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NOTES AND CORRESPONDENCE

Observations Using the Taipei Basin Broadband Downhole Seismic Network: The 26 December 2006, Pingtung Earthquake Doublet, Taiwan

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ABSTRACT

To monitor the fault activity in the Taipei area, a new broadband downhole seismic network comprised of three stations was established in the Taipei Basin over a period of three years, 2005 - 2007. The network geometry is a triangle with a station spacing of about 12 km covering the entire Taipei Basin. Each station has two holes of different depths containing modern instruments, including a low-gain broadband seismometer. The largest depth is 150 m. We report our first experience on the installation and operation of the broadband downhole seismic network in the Taipei Basin. Some representative records from the Pingtung earthquake doublet in December 2006 are shown here. Ground displacement during the Pingtung earthquake doublet can be recovered from the velocity records without the baseline corrections that are required for the acceleration records. Our network offers excellent data for accurate and effective characterization of seismic motion in the study area. Seismic data from this network will be shared with other research institutions in Taiwan and abroad for further research.

Key words: Broadband downhole seismic network, Taipei Basin, Pingtung earthquake doublet

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1. INTRODUCTION

The Taipei Basin is located in northern Taiwan and is considered to be created by the opening of the southern Ryukyu back-arc system (Teng et al. 2000). The evidence includes the presence of Quaternary extensional structures (Lee and Wang 1988; Lu et al. 1995) and extensional earthquake focal mechanisms (Yeh et al. 1991). The city of Taipei is situated at the middle and slightly eastern part of the Taipei Basin and is surrounded by Taipei County. It is the political and economical center of Taiwan. Topographically, the Taipei Basin is bounded by the Da-Tun volcanos, Mt. Guan-Yin and the northern hills of the Central Mountain Range. Geologically, it is a cave-in basin with faults on three sides, resulting in an isosceles triangle of 18 km wide from east to west and 27 km long from south to north. At its western edge, the main geological feature of the Shanchiao Fault has attracted much attention in terms of earthquake hazards during the last several decades.

Many earthquakes of moderate-to-large magnitude (5.3 $\leq M \leq 7.3$) occurred near the Taipei metropolitan area since 1659 from the limited historical records. However, no major event occurred in this area since the 1909 Taipei earthquake ($M = 7.3$). Although future large and catastrophic earthquakes are anticipated in this region, predictions of ground motion in this area are limited by a lack of instrumental data from strong earthquakes. For this reason, a new digital dense array of strong-motion seismographs, consisting of more than one-hundred stations, was widely deployed in the populated Taipei area by the Central Weather Bureau (CWB) beginning in July 1991 (Shin et al. 2003). Since then, the ground motion database for northeastern Taiwan has improved greatly. However, most of the seismic stations placed

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in Taipei metropolitan area have been operated in a trigger mode for felt earthquakes. Detailed recordings of the ground motions from smaller earthquakes (which may provide valuable insight on the fault activities beneath the Taipei area) have been missed.

In 2004, the Institute of Earth Sciences (IES) of Academia Sinica was contracted by the Central Geological Survey (CGS) of the Ministry of Economic Affairs to initiate a four-year project in metropolitan Taipei. The purpose of this project is to investigate, evaluate and continuously monitor the seismic activities of the faults and low-frequency tremors in the Taipei area. The IES was given the responsibility for setting up a portable broadband seismic network covering the main geological feature in the Taipei area – the Shanchiao Fault in 2004 and continued in the process of more site selections to install stations from 2005 to 2007.

Because the Taipei Basin is a densely urbanized area with high cultural noise, it presents a serious problem in making detailed seismic observations. Therefore, three permanent broadband downhole seismic stations were also established to avoid surface noise in this project. Installation of instruments was completed in 2005 at Daan Park (DANB), in 2006 at Guandu Nature Park (GDUB), and in 2007 at Sinjhuang Life Hall Park (SNJB). This is our first experience in installing and operating broadband downhole seismic stations in the Taipei Basin. The portable seismic stations and 3-station downhole permanent seismic network will be integrated to form a 3-D seismic network and to attain a high probability of recording micro-earthquakes (with magnitudes less than 3) in this area. The seismic data from this network and the CWB strong-motion network will be integrated to study the path and site effects from different sources in Taipei and to improve our understanding of the urban seismic hazards in Taipei.

The goal of this report is to describe the broadband downhole seismic network and their sites. We also studied the seismic waveform records from two major earthquakes occurred on 26 December 2006 off the coast of Pingtung in southern Taiwan – the first was a normal faulting event (Lee et al. 2008), and the second was dominated by a strike-slip mechanism (Lee et al. 2008). The origin time between these two earthquakes was about 8 minutes. These two events, which are of comparable magnitude (M_L = 7.0), are the most significant earthquakes to have occurred in this area in the past 47 years.

2. INSTRUMENTATION

The broadband downhole seismic network in Taipei Basin was installed over a three-year period, 2005 - 2007. Figure 1 shows the configuration of the downhole stations named DANB, GUUB, and SNJB and the mapped fault traces in the Taipei Basin. The sites were selected away from structures likely to cause significant soil-structure interaction effects that may be recorded in the data. The three downhole stations were situated in a triangular shape to provide a minimum coverage over the entire Taipei metropolitan area. Station DANB is at the southeastern side of Taipei Basin and is located in Daan Park, which is about 2 km away from the Taipei 101 Building (maximum height of 509 meters). The Park was established in 1994 and covers an area of 259293 square meters. Station GDUB is located in the Guandu Nature Park at the northern end of the Shanchiao fault. This Park is in a marsh area for migrating birds and is situated at the point of convergence of the Danshui and Keelung Rivers. Station SNJB is at the southwestern Taipei Basin and is located in the Sinjhuang Life Hall Park, Taipei County. The Park was established in 1995 and covers an area of 9978 square meters.

The design of a downhole seismic station is basically the same for all three sites. Each site has two holes with depths of 50 and 90 (or 100, or 150) m below the ground surface. Two types of triaxial force-balanced seismometers were used: a VSE-355G3R velocity sensor at a depth of 90 (or 100, or 150) m, and an AS-3250 accelerometer at a depth of 50 m. Both instruments were made by Tokyo Sokoshin, Japan. The VSE-355G3R seismometer is capable of measuring ground-motion up to 200 cm sec^{-1} in velocity with a bandwidth from 0.008 to 70 Hz. Its sensitivity has an output of 20 volts for a velocity of 200 cm sec^{-1}. The frequency range of the AS-3250 accelerometer is from DC to 250 Hz. It is capable of recording with a full scale of 2000 cm sec^{-2}. The VSE-355G3R and AS-3250 are connected to a Kinematics Quanterra Q330 recorder. The recorder has a 24-bit resolution instrument with 8 MB memory and is equipped with GPS receiver for time coordination. The outputs are digitized at three different sampling rates of 100, 20, and 1 Hz. An external hard

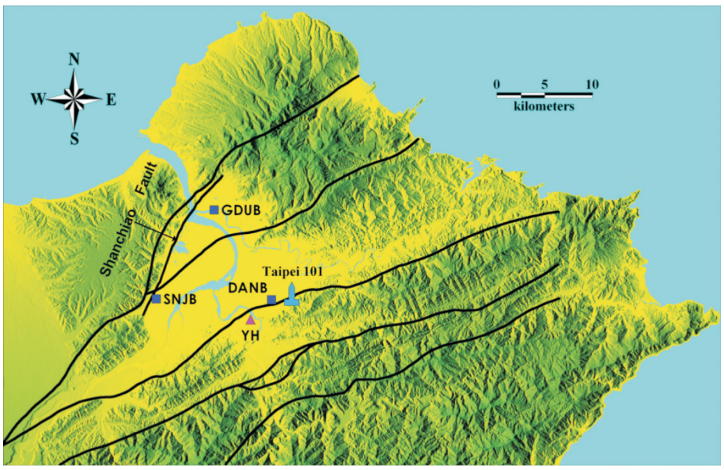

Fig. 1. Location of the broadband downhole seismic stations and the mapped fault traces in the Taipei area.

disk (Model Quanterra PB14F Packet Baler) with capacity of storing up to 20 GB is included for the data acquisition system. The acquisition system is based on continuous data storage in the Baler and real-time broadcasting of the data to the acquisition center at the IES by phone line. The relevant parameters of each station are listed in Table 1.

Figure 2 shows the layout of the downhole site. At each site, the two holes are covered by a PVC cylinder wall with diameters of 8 and 5 inches, respectively. The sensor is placed inside the PVC cylinder at the bottom of the hole. The orientation of the three-components sensors was determined using a precision compass. In order to improve the sensor to ground coupling, the PVC cylinder is filled with fine sand at the bottom of hole. The sensor cable is linked to the Fiber Reinforced Plastic (FRP) housing through an underground plastic tube. The FRP is 110 cm in width, 110 cm in length and 140 cm in height and fastened to a 120 × 120 × 15 cm concrete pad. The FRP encloses the batteries, data recording system, GPS receiver, communications equipment and other electronics. The recorder is very sensitive to many environmental parameters that can influence its response. In particular, temperature variations influence the conductivity of electronic devices. To improve the recorder's performance, a recorder vault of about 1 m deep was dug in the soil. The recorder vault is a plastic cylindrical tank that is approximately 20 cm wide and 100 cm deep with a concrete pad at the bottom. The tank is mostly buried, with less than 30 cm of it above the ground. A more detailed description of the installation is given by Huang et al. (2005) and Ton Yuan Technology & Engineering Co., Ltd. (2005). A typical broadband downhole seismic station of DANB is shown in Fig. 3.

Instrumentation of the Taipei broadband downhole seis-

Table 1. The broadband downhole seismic network.

Station Code	Lat. (E)	Long. (N)	Depth (meters)	Sensor Type	Operation period	Location
DANB	121.5352	25.0294	50	AS-3250	20051001~	Daan Park
			90	VSE-355G3R		
GDUB	121.4763	25.1145	50	AS-3250	20061103~	Guandu Nature Park
			150	VSE-355G3R		
SNJB	121.4161	25.0307	50	AS-3250	20071129~	Sinjhuang Life Hall Park
			100	VSE-355G3R		

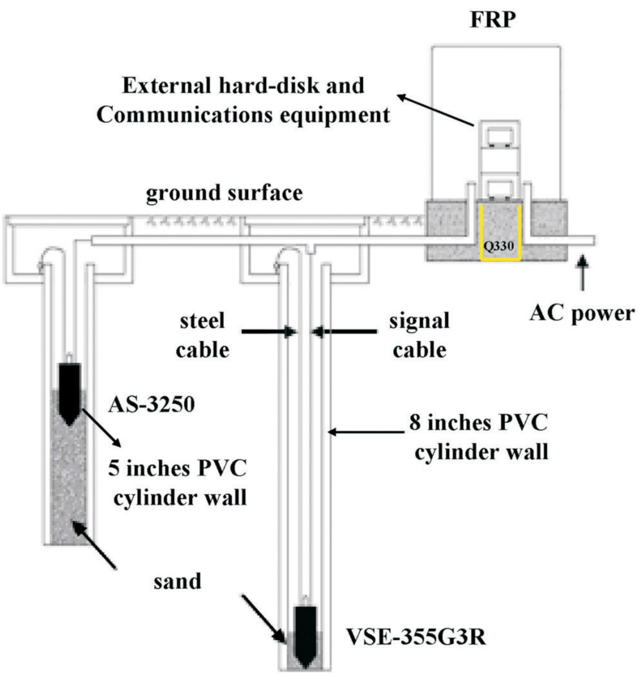

Fig. 2. Scheme of a downhole installation.

Fig. 3. Broadband downhole seismic station at Daan Park, Taipei.

mic network was begun in March, 2005 by engineers from IES and each became fully operational in 2005, 2006, and 2007, respectively. All three stations have provided recordings from local earthquakes, regional earthquakes, and teleseismic events.

3. SEISMIC OBSERVATIONS OF DANB AND GDUB FROM 26 DECEMBER 2006 PINGTUNG DOUBLET EARTHQUAKES

Figure 4 shows an epicentral map of earthquakes recorded by the DANB downhole seismic station from October 2005 to November 2007. The location of the DANB station is indicated by a solid square in Fig. 4. Approximately 100 local and regional earthquakes have been recorded. Events range in magnitude from M_L 3.7 to 7.0. Two of the larger earthquakes, which were 8 minutes apart, with similar magnitudes (M_L = 7.0) occurred just offshore near the Hengchuen township of Pingtung in southern Taiwan on 26 December 2006. The focal depth was 44 km for the first event and 50 km for the second. The spatial separation of these two events was about 35 km. The centroid-moment tensor (CMT) solution reported by Broadband Array in Taiwan for Seismology (BATS), US Geological Survey (USGS) and Harvard University showed that the pair of earthquakes had different focal mechanisms. All results indicated that the first exhibited a normal fault mechanism. However, there is some dispute as to whether the second event is due to strike-slip faulting (BATS and USGS) or is complex and does not fit well with a double-couple focal mechanism (Harvard University). In the most recent study, Lee et al. (2008) use regional ground-motion full waveform records to investigate source rupture processes and determine the fault planes of the Pingtung doublet earthquakes. Their result shows that the first event has a normal fault mechanism, while the second event has significant strike-slip motion. The pair of earthquakes was recorded successfully by the broadband downhole seismic network at DANB and GDUB in the Taipei Basin (Note: the SNJB station was completed in 2007).

Figure 5a displays a record section of east-west particle velocity data for the 2006 Pingtung doublet earthquakes at two depth levels: -90 m for DANB and -150 m for GDUB. The seismograms are shown at a common origin time. As seen in Fig. 5a, the doublet earthquakes are well-recorded by both stations. The records for the second event (12:34) are more complex compared to the first event (12:26). Figure 5b shows the displacement records that are produced by integration of velocity records from Fig. 5a without any filtering. Like the velocity records, the displacement records are considerably more complicated for second event than that for the first event. The locations of these two earthquakes are 380 km away from the Taipei Basin. At such a long source-spacing, the effects of anelastic attenuation along the ray path would be similar for the two earthquakes. Hence, the complex nature of waveform for second event is mainly due to the source effect.

Figure 6a shows a record section of the east-west displacements at depth levels of 50 and 90 m for DANB. Noticed that station DANB50 was installed with an AS-3250 accelerometer. The displacement waveform of this station was integrated twice from an accelerogram with no filter used. As seen in Fig. 6a, the displacement waveform at DANB50 was characterized by long-period oscillation features, indicative of a drifting of the baseline. On the other hand, DANB90 shows very steady displacement records from the velocity sensor. Applying a low-cut filter at frequency of 0.08 Hz to the displacement record of DANB50, the displacement records between DANB50 and DANB90 are almost identical. This indicates that data recovery of the ground displacement is much easier from the VSE-355G3R low-gain velocity sensor. Clinton and Heaton (2002), Graizer (2004), Liu et al. (2006) also demonstrated several advantages of the VSE-355G3R instrument in recording ground motions.

In the early '90s the CGS conducted a research project in the Taipei Basin. Downhole accelerometers were installed at different depths. At present, eight downhole stations are in operation. Some of them were also triggered by 26 December 2006, Pingtung earthquake doublet. One of them, coded

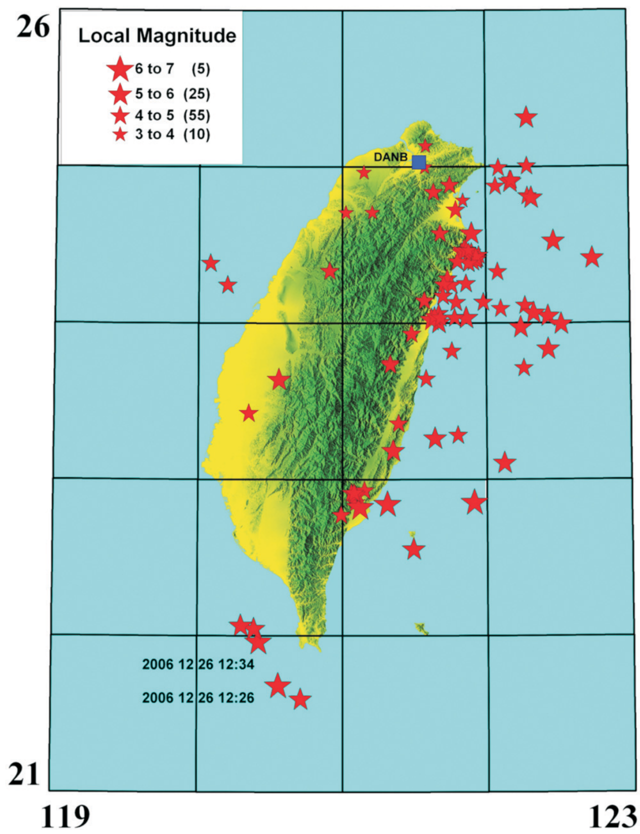

Fig. 4. The epicenter distribution of earthquakes recorded by DANB during the period from October 2005 to December 2007. Solid squared denotes the location of DANB.

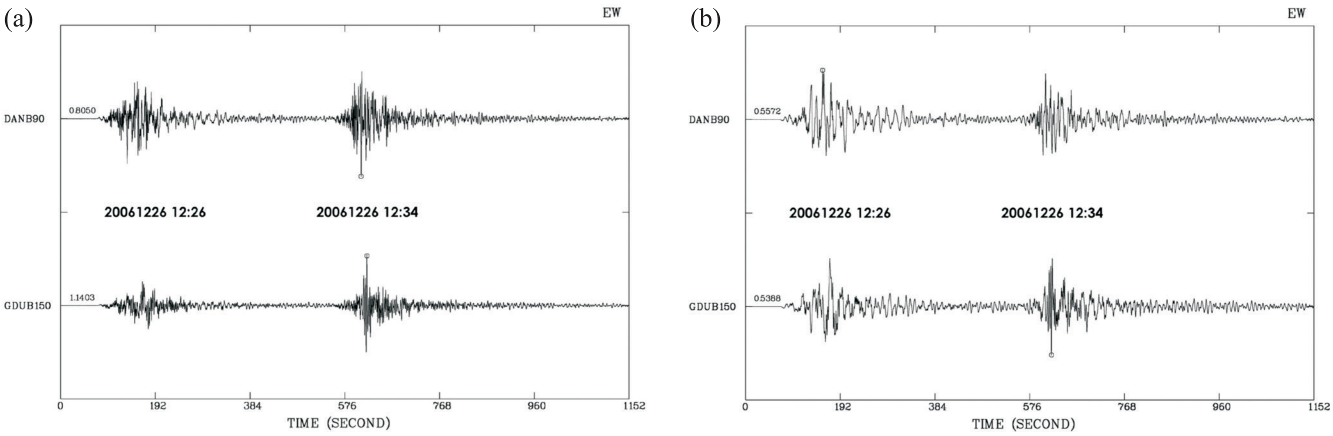

Fig. 5. (a) The particle velocities (east-west component) at stations DANB90 and GDUB150 for the December 2006 Pingtung earthquake doublet. Each seismogram is normalized to its peak value (cm sec^{-1}) as enumerated above each trace. (b) The particle displacements integrated once from particle velocities shown in Fig. 5a. Data has not been filtered. See Fig. 5a caption. The peak ground displacement (cm) is shown at the beginning of each time series.

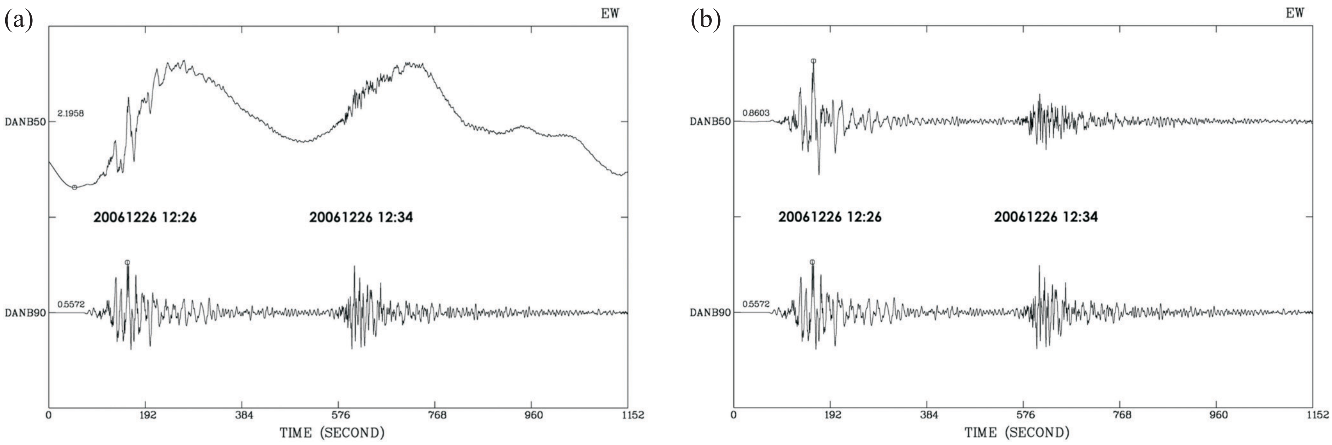

Fig. 6. (a) Displacement records of east-west component integrated once and twice from DANB90 and DANB50, respectively. Data has not been filtered. See Fig. 5a caption. The peak ground displacement (cm) is shown at the beginning of each time series. (b) Displacement records of the east-west component of DANB90 and DANB50, respectively. Data of DANB50 has applied with 0.08 Hz low cut filter. See Fig. 5a caption. The peak ground displacement (cm) is shown at the beginning of each time series.

YH, is about 2 km away from DANB to the south (see Fig. 1). This site was equipped with a K2 digital recorder and Kinemetrics FBA sensors at three depth levels: ground surface, -50 and -198 m. The displacement records of DANB50 and DANB90 are used as a reference to compare with the results recorded at the YH site. Figure 7 depicts a record section of east-west displacements with a duration of 480 seconds, which was truncated from Fig. 6b, for stations DANB50 and DANB90. Also shown in this figure is the displacement record of YH50. It was obtained from an accelerogram by double integration. Comparing these three sets of displacement waveforms, we found that the waveforms are very similar. This similarity in waveforms means that the downhole sensors have correct orientation. We further found that a peak displacement of about 0.86 cm observed from DANB50

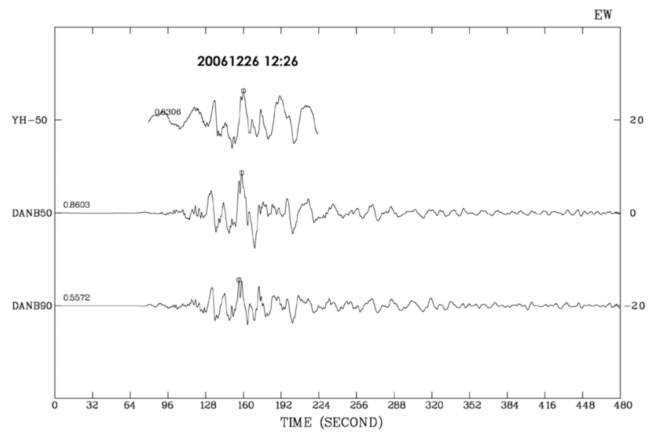

Fig. 7. Displacement records of the east-west component of DANB90, DANB50, and YH50, respectively. The seismograms are normalized in the same scale. The peak value (cm) as enumerated above each trace.

is 1.5 times higher than the peak displacement at DANB90. These amplification effects are mainly due to the local geology as seismic waves propagate through the DANB90 to DANB50. In addition, the data provided by the broadband downhole seismic stations do not miss the first motions and the latter arrivals from regional earthquakes because the recording is continuous. These waveforms are important both for their direct association with the ground motions of engineering interest, as well as for their latter arrivals which is of direct relevance to the local site effects. Thus, if we want to extract the ground motion information from earthquakes, continuously ground-motion recordings are desirable.

4. CONCLUSION

Over the past three years, a new broadband downhole seismic network, consisting of three stations, was established in the Taipei Basin. At present, it provides complete seismic waveforms of earthquakes and will help reducing the chances of missing important seismic data in the Taipei Basin when major earthquakes occur. The three stations as a part of BATS operated by the IES will enhance the seismic monitoring in northern Taiwan. In addition, the broadband downhole seismic network plays an important tool to serve as a guide for future downhole station installations. The recorded high-quality data will be used for better understanding of seismic hazards in urban areas and for developing appropriate responses.

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