Joint observation of long period tremor signals with broadband seismometer, tiltmeter and gravimeter^{*}

ZHANG Yan-bin^{1),*} (张雁滨) JIANG Jun¹⁾ (蒋 骏) LIAO Ying-chun¹⁾ (廖盈春)
LI Sheng-le²⁾ (李胜乐) ZHONG Tie-tao¹⁾ (钟铁涛)

1) Huazhong University of Science and Technology, Wuhan 430074, China

2) Institute of Seismology, China Earthquake Administration, Wuhan 430071, China

Abstract

We report here the observation result of joint observation of long period tremor signals with broadband seismometer, tiltmeter and gravimeter at the HUST (Huazhong University of Science and Technology) station. The observed data were compared and analyzed. Since 2005, the several tens of abnormal tremor signals which are weak, complex and duration of 2 to 3 days have been synchronously recorded by the different instruments. The tremor signals have the periodic domain in the range of 3 to 5 minutes, 20 to 30 minutes and even more than 1 hour. The observation shows such tremors are a physical existence. The analysis indicates that a part of the tremors caused by the typhoon from the western Pacific Ocean. These tremors have a close relationship with wind velocity of typhoon and distance between the typhoon center and the station. Except these, the cause of others is still unclear.

Key words: broadband seismometer; gravimeter; tiltmeter; long period signal; tremor; typhoon

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Introduction

Some abnormal tremor signals can be frequently recorded before and after a strong earthquake by the tiltmeter, strainmeter, gravimeter, fault deformer and broadband seismometer. Compared to an earthquake, they are called “slow earthquake” or “long period events”, *etc.*, for its lower frequencies and long attenuation time. For example, Kizawa (1972) recorded such precursory wave signals before the strong earthquakes with the gravimeter. Since the end of 1990s, with the development of observational technique, many scientists have being considerable interested in this topic. A plenty of scientist thought these signals could reveal the complexity of the earthquake occurrence process, and thus they are significant to the fundamental study of the seismology (Hirn and Laigle, 2004; Miller *et al.*, 2002; XU, 2006; WU, 2001; ZHAO *et al.*, 2001; TANG *et al.*, 2002). Nowadays, many researchers, for example, from U.S. and Japan, began to study this signal in some special tectonic regions using the GPS and broadband seismograph (Obara, 2002; Rogers and Dragert, 2003; Ito *et al.*, 2007; Shelly *et al.*, 2006; Melbourne and Webb, 2003; Szeliga *et al.*, 2004; Stokstad, 2002). They observed not only slow slip events, but also episodic tremor and ac-

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⁺ **Author for correspondence:** Zhangybn@public.wh.hb.cn

tivities of slow earthquakes.

Several days before the West to Kunlun Mountain Pass earthquake of $M_s 8.1$, Xinjiang seismograph network simultaneously recorded the long-period abnormal wave signals (YANG *et al.*, 2003). Also, we have observed the abnormal deformation before the strong earthquake with strainmeter and tiltmeter in the Yunnan Province and the Northern China (ZHANG *et al.*, 2002). Due to lack of systematical observation to these abnormal signals, there are not enough observation cases and records at present. Although there exist difference to define and name it, and observational means are different, it is common recognition that these signals are complex and weak, with wide frequency band (from a few seconds to several days).

The signals which are recorded by tiltmeter, gravimeter and the broadband seismometer contain complete information of frequency band from seismic wave to earth tides. If the abnormal tremor signals are a physical existence, the above-mentioned instruments can use to record them synchronously and multi-observe the signals, or else that is possible just a special incident. So we began joint observation at the HUST (Huazhong University of Science and Technology) Seismic and Earth Tide Observatory (HUST-SETO) in Wuhan, China, using the DZW gravimeter, VS pendulum tiltmeter and JCZ-1 broadband seismograph. Our observation mainly aims to low-frequency signal (period from minute to hour). This paper reports the continuous observation and analysis during recent three years.

1 General situation and background of observation

HUST-SETO locates at the Yujia mountain in Huazhong University of Science and Technology. The cave in length reaches 150 m, the covering thickness is more than 40 m; the variation in temperature is less than 0.1°C annually, and less than 0.0005°C daily inside the cave. The DZW spring gravimeter, VS pendulum tiltmeter (they were installed on July, 2004 and put in operation at the end of 2004) and JCZ-1 broadband seismometer (It was installed on December, 2005 and put in operation in January, 2006) are put on a block of rock. The JCZ-1 with a wide frequency response range from 20 Hz to direct current (channel BB for velocity: 20 Hz~360 s; channel LP for acceleration: 360 s~DC). The data acquisition card of NI (National Instruments) is chosen for data acquisition, the software Lab-VIEW, is doing the job of data acquisition, displaying and storing. In order to assure the signals accurate and reliable, we have done related test and analysis (JIANG *et al.*, 2006).

In order to record a smoothly tidal signal, the instrument's developer made a couple of low-pass filter (the time constant is 0.1 s and 5 s^①, respectively) in the circuit of the tiltmeter and the gravimeter. We record these two signals. One is for a higher cut-off frequency and has richer signals, and other one is for a lower cut-off frequency and apply to the analysis of the earth tides. Because of having lost most of high-frequency information after two filters, the tremor signals cannot be observed, we use the signals after just one filtering to make analysis on tremor.

JCZ-1 very broadband digital seismograph has high sensitivity, the signal from channel LP of acceleration is mostly the Earth tides, which we have analyzed (ZHANG *et al.*, 2006). In this paper, we use the signals from the channel BB of the velocity, with a broadband from 20 Hz to 360 s. Because the signal is not cut off, but attenuate gradually with the period longer than 360 s (CAI *et al.*, 1995), the Earth tides can be recorded clearly in component UD and EW of the channel BB. However, the amplitude of the tides is smaller compared with that observed with the gravimeter

^① The parameters are provided by the developer of the instruments.

and tiltmeter, while high-frequency signals are more clear compared with that observed with the gravimeter and tiltmeter (see Figure 1, one seismograph datum per 30 s and one datum of the gravimeter and tiltmeter per minute, the data value is count.). Also we can see that the observation signals of gravimeter and tiltmeter accord with the broadband seismograph.

Figure 1 Observations of broadband seismometer (BB), gravimeter and tiltmeter (2006-11-10~2006-11-20)

2 Observation of abnormal wave signal and primary analysis

2.1 Abnormal wave signal

During recent triennium, apart from the earthquake and Earth tides about 70 abnormal tremor signals have been recorded synchronously by the seismograph, gravimeter and tiltmeter. Such signals are weak; duration of 2 to 3 days (see Figure 2). Taking observation data in Figure 2 as a case, if eliminate the earth tides signal in the observation, that tremor signals like a spindle overlap with the background signal. These abnormal signals have different amplitude (Figure 3).

If filtering the signals with period larger than three hours of gravity, tiltmeter and BB channel signal (All use the data per minuter), the spectral analysis on tremor shows that, the tremors consist of rich frequencies components, the period from several minutes to the more than one hour. Though the spectrogram of tremors is different, they have some common features, *i.e.*, the signal with periods longer than 20 minutes and 70 minutes. For example, comparing the result (Figure 4) of the spectral analysis on the data in Figure 3 on 10th, 19th (have tremor signal) and 23rd August

(no tremor signal), it can be seen the background signal (23rd) have the periodic domain in the range of 10 to 16 minutes (Figure 4c), however, the tremor signal (10th and 19th) have the periodic domain in the range of 20 to 30 minutes and 20 to 30 minutes and more than 70 minutes (Figures 4a and 4b) .

Figure 2 Tremor signals observed by seismometer, gravimeter and tiltmeter (2006-08-01~2006-08-31)

Figure 3 Digital filtering residual results for gravity observation (2006-08-01~2006-08-31)

Figure 4 Spectrum analysis of the tremor and normal background noise
(a) 2006-08-10; (b) 2006-08-19; (c) 2006-08-23

2.2 Abnormal tremor signal caused by the typhoon

Our research shows that a part of the tremor signals have relationship with the typhoon from the western Pacific Ocean.

Typhoon is the tropical cyclone which rotates fiercely on the center of low air pressure, the radius of which is more than several ten kilometers to several hundred kilometers. In the region of the tropical cyclone, the gradient of level air pressure is big; it brings gale and rainstorm to where it reaches, and along with tremendous energy. The average velocity of its movement is about 20~30 km/hour. When it landfall, as influenced by the friction of the rough ground, the wind power and the energy are decreasing. Through the analysis of the relationship between the tremor signal and other factors^① such as the path of movement and velocity of the typhoon, we find that the tremor signal closely associate with wind velocity of typhoon and distance between the typhoon center and the station (Figure 5).

Figure 5 A comparison of the tremor signal with typhoon distance, wind velocity (2006-08-01~2006-08-11)
(a) Distance between the typhoon center and station; (b) Change of wind velocity; (c) Tremorsignals from gravity data

For example, Figure 5 shows the change of the distance between the typhoon center and our station in two typhoon in 2006 (Prapiroon and Saomai) (Figure 5a), the change of velocity (Figure 5b) and the tremor from gravity data (Figure 5c). The typhoon Prapiroon from the west Philippines on 1st August 2006, enter the continental shelf of the South China Sea on the 2nd, landfall the Guangdong Province on 3rd August then disappears after being weakened into the low air pressure on the afternoon on 4th August. Correspondingly, the tremor signal appears on 2nd to 4th August. The wind velocity is the largest from the afternoon of the 2nd to the 3rd that is consistent with the change of the tremor signal. Also, the tremor signal between the August 8th and the 11th comes from the famous typhoon, Saomai. It originates on August 5th and enters the South-Eastern China Sea on 9th August with wind speed accelerating, and it landfall between the Fujian Province and the Zhejiang Province on 10th August. After the landfall it weakened into tropical storm on

^① The data related to typhoon are from <http://www.typhoon.gov.cn>

the morning on 11th August, and then disappears later. That's why the tremor signal appears on 9th to 11th August, consistent with this process. As the wind velocity is the most on the August 10th and it landfall on this day so the tremor is strongest. Because the wind power of the Saomai is bigger than Prapiroon's (at the same distance), and the distance from the landfall place to Wuhan is shorter than the Prapiroon's, so the tremor signal from Saomai is stronger than from Prapiroon's.

For the past several years, whenever the typhoon is near the coastland of China or landfall, it can cause abnormal tremor signals in our observation.

2.3 Tremor signal not caused by the typhoon

Except for the tremor signals caused by the typhoon, the causation of other tremor signals is unclear, still many questions can not be answered. For example, the tremors are on November, 2006 (Figure 1), and on July, 2006 (Figure 6), *etc.*

Figure 6 The tremor observed by seismometer, gravimeter and tiltmeter before the 7.3 Indonesia earthquake (2006-07-11~2006-07-20)

These tremor signal can cause observational curve become thicker, it overlaps with the observed background signal curve as a tail. The waveform and duration is similar to the Kizawa's signals (Kizawa, 1972) observed before the Alaskan's great earthquake on 28th March and Niigata earthquake on 16th June 1964.

Obara (2002) first observed the episodic tremors in South-western Japan, and later it is also observed in Cascadia subduction zone (Rogers and Dragert, 2003). Miyazawa and Mori (2005) reported the similar signal caused by the distant earthquake. In China, XU (2006) also reported the tremor events which is recorded by the broadband seismometer, and concerned with the long range movement of stratum and strong earthquake. Reports by Ito *et al* (2007) and Shelly *et al* (2006) on the tremor signal observed in the subduction zone shows that the tremor is relevant to the slow earthquake and conformation movement in these zones. Early in this year, there was new report that the tremor with periods of 12.4 and 24 to 25 hours is modulated by the tides (Rubinstein *et al*, 2008). So the causation of the tremor signal is diversity, however, relative to an ordinary earthquake, tremor signals is weak and have longer durations.

Our observation approve the tremor is the real signal. However, how does this signal originate? Whether it concerns with the conformation movement or the earthquake? To solve these problems, it needs more analysis and research.

3 Conclusions

During recent triennium, we recorded the several tens abnormal tremor signals synchronously

by the seismograph, gravimeter and tiltmeter. These tremor signals are weak and duration of 2 to 3 days, the signal like a spindle or a tail overlaps with the observational background curve. Though the tremors have different spectrum components; but all of them have lower frequency component.

The analysis shows that a part of the tremor signals caused by the typhoon from the western Pacific Ocean. The signals have a close relationship with wind velocity of typhoon and distance between the typhoon center and the station. Besides, the other tremor signals cannot be explained clearly at present. In order to find the cause of tremor, more analysis and research with more observational data is needed.

The result of continuous observation shows that abnormal tremors are true and common signal which can be recorded by broadband seismometer, gravimeter and the tiltmeter. As the appearance of tremor signal is not accident, then the problem such as the reason, origin and the mechanism, *etc.*, is worth to discussing and getting the answer.

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