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Baseline correction for digital strong-motion records by using the pre-event portion

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Abstract: Baseline offset in digital strong-motion acceleration record and initial velocity can produce unrealistic results for ground velocity and displacement derived from the acceleration by integration. A new method is proposed for the baseline correction and initial velocity calculation. It is based on linear least-squares fitting of the pre-event portion of velocity derived from the uncorrected acceleration data. Compared with the conventional method, which is based on removing the mean values of the pre-event portions of the acceleration and velocity traces, this method has clearer physical meaning and better stability.

Key words: baseline offset; correction; acceleration records; initial velocity; least-square fitting

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1 Introduction

In the vast amount of digital strong – motion acceleration records, there exist baseline offsets which, though having little effect on the peak acceleration values, can affect the derived velocity and displacement values greatly. Figure 1 shows the EW component of the strong-motion record (the first 15 s) at Tashui stations (051AXT) for the 12 May 2008 Wenchuan earthquake (*M*8.0), and the velocity and displacement time series derived by single and double integrations. The pre-event portions show that a baseline offset in acceleration of only $-0.2\ \mathrm{cm/s^2}$ caused a displacement of more than 10 cm at 10 s. This example illustrates the need of correcting the baseline of the original acceleration record before studying ground velocity and displacement information. When handling analog records, the usual practice is to fit the whole acceleration trace[1-4] with

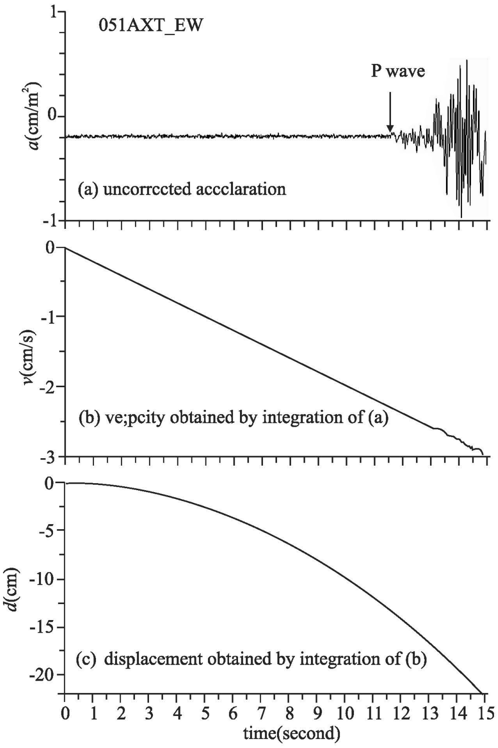

Figure 1 Velocity and displacement traces derived from single and double integration of the uncorrected acceleration records at 051AXT station (the first 15 s)

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a straight line or a quadratic curve, and then subtract the line or curve from the original acceleration trace. In digital records, some pre-event portion record can be retained and used for baseline correction. The conventional method is subtracting the average value of the pre-event portion from the original acceleration record, calculating velocity by integrating the acceleration, then subtracting the average pre-event value from the velocity trace, and finally obtaining displacement from the velocity trace by integration[5,6].

After strong shaking, the baselines of acceleration traces may be shifted owing to the ground deformation, apparatus tilting, or hysteresis lag, etc.[7,8]. When correcting such an offset, it is necessary to assume that the velocity is zero at the end of motion, and the displacement is close to zero, if there is no residual ground displacement. This is the basis used for evaluating the appropriateness of correction methods. But a prerequisite is that the initial value should be handled properly. Thus, in this paper we do not discuss such offset, but focus on the baseline offset before strong motion starts, because both velocity and displacement are sensitive to the initial values.

2 Baseline correction method

Whether a correction method is reasonable is judged by the velocity and displacement derived from the acceleration by integration. Theatrically, the average pre-event values of acceleration, velocity, and displacement should all be zero. Thus, we can use a straight line to fit the velocity trace, or a quadratic curve to fit the displacement trace. A large number of tests show that an acceptable result can be obtained by fitting a straight line to the velocity trace. The procedure is as follows:

1) Determine the P-wave arrival time (t_0) and integrate to obtain the velocity.

2) Fit a line to the pre - event portion ($0 - t_0$) of velocity by

$$v_f(t) = a_f \times t - v_0 \tag{1}$$

where, v_0 is initial velocity value, a_f is slope of the line, that is, the baseline of acceleration trace.

3) Subtract a_f from the original acceleration.

4) Integrate to obtain velocity and displacement, while constraining initial values by

$$v(0) = v_0, d(0) = 0 \tag{2}$$

Since the initial velocity and displacement are not known, they are usually assumed to be zero for the velocity and displacement traces derived by numerical integration. In general, however, the initial velocity is not zero, and there may still exist obvious baseline offset in displacement traces. For example, the acceleration in Figure 2 has been corrected and the average value of pre-event portion is approximately zero; the velocity and displacement are derived from the corrected acceleration by integration. The neglect of constraining the initial velocity to zero has obviously resulted in serious displacement distortion. On the other hand, in the velocity and displacement traces obtained by our new method (Fig. 3), the pre-event portions of both velocity and displacement have met the condition of zero average value as a whole.

3 Comparison to conventional method

The new baseline correction method can be expressed as follows:

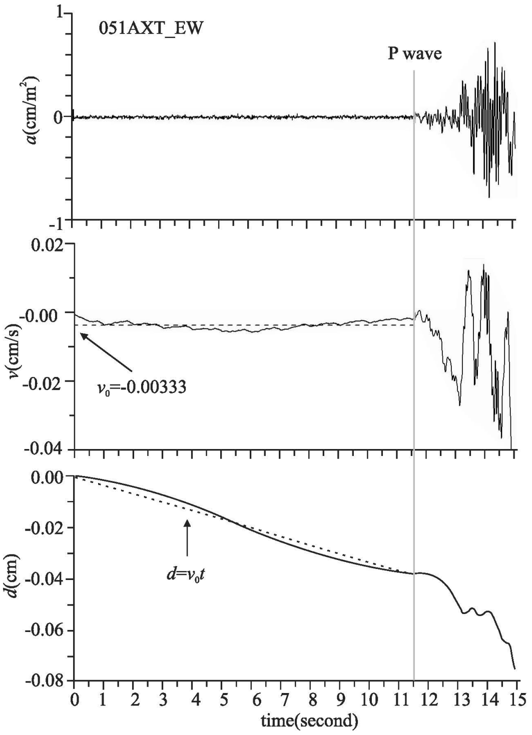

Figure 2 Velocity and displacement traces derived from corrected acceleration by integration (let initial velocity and displacement be zero)

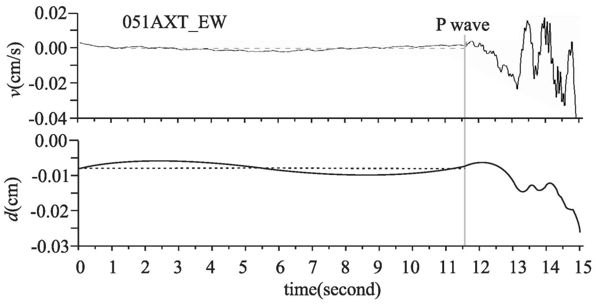

Figure 3 Corrected velocity and displacement traces obtained by the new method

$$a^*(t) = a(t) + a_f \tag{3}$$

$$v^*(t) = \int_0^t a^*(\tau)d\tau = \int_0^t a(\tau)d\tau + \int_0^t a_f d$$
$$v(t) - v(0) + a_f \times t \tag{4}$$

$$v(t) = v^*(t) - a_f \times t + v(0)$$
$$= v^*(t) - [a_f \times t - v(0)] \tag{5}$$

where a^* and v^* are uncorrected acceleration and velocity, and a and v are the corrected values. Formula (5) is the theoretical basis of this method. The corrected velocity is the residual of linear fitting to the uncorrected velocity by formula (1); it has a Gaussian distribution and noise characteristics.

The conventional correction method can be expressed as follows:

$$a(t) = a^*(t) - a_f$$

where,

$$a_f = \frac{1}{n}\sum_{i=1}^{n} a^*(t_i) \tag{6}$$

$$v^*(t) = \int_0^t a(\tau)dt = v(t) - v(0) \tag{7}$$

$$v(t) = v^*(t) + v(0),$$

where $$v(0) = -\frac{1}{n}\sum_{i=1}^{n} v^*(t_i) \tag{8}$$

From (6) to (8), it may be seen that the sum of pre-event portion is zero for both the corrected acceleration and the corrected velocity. Figure 4 compares the velocity and displacement traces obtained by the two correction methods. While there is little difference between the two velocity traces, the difference between the two displacement traces is obvious. This shows that the displacement obtained by our method fits the noise characteristics better .

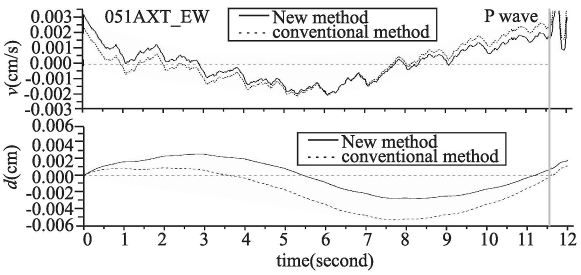

Figure 4 Comparison of correction results between the new method and conventional method

4 Stability analysis

There are various computational methods to automatically identify the P-wave arrival time (t_0), and the results obtained are usually not very consistent. By using the above-mentioned acceleration records and by wrongly assuming t_0 to be 13 s, 15 s, 17 s and 20 s (the actual t_0 being 11.62 s), we made corrections according to both the new and the conventional schemes. The results are shown in Figures 5 and 6, respectively.

After the P-wave arrival, the average values of ground acceleration and velocity may not be zero and the ground – motion amplitude is much larger than noise. Therefore, the average values of "pre – event portion" calculated by he conventional method are obviously affected by the ground motion (Fig. 5). On the other hand, the target function of our least-squares fitting is Least Absolute Deviation. As a result, the resultant coefficients are not sensitive to some abnormal values. This example illustrates that the proposed fitting method is insensitive to changes of t_0 (Fig. 6).

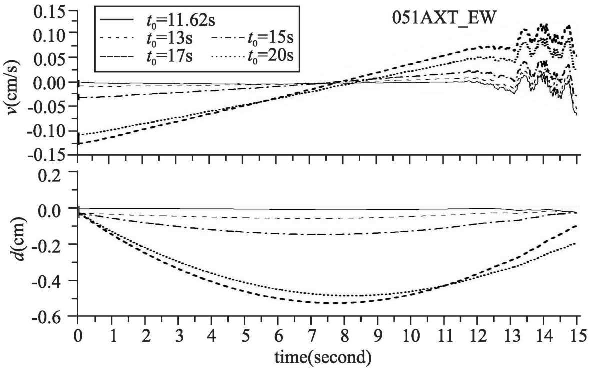

Figure 5 Correction results with different t_0 by using the conventional method

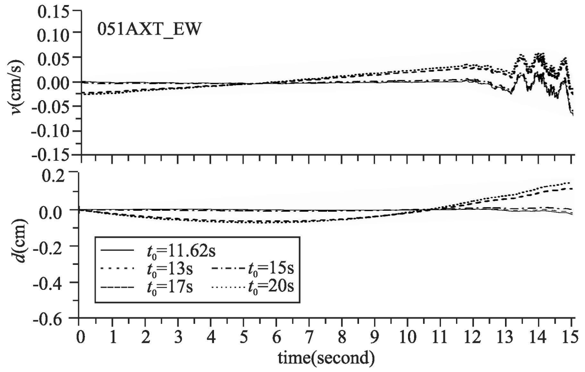

Figure 6 Correction results with different t_0 by using the new correction method

5 Conclusion

Baseline offset of strong-motion acceleration severely affects the derived velocity and displacement, which is also sensitive to the initial velocity. Therefore, it is necessary to correct baseline of the original acceleration record to gain the velocity and displacement information. The method proposed in this paper, which is based on the linear fitting of the velocity, has provides a better solution to this problem, and with clearer physical significance. It has greater stability than conventional method also.

It is worth noting that the effectiveness of correction by using the pre-event portion depends on the estimation of the P-wave arrival time, which cannot be simply taken as the pre-reserved time of the instrument, because P wave usually arrives before the instrument is triggered.

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