Movement behavior of the continuous recording GPS stations after the 2003 M_W 6.5 Chengkung earthquake in eastern Taiwan

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Abstract

There are more than 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 since 2000, and the amount of the CORS are still under increasing in this area which is recognized the suture zone between the Philippe sea plate and Eurasia plate. From the year 2000 to the end of 2005, we analyze the daily solutions to obtain the average station velocities before and after the Chengkung earthquake which occurred near eastern Taiwan at 04:38 UTC on 10 December 2003. After considering the effects of the coseismic and postseismic displacements, the difference of the horizontal components reaches 13 mm/year of the average station velocity happened in the east side of the Central Range. To the vertical component, all of the stations are risen which located in the Coastal Range, and the largest difference approaches 20mm/year.

Keywords: coseismic and postseismic deformation; Chengkung earthquake; Longitudinal Valley Fault.

1. Introduction

Since 1994, the Institute of Earth Sciences, Academia Sinica (IESAS) has settled down three continuous operation GPS reference stations (CORS), combined with campaign mode stations, to detect the surface motions of the aseismic, coseismic and postseismic displacements, to realize the conduction behaviors of the collision zone, and to study the detail structures of the near fault between Central Range and Coastal Range located in southeastern Taiwan (Figure 1). After the disaster earthquake, named Chi-Chi Taiwan earthquake (M_w 7.5), occurred on 21 September 1999 (Chien, 1999), the IESAS cooperates with the Central Weather Bureau (CWB), the Ministry of the Interior (MOI) and other research institutes to build up the CORS network of the whole Taiwan. For the deformation monitoring point of view, the IESAS calculates the daily solutions, analyses the position scatters and estimates the velocity field of this network. This network success to estimate the aseismic, coseismic and postseismic displacements following the M_w 6.5 Chengkung earthquake, happened at Taitung conty on 10 December 2003 (Chen et al., 2006).

In this paper, we adopt 28 CORS with part of the Taiwan network in the southernmost Taiwan, to study the movement behaviors after the Chengkung earthquake (Figure 1). Compared with the aseismic and postseismic velocity field in the southern Taiwan, the difference reaches 13 mm/year in the horizontal component of the average station velocities happened in the east side of the Central Range. To the vertical component, all of the stations are risen which located in the Coastal Range, and the largest difference approaches 20mm/year.

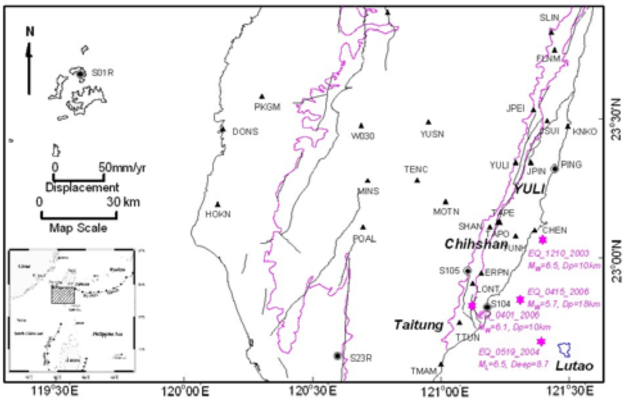

Figure 1. Show the study area with part of the CORS in the south of Taiwan. The solid circles denote the stations set up since 1994, the triangle presents the new stations begun in 2001, and the star represents the epicenter and magnitude of the larger earthquakes in the southeastern Taiwan in two years.

2. GPS Data computing strategy and their imply geological movement behaviors

2.1 GPS Data computing strategy

For the CORS of the Taiwan, the observation data was 24 hours a day, the sampling rate was 30 seconds and 1 Hz, and the cutoff angle was 10° in elevation. The raw data were transferred to RINEX (Receiver INdependent EXchange) format for post-processing. We made an effort for removing the environmental obstruction, such as trees or grass, to reduce the effect from multipath. (Yu et al., 2001). All GPS data were processed into a daily solution following the standard procedures of the Bernese V4.2 software (Hugentobler et al., 2001). The station, S01R, at Penghu located at the stable Chinese continental margin was chosen to define the "minimum constrained conditions" to its International Terrestrial Reference Frame 2000 (ITRF00) value.

The data processing procedure in IESAS is listed below.

(1) Employ the International GPS service (IGS) final orbit to reduce the effects of the orbit errors.

(2) Utilize the antenna calibration table from the Astronomical Institute University of Bern, (AIUB), National Geodetic Survey (NGS) and National Oceanic and Atmospheric Administration, U.S. Department of Commerce to reduce the effect of the phase center biases.

(3) Form the double-differenced ionosphere-free linear combination of carrier phase observation to mitigate the first order ionospheric bias.

(4) Estimate the difference between the actual zenith delay based upon a standard atmosphere model (Saastamoinen, 1973) to determine the residual tropospheric zenith delay, then conducted estimates every 2 hours per station simultaneously with the station coordinates by least squares adjustment.

(5) Constrain the daily solution to the Paisha station, at Penghu (S01R), which has a precise ITRF00 coordinate and is located in the stable Chinese continental margin.

(6) Output the daily solution in Software Independent Exchange (SINEX) format.

In this paper, we focus on study the aseismic and postseismic movement behaviors in the southeastern Taiwan, especially along the both side of the Longitudinal Valley Fault. Hence, all of the CORS located at this area are included, but only 7 stations on the Central Range and 4 stations on the Coastal Plant are chosen, although there are more than 50 CORS in the southern Taiwan.

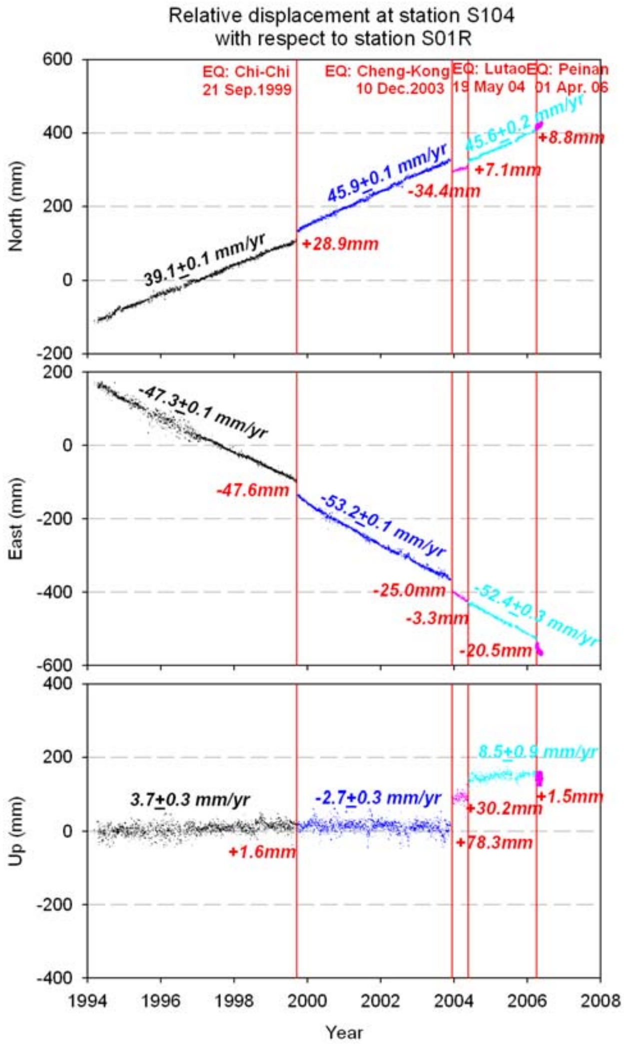

Figure 2. The daily time series of the station S104 with respect to station S01R sine 1994.

Figure 2 shows the daily time series of the station S104 with respect to station S01R since 1994. For the each subplot, the x-axis denotes the north, east and up component (units in mm), respectively, and the y-axis presents the time in years. All of the scatters are reduced the mean values The vertical lines of the subplots show the occurred time of the earthquakes which is happened near the southeastern Taiwan and the magnitude is larger than 6.0. Since 1994, there are 4 large earthquakes affect the relative positions, which are Chi-Chi earthquake on 21 September 1999, Cheng-Kong earthquake on 10 December 2003, Lu-Tao earthquake on 19 May 2004, and Pei-Nan earthquake on 1 April 2006 (Figure 1).

Station S104 locates in the east side of the Coastal Range and station S01R settles at Penghu at the stable Chinese continental margin, hence this long term daily solution can been identified with the crustal movement of the Coastal Range and Chinese continental. Moreover, these quakes cause 28.9mm, -34.4mm, 7.1mm and 8.8mm on the north component, -47.6mm. -25.0mm, -3.3 mm, and -20.5mm on the east component, and on the up component there are 1.6mm, 78.3mm, 30.2mm and 1.5mm uplifting, respectively.

To the velocity in each subplot, a large difference is occurred in the Chi-chi earthquake. The velocity make changes from 39.1±0.1mm/yr to 45.9±0.1mm/yr in the north component, -47.3±0.1mm/yr to -53.2±0.1mm/yr in the east component, and 3.7±0.3mm/yr to -2.7±0.3mm/yr in the up component. However, to the Cheng-Kong and Lutao earthquakes, the velocities are slightly affected to the north and east component. To the up component, there are not only caused 108.5mm (78.3mm and 30.2mm) uplifting and also the velocity shifts from -2.7±0.3mm/yr to 8.5±0.9mm/yr, due to station S104 is close to the epicenters.

2.2 Geological movement behaviors of the Cheng-Kong earthquake

The Longitudinal Valley Fault is an extremely active high-angle oblique thrust fault with a minor left-lateral strike-slip component (Barrier et al., 1982; Yu and Liu, 1989). The earthquake occurred in the eastern side of the Longitudinal Valley is reduced by the every quake in the east component. Table 1 shows the preseismic and postseismic velocities of the Cheng-Kong earthquake in the 28 CORS. We estimate the velocities using the liner regression algorithm in the north, east and up component, respectively.

According to the different relaxation periods caused by the vary earthquakes, the daily solutions with the nonlinear postseismic displacements have been ignored in the regression procedures (Chen et al., 2005).

Table 1. The preseismic and postseismic velocities of the Cheng-Kong earthquake.

Table 1. (Continued)

Velocity / Station	N (mm/yr)	E (mm/yr)	U (mm/yr)
CHEN	48.4±0.2 51.8±0.4	-54.8±0.3 -47.0±0.5	-4.6±0.9 14.3±1.5
DONS	-2.2±0.2 -1.4±0.3	0.9±0.2 -3.5±0.3	-49.0±1.2 -48.0±1.3
ERPN	45.6±0.2 51.6±0.2	-55.2±0.1 -54.4±0.2	3.3±1.4 9.7±0.7
HOKN	0.2±0.2 0.8±0.2	-0.7±0.2 -2.1±0.3	-20.6±0.8 -7.7±0.6
JPEI	32.8±0.3 29.2±0.2	-36.3±0.3 -35.3±0.3	-13.3±1.0 -17.3±0.9
JPIN	49.2±0.2 53.0±0.3	-45.5±0.3 -42.2±0.3	-8.9±1.0 4.8±0.9
JSUI	50.0±0.7 45.8±0.2	-49.0±0.4 -46.3±0.3	-3.9±0.8 -7.9±0.8
KNKO	50.8±0.3 54.1±0.2	-51.3±0.4 -49.2±0.3	-12.2±1.1 -10.7±0.7
LONT	30.2±0.6 24.6±0.3	-34.8±0.8 -28.6±0.3	-4.0±2.3 1.3±0.7
MINS	7.7±0.3 9.5±0.5	-36.4±0.4 -34.7±0.5	3.8±1.2 -9.1±1.3
MOTN	12.6±0.4 8.8±0.4	-35.2±0.6 -25.3±0.7	-6.4±2.0 -8.7±1.8
PAOL	3.5±0.3 4.5±0.2	-45.9±0.4 -34.7±0.5	-6.4±2.0 -8.7±1.8
PING	52.5±0.3 58.3±0.2	-51.3±0.3 -44.5±0.3	-11.0±1.0 -0.3±0.8
PKGM	4.6±0.2 4.6±0.2	0.7±0.2 -1.7±0.2	-40.5±1.1 -15.9±0.7
S23R	1.7±0.2 7.0±0.3	-52.3±0.4 -50.0±0.4	-4.7±0.9 -4.2±1.0
S104	45.9±0.1 45.6±0.2	-53.2±0.1 -52.4±0.3	-2.7±0.3 8.5±0.9
S105	22.0±0.2 15.5±0.3	-30.2±0.3 -20.0±0.3	-8.6±0.9 -6.1±1.0
SHAN	25.9±0.2 20.4±0.3	-33.8±0.3 *-21.1±0.3*	-12.0±1.0 -13.2±0.7
TAPE	28.6±0.4 21.5±0.2	-35.2±0.7 -27.7±0.7	-17.1±1.6 -10.4±0.9
TAPO	44.4±0.3 *57.5±0.2*	-47.2±0.4 -43.4±0.3	1.2±0.9 20.5±1.0
TENC	11.7±0.4 12.1±0.5	-34.7±0.5 -21.7±0.8	4.9±1.5 -12.3±1.5
TMAM	11.5±0.1 10.3±0.2	-35.4±0.2 -28.1±0.3	-4.7±0.9 -12.4±1.6
TTUN	14.0±0.2 13.3±0.4	-34.7±0.2 -33.1±0.4	11.0±1.2 -5.7±1.4
TUNH	39.5±0.3 50.3±0.3	-40.9±0.4 -40.8±0.3	-12.4±1.2 15.2±1.1
W030	3.1±0.2 12.1±0.5	-26.0±0.3 -30.1±0.3	1.8±0.8 -4.6±0.8
YULI	30.2±0.2 21.2±0.4	-35.8±0.3 -26.1±0.5	-13.9±0.9 2.1±1.4
YUSN	16.4±0.3 16.5±0.3	-38.7±0.3 -37.4±0.3	11.2±1.0 6.2±0.8

In the Table 1, the upper column denotes the preseismic velocity (data period form 1 Jan. 2002 to 10 Dec. 2003, except station S23R, S104, S105 and PING, data time period from 1 Jan 1994 to 10 Dec. 2003), and the lower column presents the postseismic velocity (data period form 11 Dce. 2003 to 31 Dec. 2005) to the north, east and up component, respectively. For the stations located in the Coastal Range, the different velocity in the north and the up components are increased after the Cheng-Kong earthquake represented in bold and the largest differences reach 13.1mm/yr and 19.3mm/yr (station TAPO), respectively, for the stations along the eastern side of the Central Range, YULI, SHAN, MOTN, S105, the east component are almost reduced 10 mm/yr.

To clarify all of the station velocities before and after the Cheng-Kong earthquake, we plot the horizontal and up components in Figure 3 and 4, respectively. In the Figure 3, the dot-dash line displays the station velocity only for station S23R, S105, PING and S104 from 1994 to 1999 and the solid line denotes the station velocity before the Cheng-Kong earthquake, and the dash line presents the station velocity after the Cheng-Kong earthquake. There are no obvious difference in the Coastal Plain (stations: PKGM, DONS and HOKN) and the west side of the Central Range (stations: W030, MINS, POAL and YUSN). Along the east side of the Central Range (stations: JPEI, YULI, TENC, MOTN, SHAN and S105) and the western side of the Longitudinal Valley (stations SHAN, TAPE and LONT), the shorten rate has 10 mm/yr in average. Most of the stations located in the Coastal Range, the velocity directions move to the north (stations: KNKO, PING, CHEN, JPIN, TUNH, TAPO and ERPN).

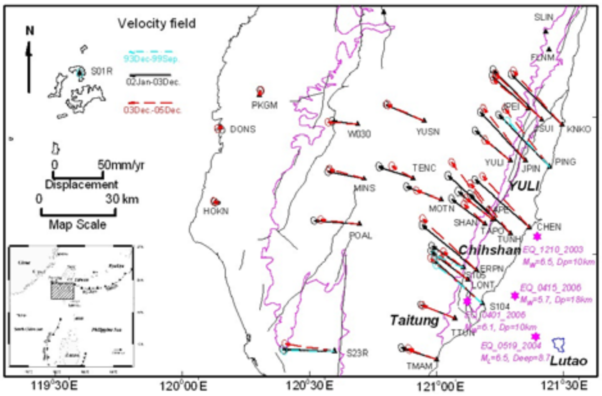

Figure 3. The station velocities before and after the Cheng-Kong earthquake in the horizontal component

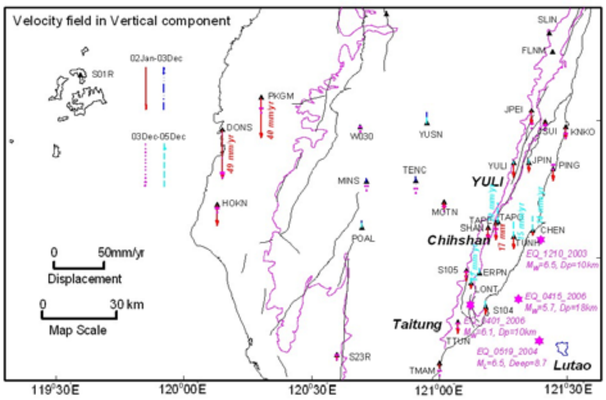

Figure 4. The station velocities before and after the Cheng-Kong earthquake in the up component

In the Figure 4, the dot-dash line displays the ascending station velocity and the solid line denotes the descending station velocity before the Cheng-Kong earthquake, and the dash line presents the declining station velocity and the dot represents the rising station velocity after the Cheng-Kong earthquake. Before the Cheng-Kong earthquake, except for the stations in the Coastal Plain (stations: PKGM, HOKN and DONS) affected by the agricultural applications caused the up component has the large declines in the seasonal changes, all of the station velocity only show a few millimeters/year variation in the up component. A slight ascend to the stations located in the Central Range (YUSN, TENC, MINS and POAL), and a few millimeters/year descend to the Coastal Range. After the Cheng-Kong earthquake, there are no obvious differences in the Coastal Plain and the Central Range (YUSN, TENC, MINS and POAL). In the Coastal Range, the up component shows a few millimeters/year ascending. The larger uplifting stations occurred near the epicenter, and the largest uplift station happened in the station TAPO with 19.3mm/yr.

3. Conclusion

We cooperate with the CWB, MOI and other Institutes to build up the CORS in Taiwan since 1994, and there are more than 200 CORS have been maintained and operated in regularly till 2006, to provide the station positions and other applications in Geomatics, Geology, and seismology studies. The Cheng-Kong earthquake occurred on 10 December 2003 is the largest inland earthquake in southeastern Taiwan in recent years, and this earthquake caused prominent coseismic and postseismic displacements have been estimated successfully from the CORS.

In this paper, we analyze the station variations of the 28 CORS from 2002 to 2006, and some conclusions can be listed below.

1. The stations located in the Coastal Range, the different velocity in the north and the up components are increased after the Cheng-Kong earthquake and the largest differences reach 13.1mm/yr and 19.3mm/yr (station TAPO), respectively.
2. The stations along the eastern side of the Central Range, YULI, SHAN, MOTN, S105, the east component are almost reduced 10 mm/yr.
3. There are no obvious different velocity in the Coastal Plain (stations: PKGM, DONS and HOKN) and the west side of the Central Range (stations: W030, MINS, POAL and YUSN).
4. Along the east side of the Central Range (stations: JPEI, YULI, TENC, MOTN, SHAN and S105), and the western side of the Longitudinal Valley (stations SHAN, TAPE and LONT), the shorten rate reaches 10 mm/yr in average.
5. Most of the stations located in the Coastal Range, the velocity directions move to the north (stations: KNKO, PING, CHEN, JPIN, TUNH, TAPO and ERPN).
6. For the up component, there are no obvious differences in the Coastal Plain and the Central Range (YUSN, TENC, MINS and POAL), but in the Coastal Range, the

differences show a few ascending.

7. The larger uplifting stations occurred near the epicenter, and the largest rising station happened in the station TAPO with 19.3mm/yr.

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Reference

1. T. L. Chien, “The 921 Earthquake Emergency Measures”, *in Proc. International Workshop on the Chi-Chi, Taiwan earthquake of September 21, 1999*, Taichung, 1999, 10-1-10-10.
2. H. Y. Chen, S. B. Yu, L. C. Kuo and C. C. Liu, ”Coseismic and Postseismic Surface Displacements of the 10 December 2003 (MW 6.5) Chengkung, Eastern Taiwan, Earthquake”, *Earth Planets Space*, Vo. 58, 2006, pp.5-21.
3. I. I. Saastamoinen, “Contribution to the theory of atmospheric refraction”, *Bull. Geod.*, Vo. 107, 1973, pp. 13-24.
4. U. Hugentobler, S. Schaer and P. Fridez, “Bernese GPS Software Version 4.2”, *Astro. Inst., Univ. of Berne, Berne, Switzerland*, 2001, pp. 515.
5. S. B. Yu, and L.C. Kuo, “Present-Day Crustal Motion along the Longitudinal Valley Fault, Eastern Taiwan”, *Tectonophysics*, Vo. 333, 2001, pp. 199-217.
6. E. Barrier, J. Angelier, H.T. Chu, and L.S. Teng, “Tectonic Analysis of Compressional in an Active Collision Zone: The Deformation of Pinanshan Conglomerates, Eartern Taiwan”, *Proc. Geol. Soc. China*, Vo. 25, 1982, pp. 123-138.
7. S. B. Yu, and C.C. Liu, “Fault Creep on the Central Segment of The Longitudinal Valley Fault, Eastern Taiwan”, *Proc. Geol. Soc. China*, Vo. 32, No. 3, 1989, pp. 209-231.
8. H. Y. Chen, S. B. Yu, L. C. Kuo and H.Y. Hu “Prominent Postseismic Displacements of the 2003 M_W 6.5 Chengkung Earthquake in Eastern Taiwan” *Int. Symp. on GPS/GNSS*, Hong Kong, 8-10 December, CD-ROM procs., 2005, paper 8B.