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Ground Motions with Static Displacement Derived from Strong-motion Accelerogram Records by a New Baseline Correction Method

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New baseline correction method of strong-motion records using pulses was developed by Minowa. This method is possible to provide static displacements from strong-motion records. Corrected acceleration is obtained by subtracting acceleration pulses from original accelerations. These pulses are obtained from the shape of velocities and displacements including errors. Corrected velocities and displacements are calculated from corrected accelerations. Corrected displacements by this method can provide static displacements. This new method was applied for strong-motion accelerations observed in Hokkaido Japan during Magnitude 8.0 Tokachi-oki Earthquake Sep. 26, 2003. Static displacements from these case studies were compared with the static movement observed before and after the earthquake using Global Positioning System by Geographical Survey Institute in Japan. Additionally, Strong-motion observation in the sites of GPS observation is proposed in order to improve baseline correction methods and obtain more reliable displacements from strong-motion records.

INTRODUCTION

Baseline correction of strong-motion accelerograms has used band-pass filters or low-cut filters in order to remove high and/or low frequency errors. Representative method was developed by Trifunac. (Trifunac 1970) These methods did not provide static displacements. Static displacements after strong earthquakes were neglected for long years by these reasons. Iwan developed new baseline correction method which applies filters in parts of accelerations.(Iwan 1985) A new method developed by Minowa does not use filters. Instead of removing long period errors by filters, Minowa's method uses pulses having some periods

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for baseline corrections. This method was developed for the correction of strong-motion accelerations observed in JMA Kobe during 1995 Kobe Earthquake. This method could provide static displacements from strong-motion accelerations. Corrected acceleration records by Minowa's method were used for the input motions of shaking table test in NIED. (Yamaguchi & Minowa 1998) This method was improved and applied for sloshing analysis of oil tanks having long natural periods.(Minowa 2003) Kazaz summarized procedures of this method and applied this method for Bingol Earthquake records on May 1, 2003. (Kazaz & Minowa)

METHODS

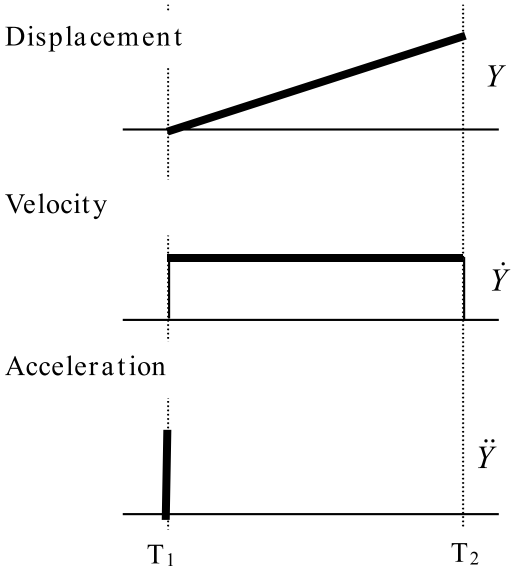
- Errors in Acceleration Records

Strong-motion records observed during earthquakes include some errors. Errors in the records are tried to reduce as possible. Latest digital recording system is one of those methods, but some errors are still included. It is considered that errors in the strong motion accelerations are included by insufficient digitizing bits of analog-digital converters, instability of sensors and analog circuit, physical external noise around seismograph, tilting of seismograph basements, etc. But these errors must be removed in calculation of velocities and displacements from original acceleration records, because integration and double integration of accelerations will increase effects of these errors. Calculated velocities and displacements by single and double integration of accelerations are including divergent components of linear and quadratic functions. In order to obtain reliable velocities and displacements from observed accelerations, baseline corrections removing errors must be applied for original acceleration records. Following two principals are used in this new baseline correction method.

- Principal

Acceleration pulse generates shift of velocities shift and sloped displacements. This relation is summarized in Figure-1. Sloped displacements and shift of velocities are transformed to the pulses of accelerations in Equation 3.

Shift of acceleration generates linear velocities and quadratic displacements. This relation is summarized in Figure-2. Quadratic displacements and linear velocities are transformed to the shift of accelerations in Equation 6. These principals are used in this baseline correction method.

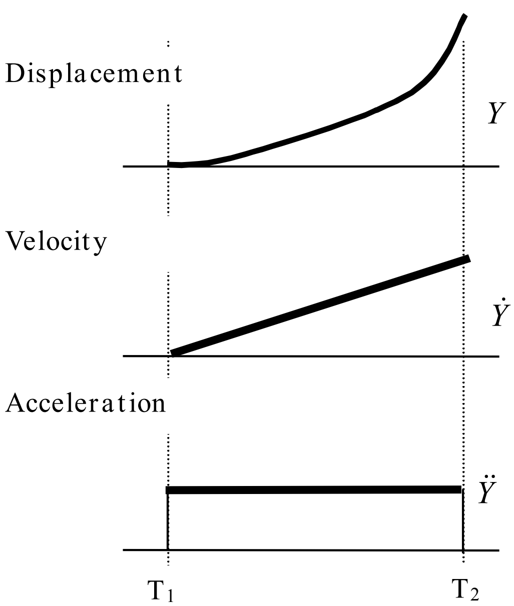


$$Y = \dot{Y} \times (T_2 - T_1) = \ddot{Y} \times \Delta t \times (T_2 - T_1) \quad (1)$$

$$\dot{Y} = \frac{d\dot{Y}}{dt} \times dt = \ddot{Y} \times \Delta t \quad (2)$$

$$\ddot{Y} = \frac{\dot{Y}}{\Delta t} = \frac{Y}{\Delta t \times (T_2 - T_1)} \quad (3)$$

Figure-1. Principal-1 Transformation from Linear Displacements and Shift of Velocities into the Pulse of Accelerations



$$Y = \frac{\dot{Y} \times (T_2 - T_1)}{2} \quad (4)$$

$$\dot{Y} = \frac{d\dot{Y}}{dt} \times dt = \ddot{Y} \times (T_2 - T_1) \quad (5)$$

$$\ddot{Y} = \frac{\dot{Y}}{(T_2 - T_1)} = 2 \times \frac{Y}{(T_2 - T_1)^2} \quad (6)$$

Figure-2. Principal-2 Transformation from Quadratic Displacements and Linear Velocities into the Shift of Accelerations

- Basic Procedures

Basic procedure of this baseline correction method is described in Figure-3. This baseline correction method assumes that velocities observed during earthquakes converge to zero. Based on this assumption, procedure of this baseline correction method is established.

At step 1, velocities and displacements are calculated by integration of accelerations. At step 2, drift of baseline and neutral line during pre-event part of acceleration records is calculated. This drift acceleration value is removed from acceleration raw records from first to end of the records. 1st corrected acceleration record is obtained. At step3, 1^{st} corrected velocities and displacements are calculated by single and double integration of 1^{st} corrected accelerations.

At step 4, 1^{st} corrected velocities and displacements are examined. When results of GPS observation are given, static displacement of 1^{st} corrected displacements is able to be compared with the static movement by GPS observations. If 1^{st} corrected velocities and displacements are feasible, baseline correction will finish. Unless those are feasible, baseline correction will be continued and moves to step 5.

At step 5, 1^{st} corrected velocities are low pass filtered. Steps 6, 7 and 8 are separated to two cases of velocities are shifted or sloped.

In case velocities are shifted. At step 6-A, least square fitting (LSF) is applied for 1^{st} corrected velocities from time T_{f1} to time T_{f2}. At step 7-A, the point of gap between LSF and initial baseline of velocities is searched. Time T_G of the gap point is decided. At step 8-A, value of pulse of accelerations is calculated by equation-3. Beginning time T_1 and end time T_2 of pulse for corrections are decided feasibly.

In case velocities is sloped. At step 6-B, least square fitting (LSF) is applied for 1^{st} corrected velocities from time T_{f1} to time T_{f2}. At step 7-B, cross point of LSF and initial baseline of velocities is searched. Time T_C of the cross point is decide. At step 8-B, value of shift of accelerations is calculated by equation-6. Beginning time T_1 and end time T_2 of shift for correction is decided feasibly.

After step 8-A or step 8-B. At step 9, the values of pulse or shift are subtracted from 1^{st} corrected accelerations. 2^{nd} corrected accelerations are obtained. At step 10, 2^{nd} corrected velocities and displacements are calculated by single and double integration of 2^{nd} corrected accelerations.

At step 11, 2nd corrected velocities and displacements are examined. When results of GPS observation are given, static displacement of 2nd corrected displacements is able to be compared with the static movement value by GPS observations. If 2nd corrected velocities and displacements are feasible, baseline correction will finish. Unless those are feasible, baseline correction will go back to step 5 for repeated corrections.

CASE STUDIES AND DISCUSSIONS

- HKD129(Tomakomai)

HKD129 site of K-net operated by NIED is located near the Tomakomai city office Building where is 3km west of fired oil tank. Location of HKD129 is indicated in Figure-4 . Photo-1 shows oil tank that was fired after 2003 Tokachi-oki Earthquake.

Figure 5, 6, 7 indicate acceleration, velocity, and displacement raw data of NS component observed at HKD129 in the earthquake. Figure 9, 10, 11 indicate acceleration, velocity, and displacement raw data of EW component

1st Correction:

Mean value of initial 1 second is removed from acceleration raw data.

2nd Correction;

Least Square Fit from 80 to 270 seconds. Subtract -0.0257 cm/s^2 from 1st corrected acceleration data of NS component after 68.61 seconds. Subtract 0.01192 cm/s^2 from 1st corrected acceleration data of EW component after 83.24 second. Figure- 8 and Figure- 12 indicate corrected displacements of NS and EW components.

GPS Observation at Tomakomai GPS site by Geographical Survey Institute (GSI) before and after the earthquake resulted ground-movement of 9cm for south-east and 3cm down. (Geographical Survey Institute Sep.2003)

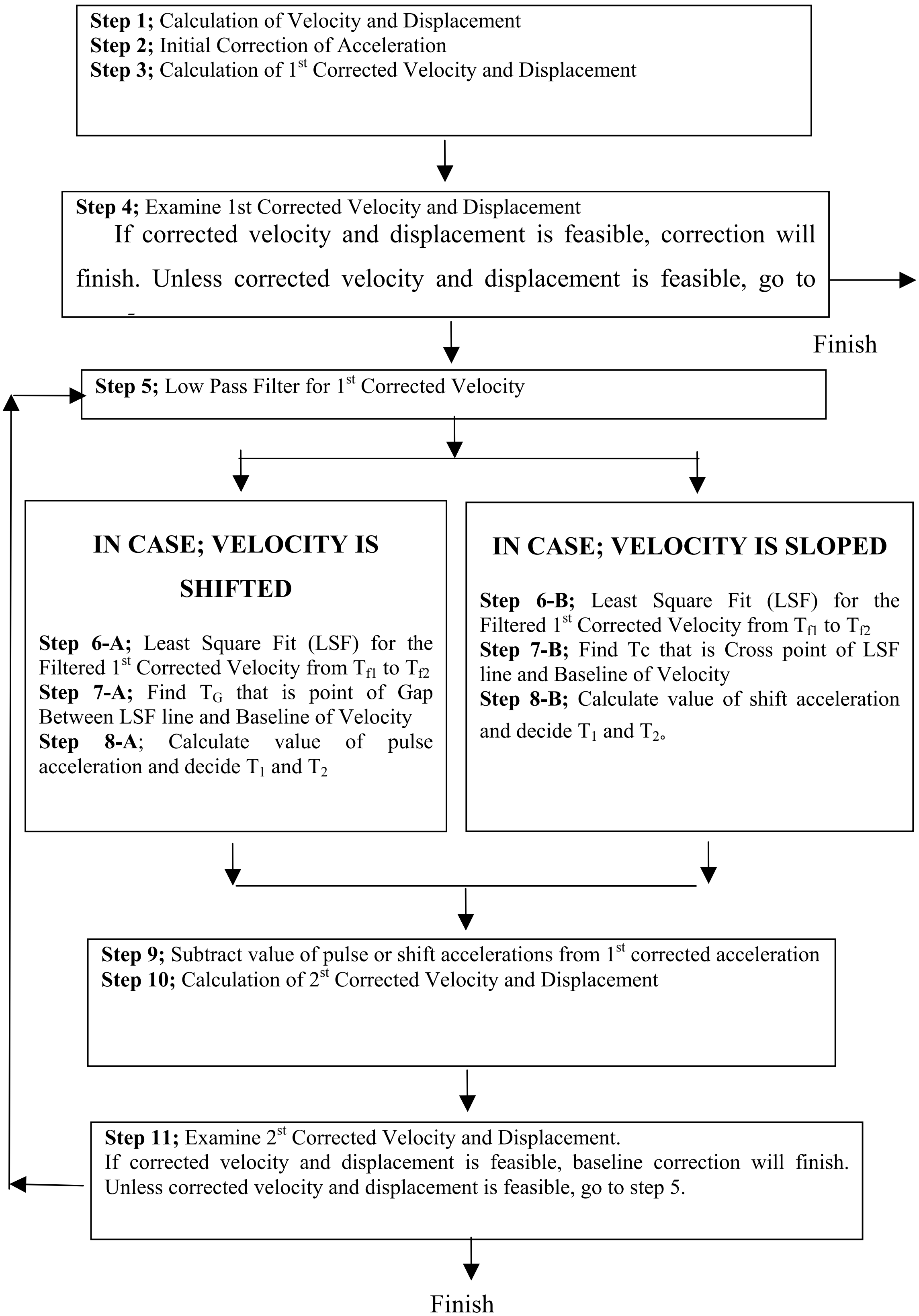


Figure-3. Basic Procedure of Baseline Correction

Figure-4. Location of HKD129 and Fired Tank

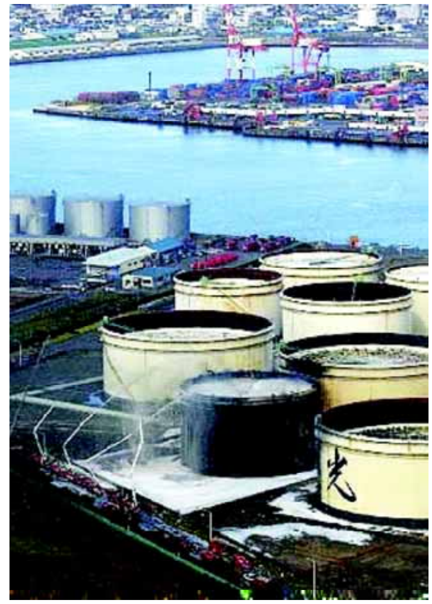


Photo-1. Fire of Oil Tank after the Earthquake

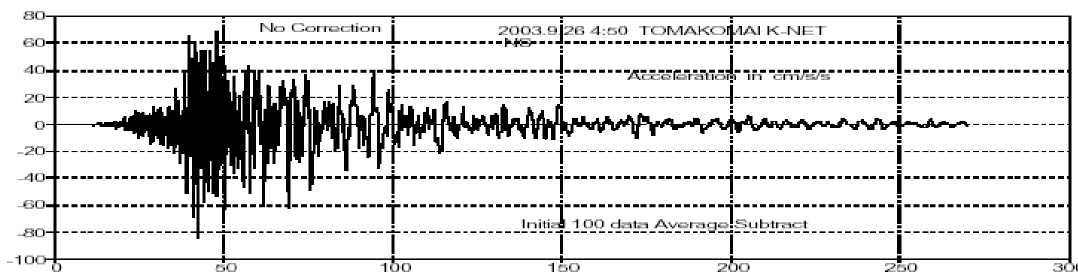


Figure-5. Acceleration Raw Data of NS Component

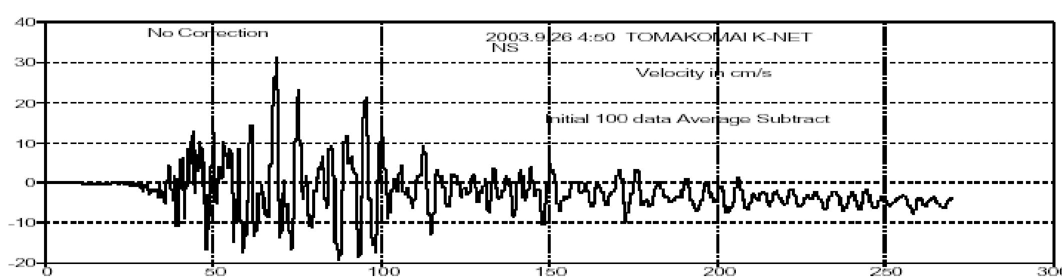


Figure-6 .Velocity Raw Data of NS Component

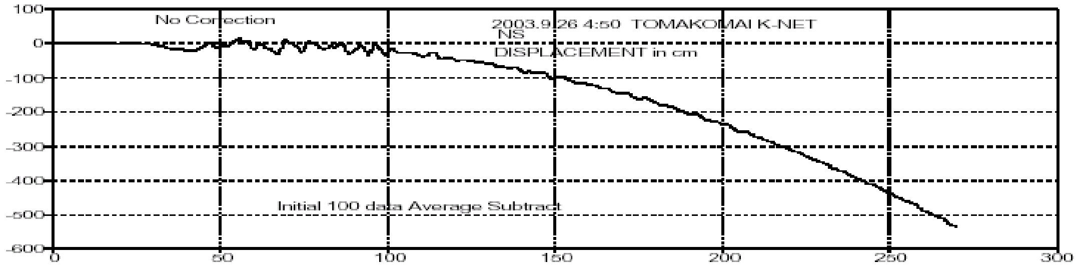


Figure-7 . Displacement Raw Data of NS Component

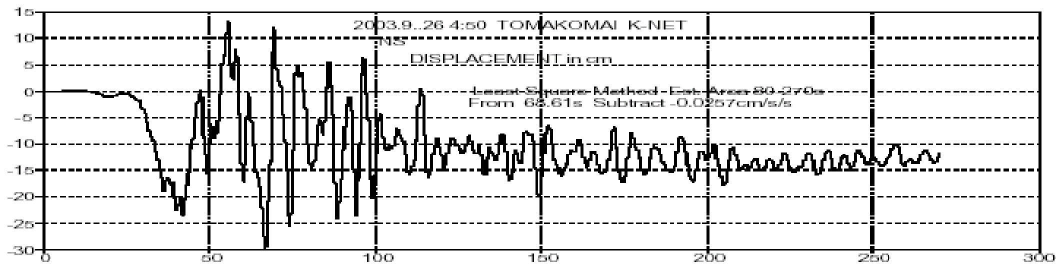


Figure-8 . Corrected Displacement of NS Component

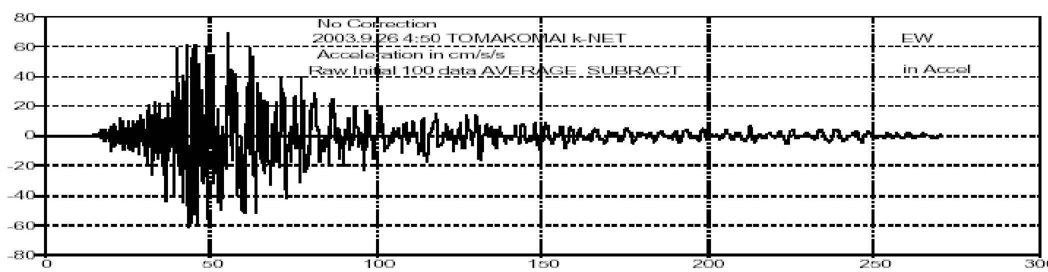


Figure- 9. Acceleration Raw Data of EW Component

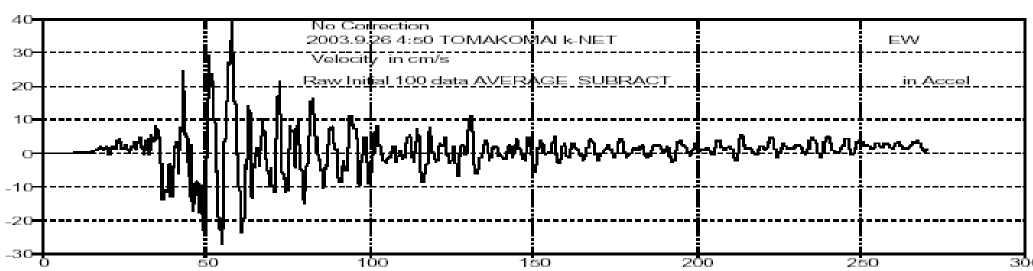


Figure-10. Velocity Raw Data of EW Component

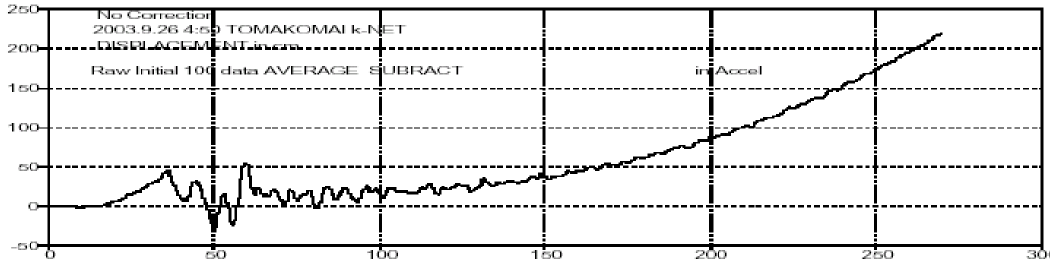


Figure-11 . Displacement Raw Data of EW Component

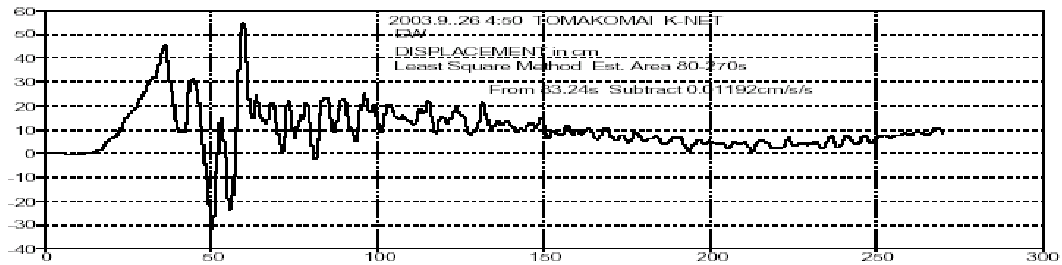


Figure-12 . Corrected Displacement of EW Component

- HKD100(Hiroo)

HKD100 site of K-net is located near the Hiroo Town office Building.

Figure 13, 15, 17 indicate acceleration and velocity raw data of NS, EW, UD component observed at HKD100 in the earthquake.

1st Correction:

Mean value of initial 1 second is removed from acceleration raw data.

2nd Correction;

Subtract 2.978 cm/s^2 from 1st corrected acceleration data of EW component after 33.9 seconds. Equivalent tilt of 1280/1500 is assumed after 46.8 seconds, and equivalent tilt of 0.0228 is assumed after 72.2 seconds for UD components.

Figure 14, 16, 18 indicate corrected velocity and displacement raw data of NS, EW and UD components.

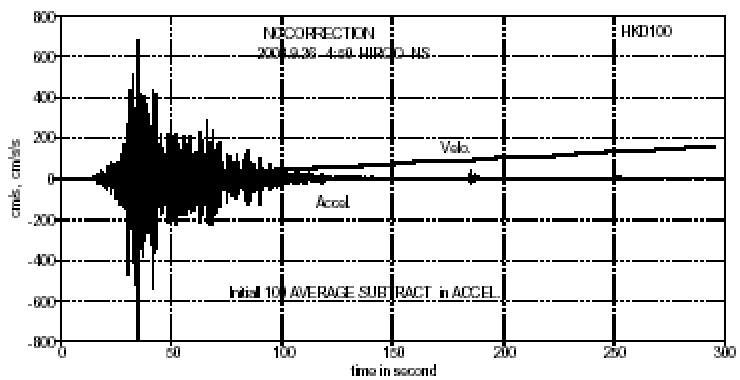


Figure-13 . Acceleration and Velocity Raw Data of NS Component

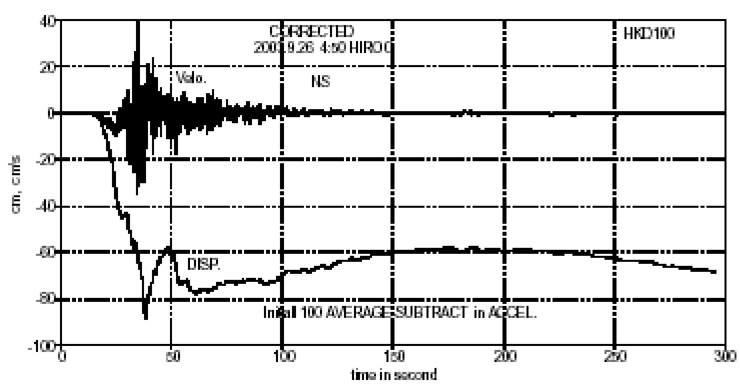


Figure-14. Corrected Velocity and Displacement Data of NS Component

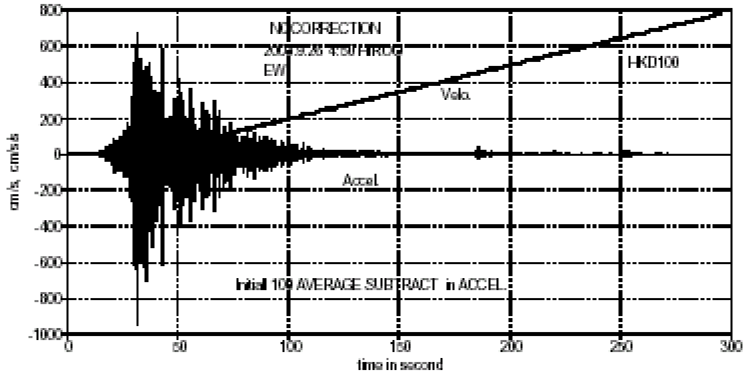


Figure-15 . Acceleration and Velocity Raw Data of EW Component

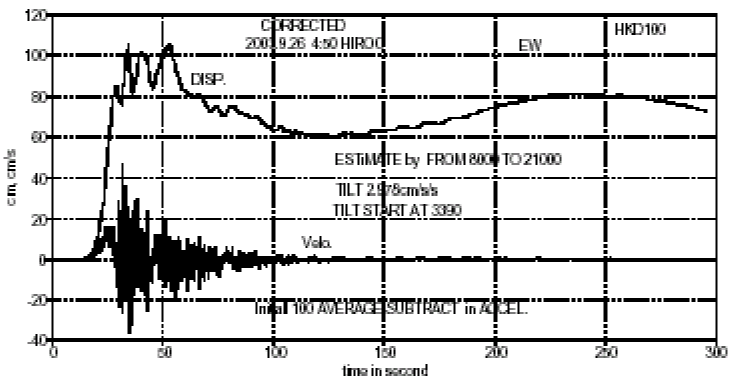


Figure-16. Corrected Velocity and Displacement Data of EW Component

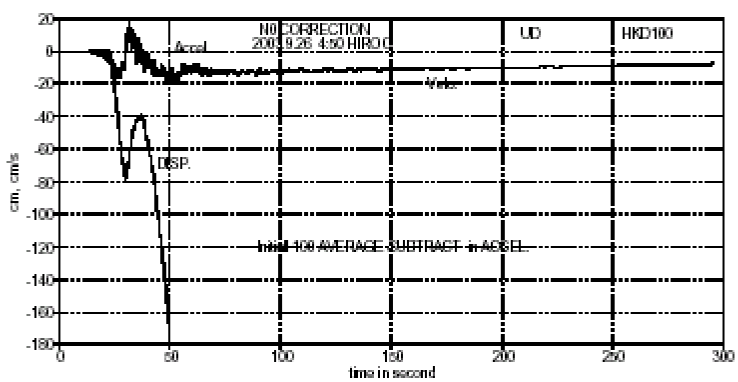


Figure-17 . Acceleration and Velocity Raw Data of UD Component

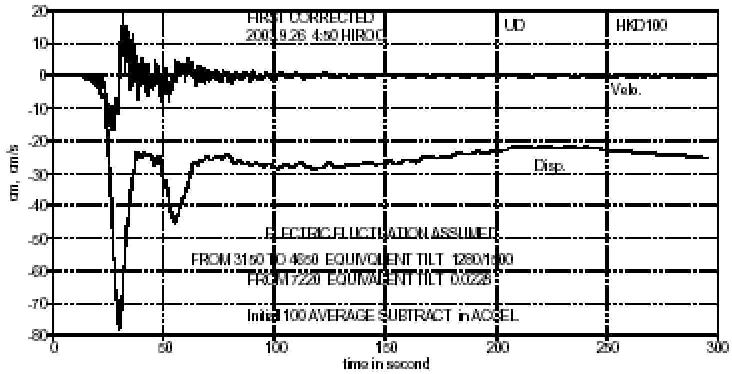


Figure-18. Corrected Velocity and Displacement Data of UD Component

- Observation Using GPS

Geographical Survey Institute (GSI) observes diastrophism of Japan using Global Positioning System (GPS). They observed diastrophism of Hokkaido before and after 2003 Tokachi-oki Earthquake.(Geographical Survey Institute Sep.2003) Figure-19 indicates horizontal movement of Hokkaido before and after the earthquake. Figure-20 and Fogure-21 indicate vertical movement of Hokkaido observed by GPS and survey before and after the earthquake. (Geographical Survey Institute Dec. 2003)

Figure-19 . Horizontal Movement during 2003 Tokachi-oki Earthquake Obtained from GPS Observation by GSI

Figure- 20. Vertical Movement during 2003 Tokachi-oki Earthquake Obtained from GPS Observation by GSI

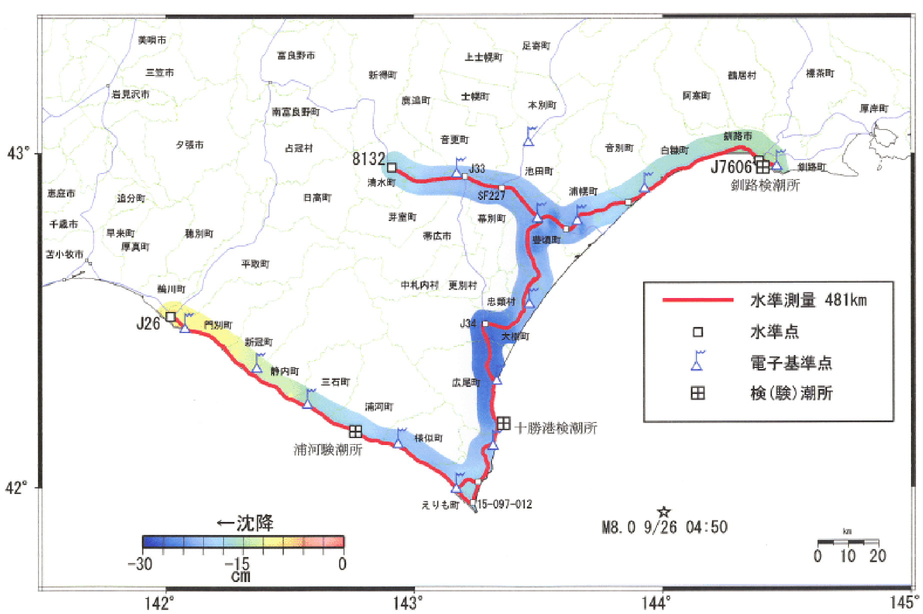


Figure-21. Vertical Movement after 2003 Tokachi-oki Earthquake Obtained from Survey by GSI

➢ Static Displacement

It was difficult to obtain static displacement from accelerations by standard baseline correction method using traditional filtering method. Lately, GPS observation can provides diastrophism before and after strong earthquakes. This new baseline correction produces displacements with static displacements consequently. When results of GPS observation are given, these data is able to be used in the procedures of this baseline correction in order to obtain more reliable velocities and displacements.

➢ Proposal

Combination of strong-motion observation and GPS observation at same sites is proposed. Combining this new baseline correction method and results of GPS observation, more reliable velocities and displacements with static displacements during strong earthquakes will be provided.

CONCLUSIONS

New baseline correction method was descried.

This new baseline correction produces displacement including static displacement.

Combining this new baseline correction method and results of GPS observation, more reliable displacements with static displacements during strong earthquakes will be provided.

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Kazaz I., Minowa C., Baseline Corrections for May 1, 2003 Bingol(Turkey) Earthquake Strong Motion Record and Effect of Baseline Corrections on the Displacements and Response Spectra

Press-Release, Geographical Survey Institute, Sep.30,2003

Press-Release, Geographical Survey Institute, Dec.8,2003

APPENDIX

CORRECTION OF SEISMIC GROUND-MOTION RECORDS OBSERVED ON LIQUEFIED GROUND DURING 2003 TOKACHI-OKI EARTHQUAKE

K-net operated by NIED has thousands of seismic observation sites in Japan. One of the observation site HKD086 Chikubetu was constructed on the soft soil ground. Strong ground-motions were observed there in 2003 Tokachi-Oki Earthquake. K-net distributed the records at HKD086 and reported that the foundation of HKD086 floated, tilted and rotated during the earthquake. Minowa visited the site HKD086 after the earthquake and found that back fill sand of the foundation for instrumentation was boiled up. Figure A1, A2 and A3 show the seismic observe site HKD086, which indicate disturbed ground and the tilted foundation by the earthquake.

The records of HKD086 include the process of tilting of the foundation during the earthquake. Figure A4(a) is single integral of raw acceleration of the NS component that is velocity of NS component. Although velocity should be zero in the end of the ground-motion theoretically, figure A4 indicates divergence of velocity. It is estimated that errors in the records cause these divergence. Tilt of the foundation generates these divergence of velocities in this case. Errors in the horizontal and vertical acceleration records by the tilt of foundation are described in Equation-A1 and Equation-A2 respectively. θ and g are the tilt of foundation and gravity acceleration. $\ddot{X}_{error}$ and $\ddot{Y}_{error}$ are acceleration errors in the horizontal and vertical records.

$$\ddot{X}_{error} = g\theta \tag{A1}$$

$$\ddot{Y}_{error} = -\frac{g\theta^2}{2} \tag{A2}$$

Baseline correction for the acceleration records by Equation-A1 and Equation-A2 provides the process of the tilt of foundation. Figure A4(b) shows process of acceleration errors in the records by the tilt of foundation. Figure A4(c) indicates calculated accelerations for corrections according to the process of acceleration errors in the records in Figure A4(b). Figure A5(a) and A5(b) indicates corrected velocity and displacement from corrected accelerations. It is observed that the final part of velocity and displacement in figure A5(a) and A5(b) are not stable. The complex motion of foundation observed on liquefied soil might cause these records.

Figure A6(a) are raw acceleration and velocity for EW component of HKD086 records, figure A6(b) is process of errors in the records by the tilt of foundation. Figure A6(c) is calculated accelerations for error corrections. Figure A7 (a) and A7(b) are corrected velocity and displacement.

Figure A8(a) are raw acceleration and velocity for UD component of HKD086 records, figure A8(b) is process of errors in the records by the tilt of foundation. Figure A8(c) is calculated accelerations for error corrections. Figure A9(a) and A9(b) are corrected velocity and displacement. In usual baseline correction of strong-motion records, error in vertical component is less than those of horizontal component and neglegible. But the errors of vertical components in this station is obvious as shown in Figure A8(a). Because this records includes effect of liquefied soil ground.

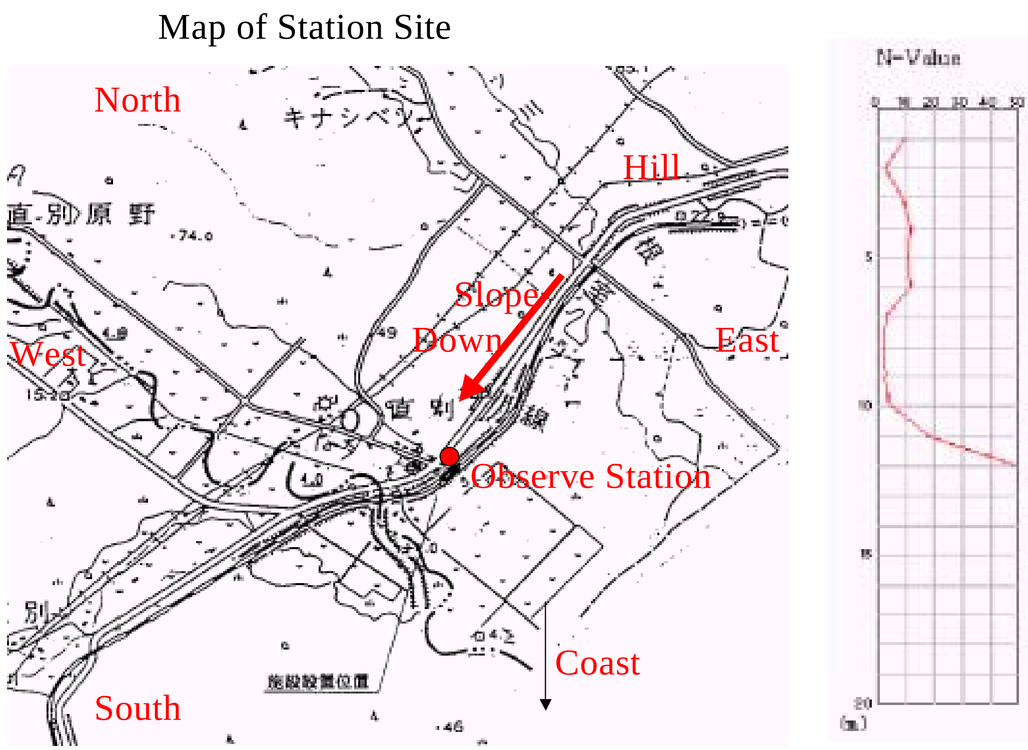

Figure A1. Location and soil profile of observation site HKD086

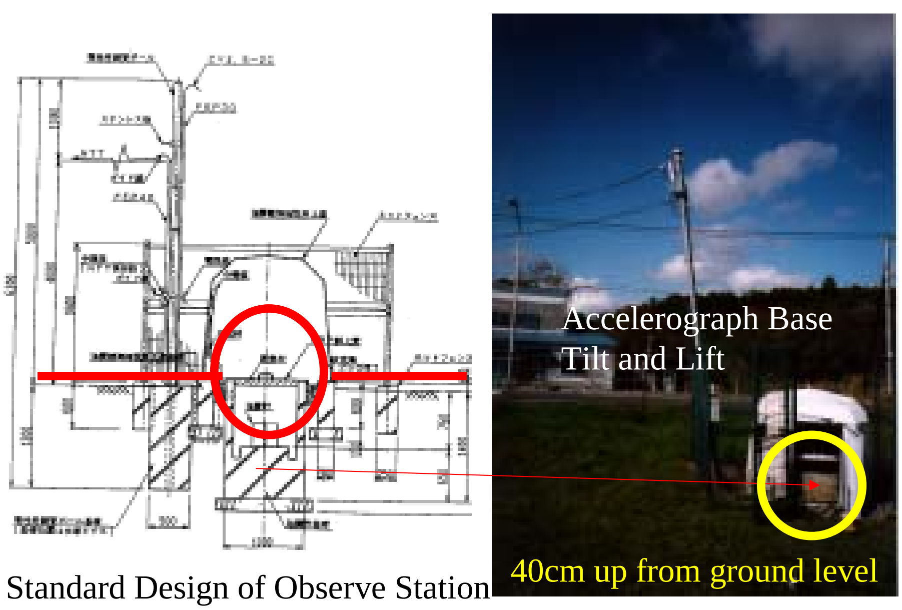

Figure A2. Drawing and photo of observe site and floated foundation

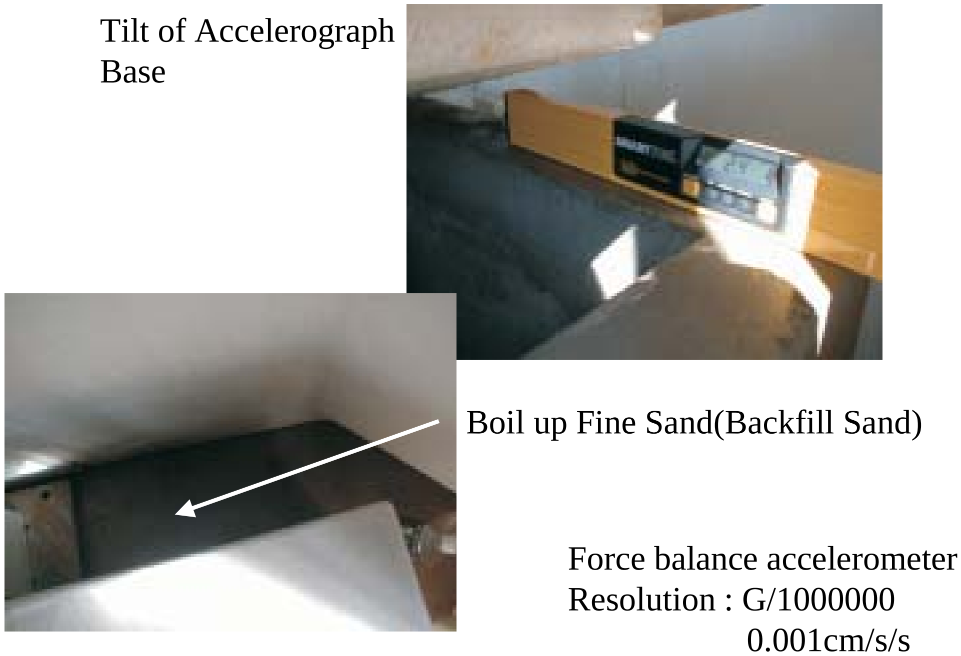

Figure A3. Boiled sand around tilted foundation for instrumentation

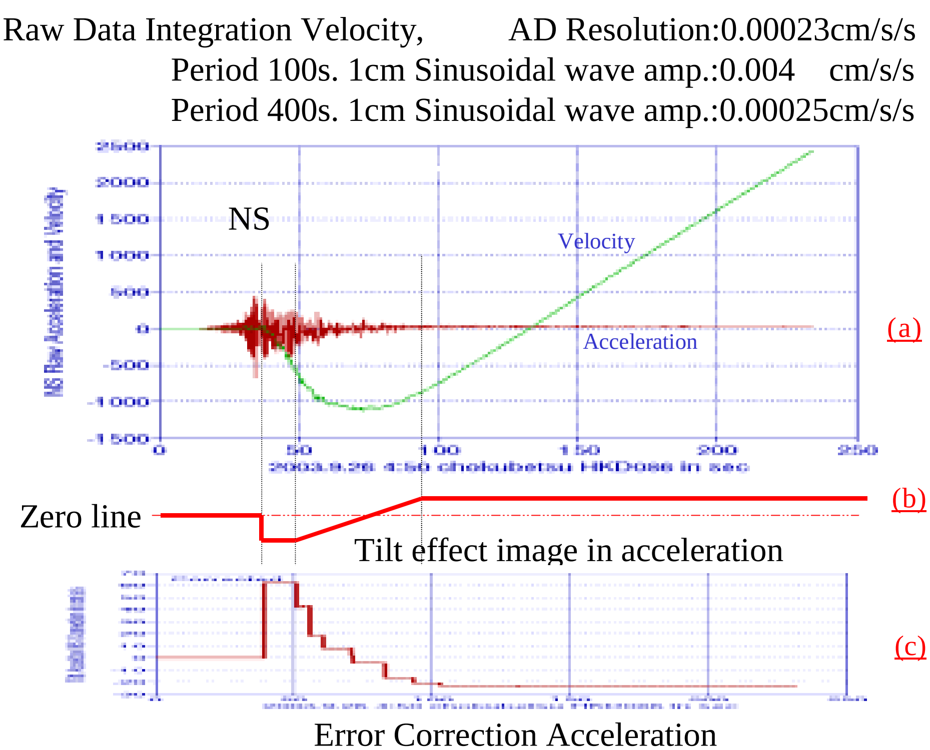

Figure A4. Acceleration raw, process of errors and acceleration for correction of NS component

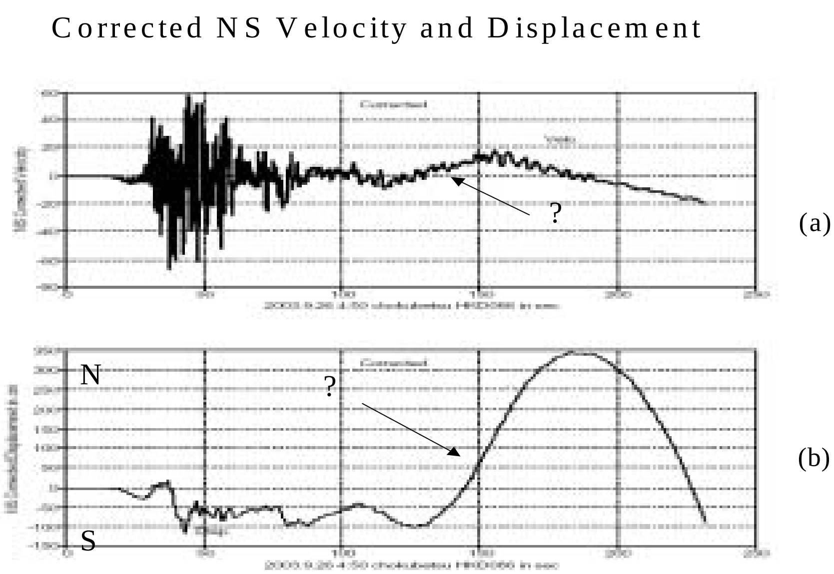

Figure A5. Corrected velocity and displacement of NS component

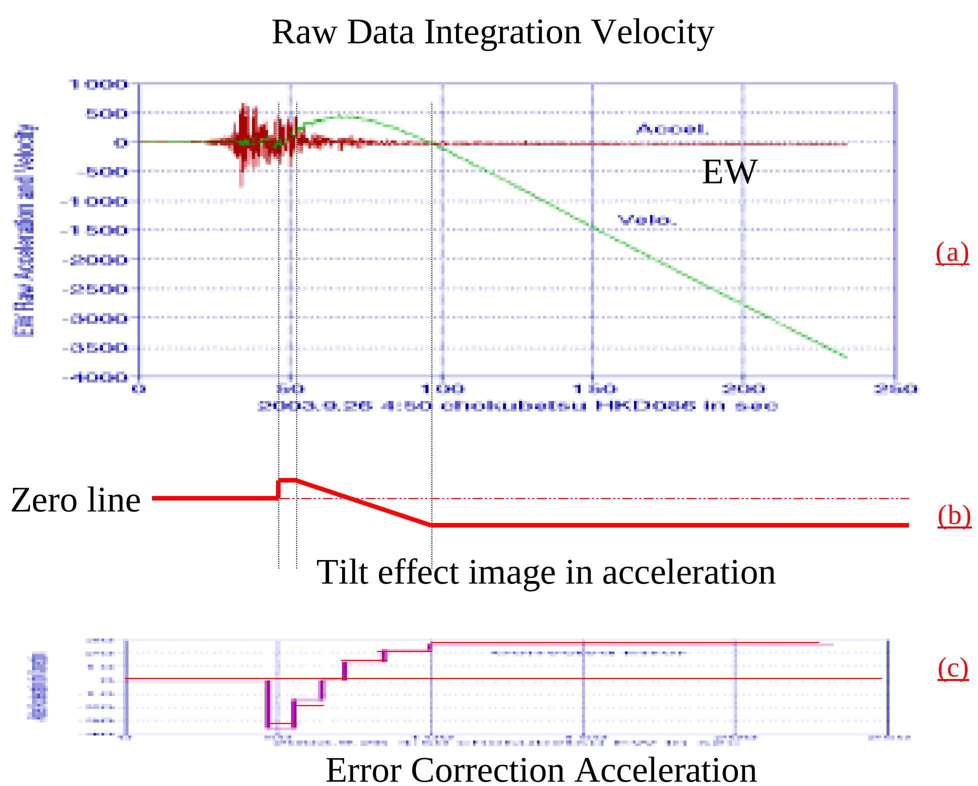

Figure A6. Acceleration raw and velocity, process of errors acceleration and acceleration for error correction of EW component

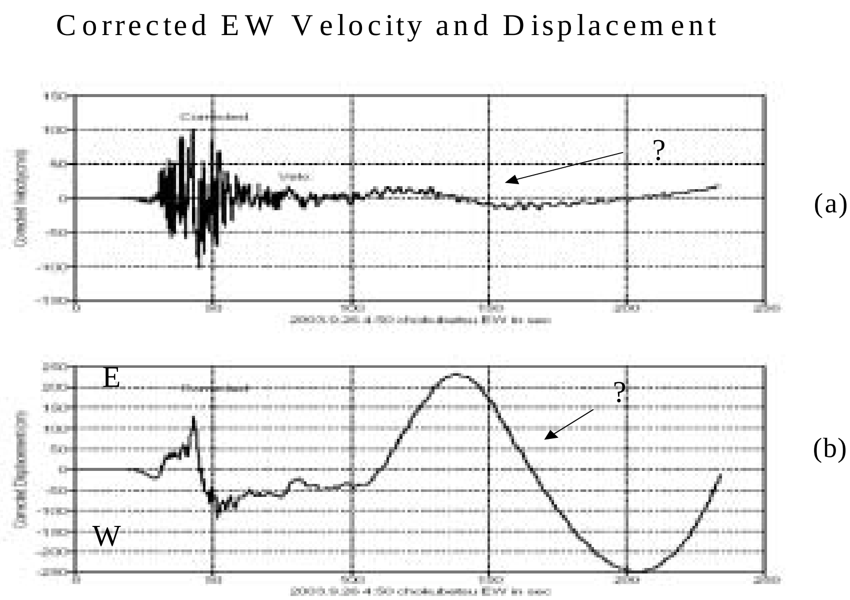

Figure A7. Corrected velocity and displacement of EW component

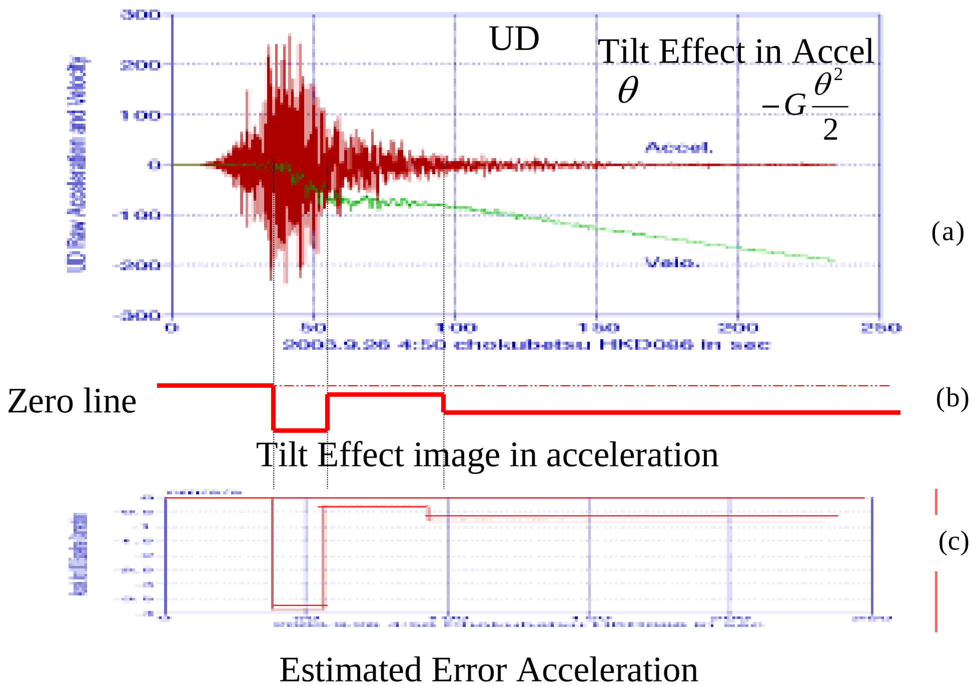

Figure A8. Acceleration raw and velocity, process of errors acceleration and acceleration for error correction of UD component

Corrected UD Velocity and Displacement

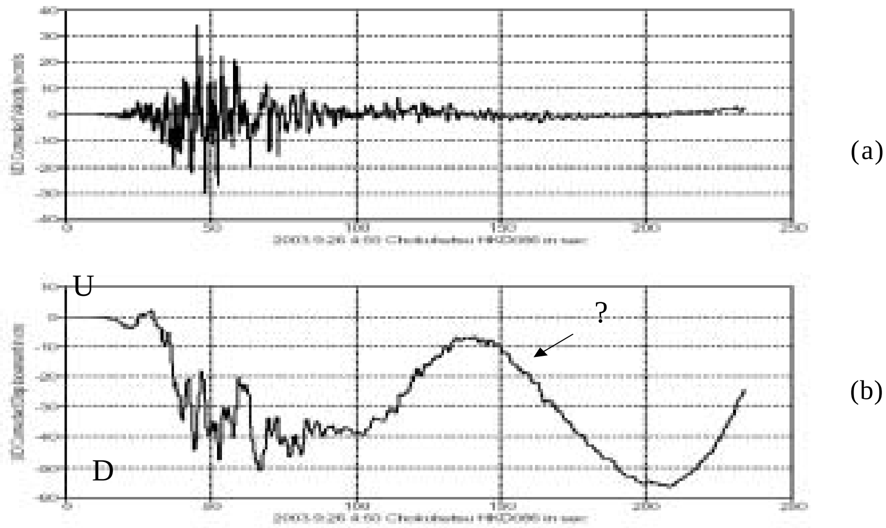

Figure A9. Corrected velocity and displacement of UD component