CRUSTAL DEFORMATION STUDY IN PENINSULAR MALAYSIA USING GLOBAL POSITIONING SYSTEM

Kamaludin Mohd Omar, Jhonny
Geomatic Engineering Department
Faculty of Geoinformation Science and Engineering
Universiti Teknologi Malaysia
kamaludinomar@utm.my, xujhonny@gmail.com

ABSTRACT

From the Global Positioning System (GPS) measurement over a large part of South East-Asia in 1994 – 1996 showed that Sundaland is a stable tectonic block with velocity 12 ± 3 mm/yr moving relatively to East – South East respectively to Eurasia. In December, 2004 and March, 2005 there were two big megathrust earthquakes occurred near to the west coast Aceh with 9.3 Mw and Nias with 8.7 Mw. These earthquakes had caused deformation on the stable Sundaland. Due to first earthquake, the GPS station in the northern part of Peninsular Malaysia deform until 17 cm and the southern part until 1 cm. In order to understand the deformation that caused by those earthquakes, it is necessary to study the tectonic setting of Peninsular Malaysia and measurements through GPS. The tectonic setting of Peninsular Malaysia shows that Peninsular Malaysia is divided into two tectonic blocks; and beside that Peninsular Malaysia also has a few major faults which crossing the Peninsular Malaysia from north to south, and west to east. GPS data over the Peninsular Malaysia and 30 International GPS Services (IGS) stations over the world from 2004 until 2008 were used to measure the deformation. From the measurement showing that several co-seismic during 2004 until 2008 indicated that north-west of Peninsular Malaysia suffer the worse deformation than the other place. The post-seismic motions always change in the magnitude and directions. The other side there were some phenomena recorded in Peninsular Malaysia such as sink hole in Ipoh and Batu Gajah, tremors in Bukit Tinggi area (2007-2008) and tremor at Jerantut (2009). The combination from GPS measurement with those phenomena indicated that there is a seismic activity going on this land. Because of that it is necessary to carry out the combine research which is not only focusing on GPS but also another tool such as micro gravity, seismic and so on which could improve the understanding of the structure and deformation of Peninsular Malaysia.

Key words: Crustal, Deformation, GPS, Peninsular Malaysia, Tectonic, Structure, Earthquake
INTRODUCTION

South East Asia (SE-Asia) for many past years has been explored by many researchers from over the world. One of the researches that already carried out is Geodynamics of South and South East Asia (GEODYSSSEA). As 46 GPS stations was build up over the SE-Asia to study the plate motions in SE-Asia. The result from that study indicated that SUNDALAND tectonic block which is covered most of SE Asia region is not attached to Eurasia plate. It has its own motion (Michel et al, 2001). Somehow in December, 2004 and March, 2005 two mega thrust earthquakes occurred near Aceh with 9.3 MW and Nias with 8.7 Mw, which is give the big impact to the motion of SUNDALAND. Most of the west part (Sumatra, Peninsular Malaysia, Southern Thailand) have been deformed strongly and the motion of the existing GPS over that place change extremely. Due to the first mega earthquake, northern part of Peninsular Malaysia such as Arau and Langkawi had displaced 17 cm, meanwhile southern part of Peninsular Malaysia such as Tanjung Pengerang, Mersing and Johor Bahru only experience 1 cm displacement. By times goes on the deformation on Peninsular also influence by the other several earthquakes that occurred at the west coast of Sumatra after December, 2004. This study focused on the crustal deformation in Peninsular Malaysia that caused by those big earthquakes using the existing infrastructure from 2004 till 2008.

TECTONIC SETTING OF PENINSULAR MALAYSIA

The tectonic setting of Peninsular Malaysia is one of the most important information required to study the crustal deformation. Generally Peninsular Malaysia is divided into two blocks by Raub-Bentong suture (Figure.1), the western part belonging to the Sibumasu block and the eastern part belonging to the East Malaya block (Indochina block) (Metcalf, 2002 ; 2006). There are two major granite intrusions, in the western part and eastern part which is supposed to be Late Paleozoic (280 and 200 Ma ago) at age (Cobbing at.al, 1986). Those intrusions are believed to be formed by the subsequent crustal extension during that period. The Middle of Peninsular Malaysia which is surrounded by the intrusion is believed as graben which is bounded by the normal fault (Tan, 1984 in Harbury et.al, 1990).

In 2008, the seismotectonic map of Malaysia (Figure.2) which is published by the Department of Mineral Geosciences Malaysia (DMGM) reveals that there are few major faults in Peninsular Malaysia such as Bukit Tinggi Fault, Kuala Lumpur Fault, Lebir Fault, Baubak Fault and Mersing fault, but all of which are stated inactive (DMGM, 2008). Some how after the big earthquakes occurred there were some phenomena recorded in Peninsular Malaysia, such as the sink holes at Ipoh and Batu Gajah, tremors in Bukit Tinggi area (2007-2008) and Jerantut (2009).
PRE SEISMIC MOTION

Earthquake can cause deformation into the near or surrounding area to the epicenter and if the earthquake relatively big, the impact can be feel few hundred km away from the epicenter. Therefore it is necessary to know the seismic motion cycle of earthquake. Basically there are three seismic motion of earthquake. The first motion known as pre-seismic motion occurred before the earthquake taken place. The second one known as co-seismic motion occurred during the earthquake taken place; usually take short time such few minutes or hours. The third one known as post-seismic motion which is occurred after the earthquake occurred, usually need long time such months, years or couple of decade.

The pre-seismic motion of Peninsular Malaysia can be achieved through long time GPS measurement. Unfortunately only Malaysia Active GPS System (MASS) was well established before 2004, which consist of ten stations in Peninsular Malaysia and eight stations in Borneo.
Malaysia. Because of that, it is necessary to create model to describe the pre-seismic motion in Peninsular Malaysia. Based on MASS stations Kee et.al, 2005 created pre-seismic model (Figure 3) and also computing the rotation pole for Peninsular Malaysia. The rotation pole is located at 41.761° latitude and -87.935° longitude with rotation rate 0.392°/Myr.

![Figure 3: Observed and modelled velocities for MASS stations due to plate motion before earthquake (Kee et.al, 2005).](image)

Before the first earthquake occurred there was GEODYSSSEA project which is established GPS stations over Thailand, Myanmar, Philippines, Malaysia, and Indonesia from 1994 until 1996. Result from that project shows that Sundaland (Figure 4) was moving to the southeast – east ward with 2-5 cm/year and also an indication that Sundaland is not attached to the Eurasian plate.

![Figure 4: Predicted and Final GEODYSSSEA station velocity in ITRF 1996 (Simons et.al, 1999).](image)
Therefore, the pre-seismic motion of Peninsular Malaysia was well described by the model made by Kee et.al, 2005 and GEODYSSEA.

**CO SEISMIC MOTION**

When the first earthquake (Aceh) occurred most of GPS stations on the northern part of Peninsula Malaysia experienced worse deformation than the southern part (Figure.5). When the second earthquake (Nias) occurred the west coast of Peninsular Malaysia suffer the worse deformation compare to the other place (Figure.4).

![Figure.4 Co-seismic deformation in Peninsular Malaysia due to Aceh Earthquake (Kee et.al, 2005).](image4)

![Figure.5 Co-seismic deformation in Peninsular Malaysia due to Nias Earthquake (Kee et.al, 2005).](image5)
The deformation caused by those earthquake was deeply investigated by the “SEAMERGES (South East Asia: Mastering Environment Research with Geodetic Space Techniques) group” (Vigny et. al, 2005). The deformation characteristic due to Aceh can be summarized as follows;

1. Magnitude of co-seismic displacement due to Aceh earthquake in Peninsular Malaysia as detected from GPS network varies from the largest magnitude 17cm at Langkawi (LGKW) and the smallest magnitude 2cm at Tanjung Pengelih (TGPG).
2. Small but significant co-seismic displacement with magnitude from 5 to 10 mm were clearly detected more than 3000 km away from epicentre such as Kunming (southern China), Bangalore (continental India), and Malaysia Borneo.

The deformation characteristic due to Nias can be summarized as follows;

1. The largest deformation magnitude was detected at Pangkor station (PUPK). The magnitude is about 6 cm.
2. The smallest deformation magnitude was detected at Tanjung Pengerang station (TGPG). The magnitude is about 1 cm.

On the other hand, the above deformation may be not pure co-seismic, but probably already influence by the post-seismic. Because when those GPS stations processed using kinematic strategy show that the displacement are not as big as shown by Figure.4 and Figure.5. The co-seismic for northern part of Peninsular Malaysia due to Aceh earthquake is only about 4 – 8 cm in north and east direction (Figure.6). The southern part displaces only about 1-2 cm in both directions (Figure.7). Due to Nias earthquake only displace in few cm in both direction (Figure.8 & Figure.9).
Figure 6 The co-seismic deformation at a) Langkawi and b) UUMK due to Aceh earthquake.

Figure 7 The co-seismic deformation at a) Mersing and b) Johor due to Aceh earthquake.
The others earthquake that occurred after March, 2005 such as Bengkulu earthquake in March, 2007, September, 2007 and October, 2007 then Padang earthquake in September, 2007 and etc are not impacted deformation on Peninsular Malaysia as big as the mega thrust earthquakes.

**POST SEISMIC MOTION**

Post-seismic motion of earthquake can be take couple of days, month or even years. The post-seismic of Aceh earthquake was influence by the co-seismic of Nias earthquake. The post-seismic of the Nias earthquake are not pure from Nias earthquake but influence by the first earthquake motion (Figure.10). The later earthquakes that occurred at the west coast of Sumatra also influence the post-seismic motion.
Figure 10 Post-seismic displacement at a) Langkawi, b) PUPK, c) Gua Musang, d) Mersing and e) Johor from 2004 until 2008.

The post-seismic displacement is not equal at every place. The northern part such as Langkawi has the largest displacement compare to the other (Figure 10). The southern part has the less displacement. From the end of 2006 the southern part station such as Mersing and Johor were turning back. The northern part still influence by the co-seismic displacement from both earthquakes.

DISCUSSION AND CONCLUSION

Varies motion of GPS stations in Peninsular Malaysia over the time showing an irregularly deformation form (Figure 11). The north-west part of Peninsular Malaysia such as Langkawi, Arau, UUMK, SGPT, and etc has major displacement than the others. The magnitudes of each station are not equal. From the total displacement at 2005, 2006, 2007 and 2008 show that Peninsular Malaysia are moving anti-clockwise (Figure 11). In the end of 2006, the GPS stations in the southern area such as JHJY were moving to the south-southeast direction. The motion becomes clear in March, 2007.
Somehow, if look at the stations motion from time to time especially in 2006 indicate that Peninsular Malaysia may have seismic activity that come from inside Peninsular Malaysia (Figure.12). In November, 2007 until January, 2008 there were 13 tremors recorded in Bukit Tinggi area and in March, 2009 tremors occurred again at Jerantut. This seismic activity could be resulted because of the movement of faults. The movement of faults in that area could be detected by the motion of GPS stations from 2006 – 2008, but unfortunately the motions of the stations are not so clear. Therefore in the future it is necessary to carry out one combine research between geodesy, geology, and geophysics in order to get more knowledge of Peninsular Malaysia deformation and tectonic structure.
Figure 12 Stations motion from May-June, 2006; September-October, 2006; November-December, 2007; and January-February, 2008.
REFERENCES


