and displacement traces. Major baseline errors, including low-frequency instrument noise, low-frequency background noise, the small initial values for acceleration and velocity, manipulation errors [1], hysteresis of the transducers [2], ground rotation and tilting [3–7] have been identified in previous studies. To remove the baseline-error-induced shifts and achieve true ground motion records, scholars have proposed various baseline correction methods. At present, the baseline correction methods for ground motion recorded by modern digital accelerometers can be classified into two categories: the filtering method [1,8–10] removing low-frequency errors and the piecewise correction method [2,4,11,12] based on velocity seismogram.

In general, low-frequency noise errors are related to very long period motions (e.g., > 20 s) that are of little engineering concern [13]. Therefore, the baseline errors relating to the low-frequency component can be effectively removed by applying a high-pass filter [1,10]. The high-pass filtering of the recorded strong ground motion time histories is also a processing step of the standard procedure used by the PEER Strong Motion Database [8,9,14]. However, high-pass filtering removes not only the baseline errors but also the low-frequency signal content including the static offset of displacements [11]. Accordingly, the fling-step effect and permanent displacement will be eliminated in the ground displacement time history. This elimination will considerably influence the simulated seismic response of a spatially extended engineering structure crossing a fault-rupture zone [15]. Therefore, the high-pass filtering method may be not suitable for near-source records (i.e., distances less than 20 km) if the permanent displacements are expected.

The piecewise correction method based on the velocity seismogram is another option [2,4,12], which is also referred to as the empirical baseline correction. The piecewise correction method assumes that for

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several reasons (transducer hysteresis, ground tilting, etc.) baseline shifting occurs during the strong shaking phase of the entire time history. By using the bilinear piecewise velocity time history to compensate for the drifted velocity records, the true ground motion time history can be recovered. Since the piecewise correction method is irrelevant to high-pass filtering, the static displacements can be preserved. Certainly, this kind of baseline correction methods aims at eliminating or minimizing the baseline errors to recover the true ground motion records. To validate the effectiveness of these methods, the final displacements derived from the empirical baseline correction are often compared with coseismic displacements from geodetic data like Global Positioning System (GPS) measurements [4,7,11–13] and Interferometric Synthetic Aperture Radar (InSAR) data [11,16], because generally, the ground static displacement is most accurately measured by geodetic methods. Particularly, the high-rate GPS measurements (1 Hz) could provide near-field velocity and displacement seismograms to examine the results of the baseline correction over the time history [17,18].

In general, the ground displacements of seismic motion can be decomposed into dynamic and pseudo-static displacements [19,20]. Accordingly, the structural responses can be taken as the sum of two parts: the dynamic response caused by the acceleration time history and the pseudo-static response due to support movement. For spatially extended structures that cross a fault-rupture zone, like bridges, the non-uniform excitations of the two sides of the fault rupture may produce totally different permanent ground displacements. The relative displacement of the two fault sides will be applied on the bridge piers and cause additional pseudo-static deformations to the bridge structure, which is similar to bridges that are subjected to spatially varying ground motions with the considerations of the wave-passage, spatial coherency and local-soil effects [21–23]. In 1999 Chi-Chi, Taiwan earthquake, several bridges crossing the Chelungpu fault collapsed due to the extremely large relative displacement caused by the fault dislocation [24]. Therefore, the permanent ground displacement is an important factor for the seismic response of fault-crossing bridges and should be handled with caution. Though the current baseline correction method has noted that some parameters can be used to determine the permanent ground displacement [4], the modification results are not perfect and the range of applications is limited. For the seismic response study of fault-crossing bridges, ground motions with different levels of final displacement, not only peak ground acceleration (PGA), are needed. Though some researchers have proposed simulation methods of across-fault ground motions [25,26], these methods are not easy for practical use.

To solve the problem of seismic excitations for fault-crossing bridges, it is necessary to develop a baseline correction method, in which the desired ground permanent displacements can be achieved without influence on the dynamic component. A new baseline correction scheme is proposed in this study. The new method is developed based on the method of Iwan et al. [2], in which an additional offset displacement controlled by the target final displacement is introduced. The new correction scheme is then examined with respect to three aspects including time history, response spectra and structural response.

2. Current methods of the baseline correction

Iwan et al. [2] assumed that the baseline shifts of the strong-motion records are caused by minute mechanical or electrical hysteresis within the transducer system during the strongest portion of ground shaking. Their experimental results indicate that very little transducer hysteresis occurred for accelerations less than 50 cm/s^2. The basic idea of the Iwan method is to divide the entire time history into three phases, i.e., pre-seismic, strong shaking and post-seismic phases, and use two constant acceleration values (a_m and a_f in Fig. 1) to modify the strong shaking phase and post-seismic phase, respectively. The recommended approach (Option One) allows the start and end time of the strong shaking phase (t_1 and t_2 in Fig. 1) to be determined by the first and last time points, respectively, when the absolute acceleration exceeds a threshold of 50 cm/s^2. A least-squares fit of the final portion of the velocity data (from t_{f1} to t_{f2}, where t_{f1} is an appropriate time of the post-seismic phase and t_{f2} is the end time of the velocity seismogram) is used to determine the correction for the final offset. The correction can be expressed as

$$v_c(t) = v_0 + a_f t \tag{1}$$

where a_f is the correction acceleration of the post-seismic phase. Then, the correction acceleration value of the strong shaking phase can be given by

$$a_m = \frac{v_c(t_2)}{(t_2 - t_1)} \tag{2}$$

After the correction of the acceleration history, the corrected velocity and displacement histories can be obtained through single and double integration, respectively.

Although various studies [3–6,16] have demonstrated that hysteresis in sensors is one of the numerous possible sources of the offsets (with another major source of offsets being ground tilting), the bilinear piecewise correction is still accepted as an appropriate form. Boore [4] believes that setting a threshold of shaking to determine the time parameters t_1 and t_2 is not always a good choice as the baseline shifts differ from case to case. In his approach, t_1 and t_2 are set as free parameters based on Iwan et al. [2] method. Then, a wide range of final displacements can be obtained for various choices of the free parameters. Note that the final displacement of a ground motion record can be defined as the mean value of the displacement history in the last portion of the post-seismic phase. For example, for ground motions recorded in the Chi-Chi earthquake, the last portion can be taken from 65 s to 90 s (t_{f1} and t_{f2} in Fig. 1), during which the shaking intensity was fairly small.

As is stated by Boore [4], time parameter t_1 should be chosen at the point in the record where the baseline shifts start to occur; for t_2, any value between t_1 and the end of the record will satisfy the constraint that the average of the corrected velocity be zero near the end of the record; and the different durations between t_1 and t_2 will achieve different final displacements. If a ground motion record with a final displacement is desired, the method of Boore [4] seems to be reasonable. However, there is a limitation that cannot be neglected. No matter how t_2 floats between t_1 and t_f, the covered area between the bilinear fitting function and the coordinate axis of time, i.e., the final offset displacement, has a maximum and a minimum that represents the areas of trapezoid a-b-c-d and triangle a-c-d (Fig. 2), respectively. Therefore, the variation range of final displacements is limited. The limitation will be much more obvious when the baseline shift of the raw ground motion record is small. The problem has been noticed by Boore [4], who stated that "for the stations on the hanging-wall side of the fault (TCU052, TCU068), the final vertical displacements are not sensitive to the baseline correction." Apart from the limitation discussed above, many times of trial computation or even an iterative computation scheme is required to find the proper parameter t_1 and t_2 corresponding to a desired final displacement, which is not convenient for practical use.

Inspired from the Boore [4] correction scheme, an alternative approach to acquire a ground motion record with an expected final displacement through baseline correction could be feasible. That is, applying a small modification to add or subtract an artificial displacement in the strong shaking phase, which is similar to changing the covering area between the bilinear fitting function and the coordinate axis of time in Boore [4] method (Fig. 2).