Journal of Global Positioning Systems (2006)
Vol. 5, No. 1-2:35-39

Journal of Global Positioning Systems
2006
© CPGPS

Prominent Postseismic Displacements of the 2003 MW 6.5 Chengkung Earthquake in Eastern Taiwan

Horng-Yue Chen[1], Shui-Beih Yu[1], Long-Chen Kuo[1] and Hsueh-Yen Hu[2]

1. Institute of Earth Sciences, Academia Sinica, P.O. Box 1-55 Nankang, Taipei, Taiwan
2. Kun San University of Technology, No. 949 Da-Wan Rd, Yeong-Hang, Tainan, Taiwan, ROC

Abstract. The M_W 6.5 Chengkung earthquake occurred at 04:38 UTC on 10 December 2003. Thirty continuously recording GPS stations (CORS) have been set up at different geological sites and distributed throughout a 140 km by 140 km area in southern Taiwan beginning in 2000. The GPS data is recorded daily for the CORS in 30 seconds sampling rate. The GPS data is utilized to study the coseismic and postseismic deformation associated with the Chengkung earthquake. The coordinates of the daily solution for each station were extracted from SINEX (Software INdependent EXchange) files to establish time series in the topocentric north-east-up (NEU) coordinate system. The secular crustal deformation of the station during the one year period was removed by applying the 2000-2003 interseismic velocities. The CORS near the Chihshan fault, which are located at the southern segment of the Longitudinal Valley Fault, indicated the largest postseismic displacement in eighteen months approached 86 mm (station SHAN) and 91 mm (station TAPO) in the horizontal and vertical components, respectively. The results of the CORS provide detailed information for the temporal process of postseismic deformation.

Keywords: postseismic deformation; Chengkung earthquake; Longitudinal Valley Fault

1. Introduction

A shallow earthquake (MW 6.5 and named Chengkung earthquake) occurred in eastern Taiwan at 12:38 local time on 10 December 2003. According to the Central Weather Bureau (CWB) of Taiwan (CWB earthquake report, 2003), the epicenter was located at 23.07°N, 121.40°E, with a focal depth of 17.7 km.. The coseismic horizontal displacements in the footwall of the LVF (the Central Range and the Longitudinal Valley) showed a fan-shape distribution with vectors towards N-NNE in the north, E-ESE in the middle, and SE-SSE in the south. On the other hand, the coseismic horizontal movements of the hanging-wall in the Coastal Range, revealed a mirror fan shape with vectors toward N-NNE in the northeast, NW-W in the middle-west, and SW in the south (Figure 1, Chen et al., 2006). The relocated hypocenter in the deep crust is surely more consistent with an east dipping seismic zone as determined by hundreds of aftershocks in the following days. This seismic zone is also consistent with the fault plane solution of the main shock as determined by the CMT inversion of broadband waveforms recorded at the Broadband array in Taiwan for seismology (Figure 2, Lin 2004).

To realize the movement characteristics of the Longitudinal Valley Fault after the Chengkung earthquake occurred on 10 December 2003, the data was acquired from thirty continuously recording GPS stations (CORS) of the Taiwan GPS network, established by Ministry of Interior (MOI), Central Weather Bureau (CWB), and Institute of Earth Sciences, Academia Sinica (IESAS) in this area. According to the pattern of the coseismic displacements of this earthquake, the deformation areas contained not only the Coastal Range, the Longitudinal Valley, the east side of the Central Range, but also extended to the west side of the Central Range in southern Taiwan.

Hence, we focused on a 140 kilometres square area, which almost covers the whole southern Taiwan. To accurately obtain the spatial and temporal variations of the postseismic displacements, the processing procedures (Chen et. al., 2006) have been applied, to precisely gain the movement characteristics after the earthquake. The relaxation times have been computed near the fault from the position variations. To clearly analyse the relative displacements across the Longitudinal Valley Fault, the profiles in the north, east and up components have been discussed. Due to the high relative velocity in this area and the longer observation period in this study, the determination of the temporal variations and postseismic displacements needs to be considered by the secular crustal motion of the stations which are computed by applying the 2000-2003 interseismic velocities.

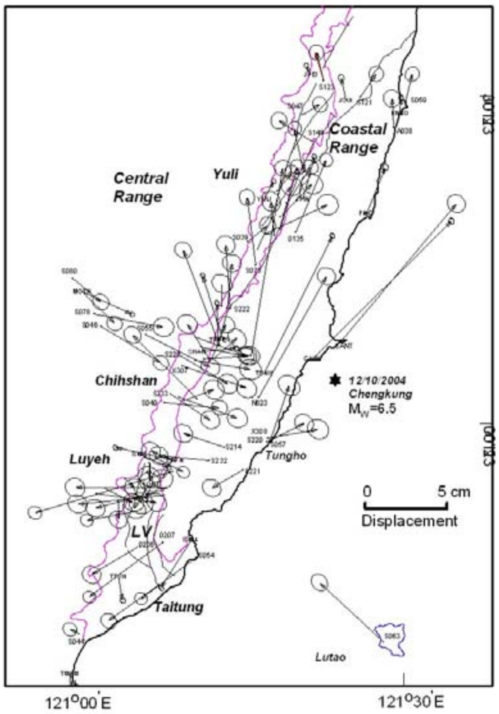
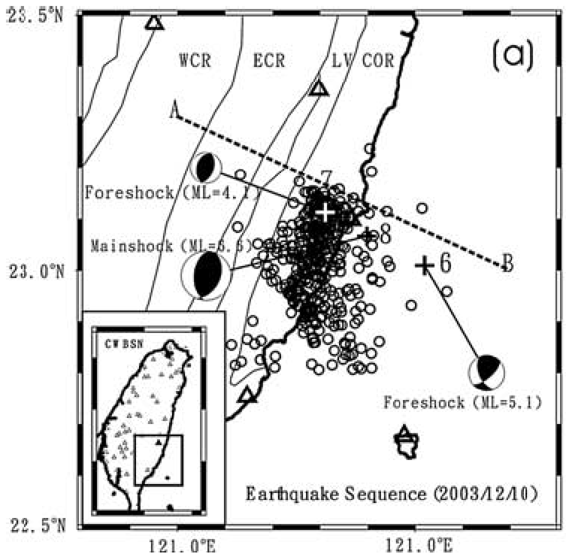


Figure 1. Horizontal coseismic displacements relative to Paisha, Penghu. The 95% confidence error ellipse is shown at the tip of each coseismic vector. The epicenter is marked by a solid star. LV and LVF denote the Longitudinal Valley and Lnogitudinal Valley Fault, respectively



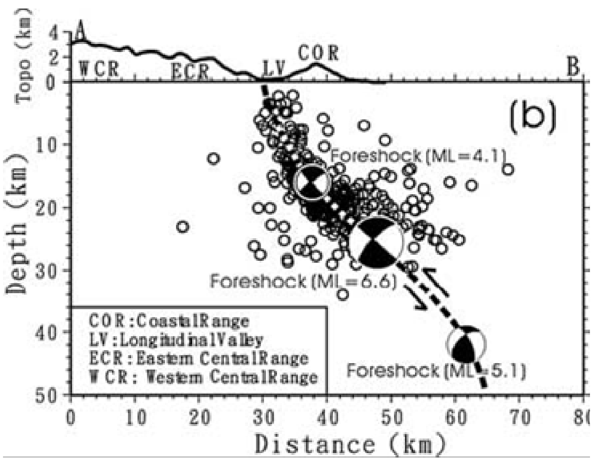


Figure 2. (a) Locations of aftershocks (circles), the main shock and two immediate foreshocks (pluses) of the December 10, 2003 earthquake sequence in the Chengkung area of eastern Taiwan. The focal mechanisms of the main shock and two foreshocks are also shown. The index map shows the study area and a regional seismic network (CWBSN) in the Taiwan area. (b) Projections of the aftershock hypocenters and focal mechanisms of the main shock and two foreshocks on the back-wall hemisphere in the A-B profile.

After the careful procedures, the relaxation times of postseismic deformation are acquired around 80 days for the Chihshan area in average and the maximum horizontal postseismic displacement in eighteen months was 86 mm at station SHAN which is three times larger than coseismic displacements and 91 mm of vertical components at station TAPO which is 1.2 times larger than coseismic displacements, respectively. To clarify the different periods of the postseismic displacements, six stage results have been displayed and discussed in every three months. However, almost a half of the total displacement occurred in the first three months of the eighteen months.

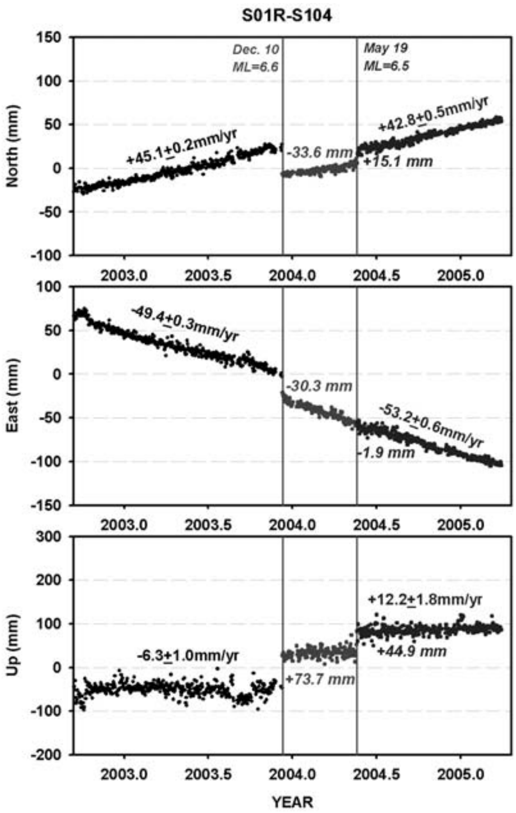
2. GPS network and data processing

The secular velocity field model and the reliable procedure for data processing are the main factors to obtain the precise displacements due to the earthquake, landslide or other temporal events. We established preseismic station velocities to determine each expected station position of the CORS, and adopted the standard procedures of the Bernese V4.2 software to acquire the daily solution from the years 2000 to 2003 (Chen et al., 2006).

We downloaded the regularly daily observations of the 30 stations of the CORS, and maintained the daily solution into SINEX (Software INdependent EXchange) files by Bernese V4.2 (Hugentobler et al., 2001) until June 2005, which was about 18 months after the mainshock. All of the solutions were referred to the Paisha station (S01R) at Penghu in the Taiwan Strait, and S01R is selected to define the “minimum constrained conditions” to its

International Terrestrial Reference Frame 2000 (ITRF00) coordinates.

In this study, we estimated the daily solution and constraining S01R's ITRF00 coordinate system, the results of the CORS provide detailed information for the temporal variations of postseismic deformation. The coordinates of the daily solution for each station were extracted from SINEX (Software INdependent Exchange) files to establish time series in the topocentric north-east-up (NEU) coordinate system. The secular crustal motion of the stations during the 18 month period was removed by applying the 2000-2003 interseismic velocities. On 19 May 2004 another large earthquake occurred near the Lutao island (Figure 5). The focal depth of the main shock was located at the depth of 8.7 km by CWB. The effect of the displacement can be found and estimated in the time series of the CORS (Figure 3). Considering the factors of the secular crustal motion, the coseismic displacement of other earthquakes and the postseismic displacement can be determined.



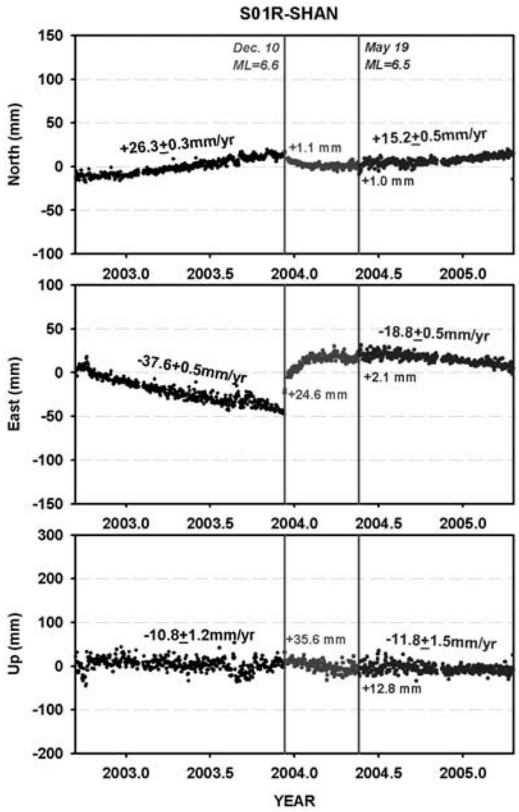


Figure 3. Position variation in station pairs, S01R-S104 (upper graph) and S01R-SHAN (lower graph). For each subplot, the abscissa denotes the time in year, and the ordinate are the north, east and up components of each baseline, respectively. The vertical line in each subplot indicates the time of the earthquakes, the number with the uncertainty values of the line express the relative velocities and the numbers without the uncertainty value means the relative coseismic displacements of the earthquake.

Figure 3 shows the preseismic variations, the coseismic offsets and the postseismic displacements in station pair S01R-S104 and S01R-SHAN from 2003 to 2005. We can find the coseismic displacements caused by two earthquakes (occurred on 10 Dec. 2003 and 19 May 2004) especially in the vertical component reach 77.3 and 44.9 mm for the station pair S01R-S104. The station pair S01R-SHAN only shows a small displacement by the second earthquake, but a significant nonlinear postseismic displacement can be seen after the first earthquake. This feature is commonly found around the Chihshang area. To figure out this significant nonlinear postseismic displacement behavior, the temporal variation can be computed by equation 1, and then the movement characteristics after the earthquake and the relaxation times near the fault can be estimated from the position variations (Figure 4).

$$Y = a - be^{-t/\tau} \tag{1}$$

where, t denotes day, y represents variation in different components, presents the relaxation time, a, b is the unknown coefficients.

Figure 4 shows the temporal variation in station pairs, S01R-SHAN (upper graph) and S01R-TAPO (lower graph). All of the point values in the different components of Figure 4 have been subtracted of the secular velocities due to the long time period and rapid relative velocity in this region. The largest relaxation time is 87 days, and it's almost 3 months.

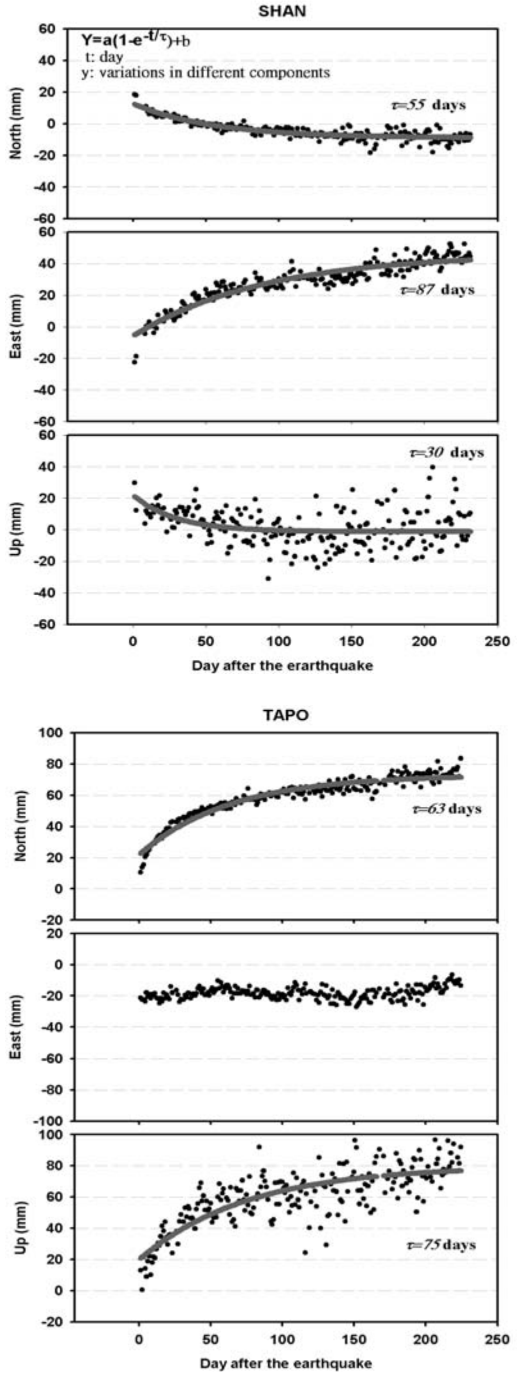


Figure 4. Temporal variation in station pairs, S01R-SHAN (upper graph) and S01R-TAPO (lower graph). For each subplot, the abscissa denotes the time in year, and the ordinate are the north, east and up components of each baseline, respectively.

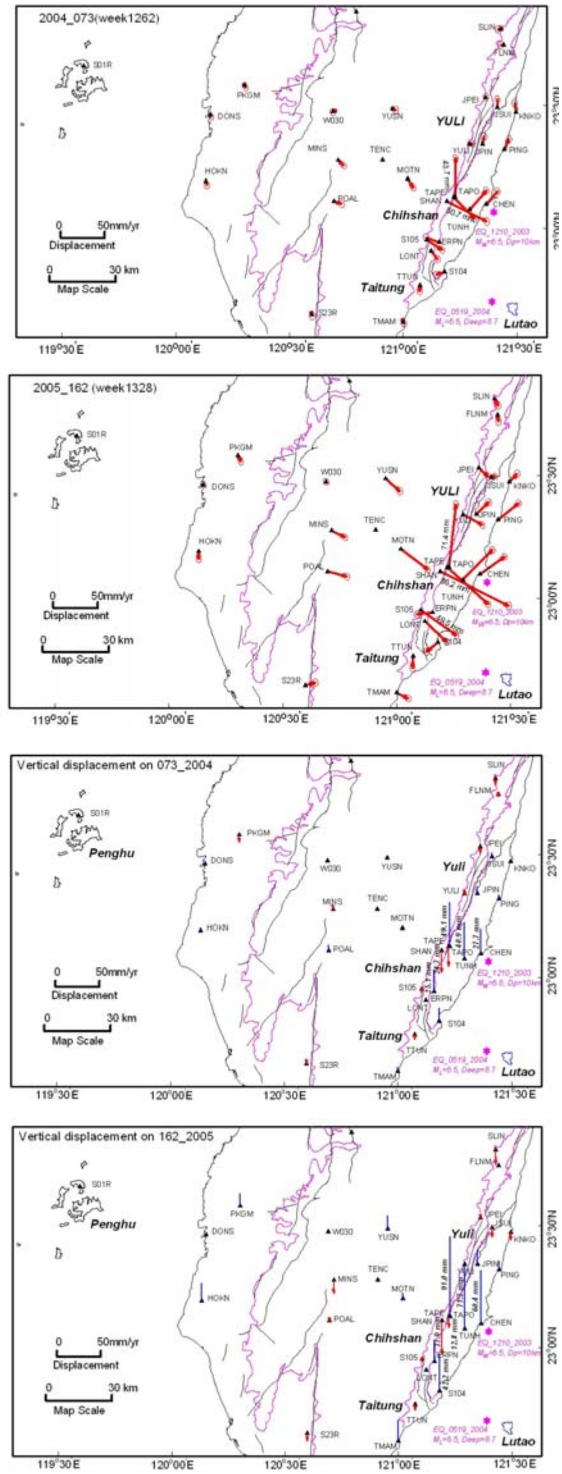


Figure 5. Poseismic displacements relative to Paisha, Penghu (S01R). The upper graph show the horizontal postseismic displacement in third and eighteenth month and the elevation changes in GPS height for the posteismic displacements (lower graph), respectively.

We plot the postseismic displacement at the third and eighteenth month of the postseismic displacement (Figure 5).The 95% confidence error ellipse is shown at the top of each postseismic vector. The epicenter is marked by a solid star. LV and LVF denote the Longitudinal Valley and Lnogitudinal Valley Fault, respectively.

The stations at the west side of the Longitudinal Valley, Central Range move a fan shape: the stations moved eastward near the latitude of the epicentre, and they moved northward or northeast ward in the northern part and southward in the southern part of the Central Range. The stations in the hanging-wall of the Coastal Range, from the north to the south, the station movements show a clear fan shape, which likes a mirror of the fan of the foot-wall displacements. This movement behaviour is the same as the coseismic displacement (Chen et al., 2006).

3. Discussion

In this study, we estimate the postseismic displacements of the CORS in southern Taiwan from the earthquake to July 2005. Two different stages of deformation have been determined, which are 3 and 18 month after the Chengkung earthquake. The results reveal a rapid motion in postseismic displacements around the Chihshan area, which is located on both sides of the Longitudinal Valley. The largest postseismic displacement in eighteen months approached 86 mm (station SHAN) and 91 mm (station TAPO) in the horizontal and vertical components, respectively. However, the station MOTN, which is located in the Central Range, moves to eastward and the postseismic displacement reaches 38 mm.

The poseismic displacements for the stations at the west side of the Longitudinal Valley, Central Range show a fan shape: the stations moved eastward near the latitude of the epicenter, and they moved northward or north-eastward in the northern part and southward in the southern part of the Central Range. The stations in the hanging-wall of the Coastal Range, from the north to the south, the station movements show a clear fan shape, which likes a mirror of the fan of the foot-wall displacements. This movement behavior is the same as the coseismic displacement.

Comparing to the relative coseismic displacement in Chihshang area, they are +40.8 mm, -36.6 mm and +35.2 mm for the north, east and up components, respectively. For the relative postseismic displacement, they are +109.5 mm, -69.0 mm and +128.9 mm, respectively eighteen months after the mainshock. It reveals that the surface postseismic displacement of the earthquake near the Chihshang area are two to three times more than that of the relative coseismic displacements.

References

Broadband array in Taiwan for seismology (2003) http://bats.earth.sinica.edu.tw/.

Hugentobler U., Schaer S., Fridez P. (2001) ***Bernese GPS software Version 4.2***, 515pp, Astro. Inst., Univ. of Berne, Berne, Switzerland.

Chen H.Y., Yu S.B., Kuo L.C., Liu C.C. (2006) ***Coseismic and postseismic surface displacements of the 10 December 2003 (MW 6.5) Chengkung, eastern Taiwan, earthquake***, Earth, Planets and Space, 58, 5-21.

Lin C.H. (2004) ***Repeated foreshock sequences in the thrust faulting environment of eastern Taiwan***, Geophysical Research Letters, vol. 31, L13601, doi:10.1029/2004GL019833.