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Empirical Study of the Frequency and Severity of Earthquakes in Taiwan

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Abstract The rate at which earthquake occurs in Taiwan was investigated for the period of fifty years (1961 – 2010). The result shows that the study area is characterized predominantly by minor, light and moderate earthquakes with the percentage of strong and major extremely low. The result also revealed that for each magnitude range, the number of shallow focus earthquakes is more than the intermediate focus earthquakes. No deep focus earthquake was observed. The shallow earthquake events with magnitude 4.0-4.9 (light) were the most frequent, followed by 5.0-5.9 (moderate), 3.0-3.9 (minor), 6.0-6.9 (strong) and the least frequent were with magnitude 7.0-7.9 (major). While for intermediate earthquakes, events with magnitude 4.0-4.9 were the most frequent, followed by 3.0-3.9, 5.0-5.9, 6.0-6.9 and the least frequent with magnitude 7.0-7.9 . It was also discovered that about three (3) shallow earthquakes occur monthly and about two (2) intermediate earthquakes occur yearly in Taiwan on the average. Furthermore the b-values were calculated for shallow and intermediate focus earthquakes to be 0.80 and 0.74 respectively. The b- values were calculated using the Gutenberg-Richter Relation. The low b- value indicates localized high stresses which are favourable for future rupture.

Keywords: *earthquake, magnitude, b value, rupture, Gutenberg-Richter*

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1. Introduction

Studies have shown that earthquakes are very complex phenomena which are caused by different processes taking place in the earth. Most earthquakes are too small to be noticed by people, only sensitive scientific instruments such as the seismograph can record their passage. Every year hundreds of earthquakes occur which are strong enough to change the face of the land and are capable of causing injuries, deaths and damage to property if there occur in a populated area [2]. Many studies have been carried out to develop reliable estimates on the pattern of seismicity in various regions in the world [5,6,9,10,12,14,15,20,21]. Seismological pattern of any area enables Seismologist to predict when (though not exact time) and where the next main shock will occur.

The history of earthquake activity in the Taiwan can be dated back to the seventeenth century. Before 1897, the historical records of earthquakes in Taiwan primarily came from government documents. The earthquakes in Taiwan generally have a complex structural background. Most of the disastrous earthquakes in the history have occurred in the west seismic zone, a densely populated zone in Taiwan [7]. As Taiwan gradually evolves from a developing country to a developed country, one of its major challenges is how to cope with the rate at which earthquakes occur in the region. Earthquake being a natural event, cannot be prevented, but maximum efforts to reduce the damage associated with it have been put in place in the region [7].

Earthquake can be classified based on focal depth consisting basically of shallow, intermediate and deep-focus earthquakes. The focal depth refers to the depth at which an earthquake occurs. In seismology, Earthquakes occurring at a depth of less than 70km are classified as shallow-focus earthquake, while those with a focal depth between 70km and 300km are commonly termed mid-focus or intermediate-depth earthquakes, deep-focus earthquakes may occur at much greater depths in the mantle ranging from 300km up to 700km. Deep focus earthquakes typically occur at oceanic continental convergent boundaries along Wadati-Benioff zones (the zone of active seismicity). Earthquakes with shallow focal depths occur in all seismically active zones. The largest proportion (about 85%) of the annual release of seismic energy is liberated in shallow-focus earthquakes, the remainder is set free by earthquakes with intermediate focal depths (about 12%) and also by deep-focus earthquake (about 3%) [8]. In Taiwan, in the 20th century, the largest earthquake on land was the chi-chi earthquake of 1999 [3].

2. Earthquake Magnitude

In 1935, C. F Richter attempted to grade the sizes of local earthquakes in Southern California on the basis of the amplitude of the ground vibrations they produced at a

known distance from the epicenter. The vibrations were recorded by seismographs which were standardized to have the same response to a given stimulus. Richter's original definition of magnitude was based on surface-wave amplitude (A_s) recorded by seismograph at an epicentral distance of 1000km. Seismographs were located at various distances from the earthquake, therefore an extra term was added to compensate for attenuation of the signal with increasing epicentral distance. The surface wave magnitude (M_s) of an earthquake was defined by equation (1) [8].

$$M_s = \log_{10}(A_s / T) + 1.66\log_{10}(\Delta) + 3.3 \quad (1)$$

Where A_s is the vertical component of the ground motion in micrometers (μ_m) determined from the maximum Rayleigh-wave amplitude, T is the period of the wave (18-22s), Δ is the epicentral distance in degrees ($20° \leq \Delta \leq 160°$).

The depth of the source affects the nature of the seismic wave train, even when the same energy is released. An earthquake with a deep focus may generate only a small surface-wave train, while shallow earthquakes cause very strong surface wave [8].

Earthquakes are classified in categories ranging from minor to great, depending on their magnitude.

Table 1. Richter Earthquake Magnitude Scale classes [16]

MAGNITUDE	DESCRIPTION
1.0-1.9	Micro
2.0-2.9	Minor
3.0-3.9	Minor
4.0-4.9	Light
5.0-5.9	Moderate
6.0-6.9	Strong
7.0-7.9	Major
8.0-8.9	Great
9.0 and greater	Great

2.1. Seismicity of the Taiwan Island Region

Taiwan island region is located on the western circum-pacific seismic belt off the east coast complex juncture between the Eurasian plate and the Philippine Sea plate. It plunges northward under the Eurasian plate along the Ryukyu trench, While the Eurasian plate subducts eastward beneath the Philippine sea plate off the southern tip of the island of Taiwan [15,20]. Most of the Taiwan island region is under NW-SE compression with a convergence rate of about 8cm/year [22]. These two plates interact in complex patterns that have resulted in many highly complicated regional geological features and very high active seismicity.

According to the plate tectonic setting and seismic characteristics, the Taiwan region can be classified or divided into four different seismogenic zones [17,19];

A. **Western seismic zone:** This is located within the Eurasian plate. Most of the earthquakes in this zone can be associated with active faults on the Taiwan Island. Many large damaging earthquakes for example, the Chi-Chi earthquake of 1999 occurred in this Zone.
B. **Southwestern seismic zone:** This is located mainly in the South China Sea block of the Eurasian plate. In terms of seismic activity, this is the least active zone among the four.
C. **Northeastern seismic zone:** Associated with the Ryukyu subduction system and shows high seismicity with occasional damaging earthquakes.
D. **Southeastern seismic zone:** This zone is mainly caused by the collision of the Eurasian plate and the Luzon island arc on the Philippine Sea plate. Most of the seismic activities in the Taiwan region, including many large earthquakes occur in this area.

When comparing seismic activity in different regions of the Asia-pacific area, it can be found that seismic activity in Taiwan is characterized by high frequency and extensive distribution.

2.2. Gutenberg-Richter Relation

The relationship between size distribution of earthquakes and magnitude was first discovered in 1939 in Japan and later by Gutenberg and Richter (1944) in California.

The Gutenberg-Richter's relationship (power law) is given by;

$$\text{Log } N = a - bM \quad (2)$$

Where N is the number of events having magnitude $\geq$ M, and a and b are constants.

The parameter 'a' describes the total seismicity rate of the region and 'b', the slope of the frequency-magnitude distribution, describes the relative size distribution of events. 'a' is a function of quantity of earthquakes throughout the years covered in the study area while 'b', in general is approximately equal to 1. Large value for b (>1) indicates predominantly small earthquakes while small values of b (b<1) implies predominantly large earthquakes [1]. The a- and b-value in the Gutenberg-Richter relation are parameters that supply essential information in seismotectonic studies and seismic risk analysis, hence their correct computation reveals important information on seismology of an area [1].

3. Materials and Methods

The data used for this study was obtained from the website of the Advanced National Seismic System (ANSS) composite earthquake catalog search, Northern California Earthquake Data Center and UC Berkeley. The selected data consisted of natural earthquakes of magnitude M≥3.1 and M≥3.2 for focal depth of 0-70km and 70km-300km respectively for the study area from 1st January 1961 to 31st December 2010 (50 years).

The data comprised of the date of occurrence of different earthquakes, time of origin, coordinates of epicenter, magnitude, event identification, focal depth of earthquake and event type. The region of study is situated between latitude 22°N to 25°N and longitude 120°E to 122°E (Figure 1). Shallow focus earthquakes with focal depth of 0-70km yielded 1846 events, intermediate focus earthquakes with focal depth of 70km-300km yielded 109 events and there was no event of deep focus earthquake of focal depth of 300km-700km, therefore, making a total of 1955 events used in the study.

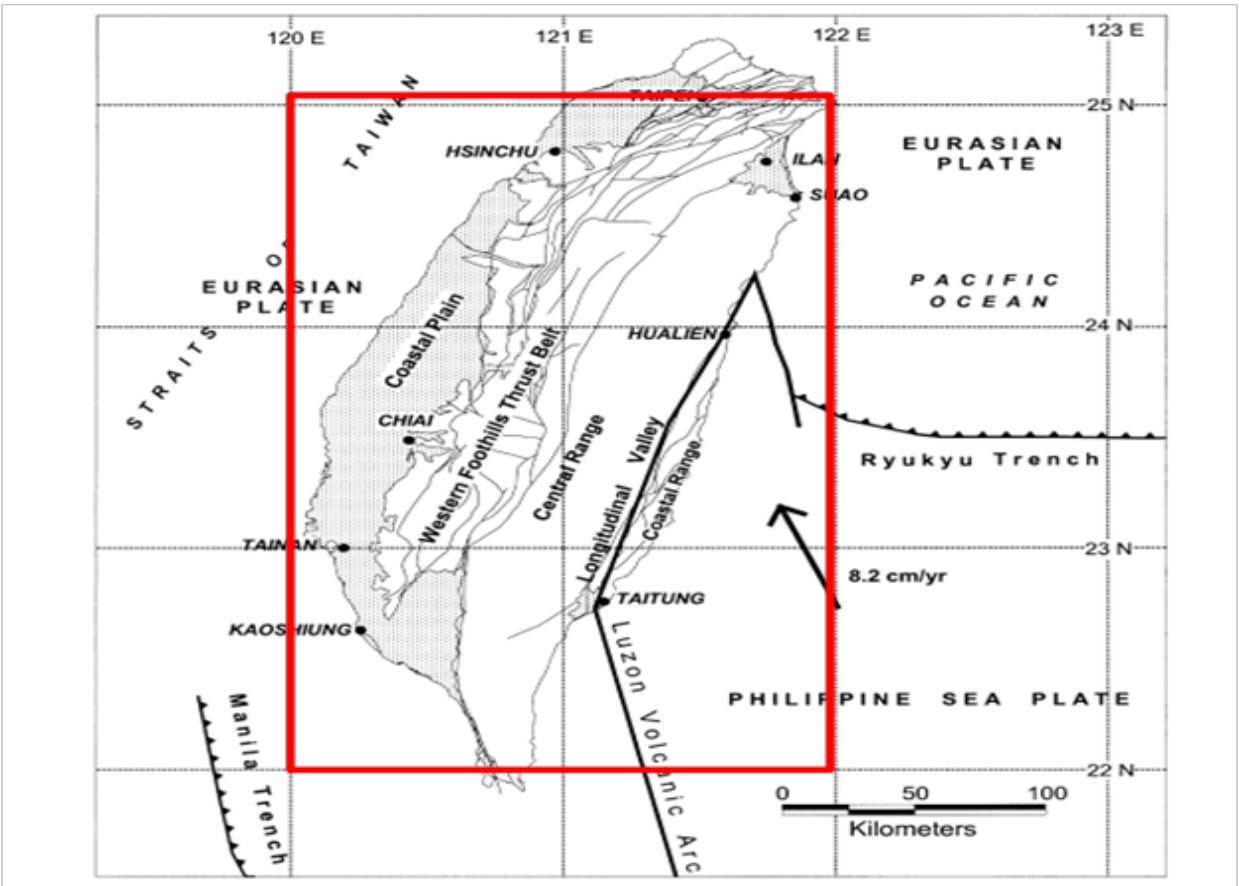

Figure 1. Location map of the study region in Taiwan (Campbell et al., 2007)

The following features of event were considered for shallow, intermediate and deep-focus earthquakes, they are: the number of events of each magnitude (N), the cumulative of the number of events (CUM N) and the logarithm of the cumulative of the number of events (LOG CUM N).

Table 2. Classification of events according to their focal depth

Depth(km)/Mag	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	Total
0-70	209	1085	527	23	2	1846
70-300	23	70	15	1	0	109
300-700	0	0	0	0	0	0
						1955

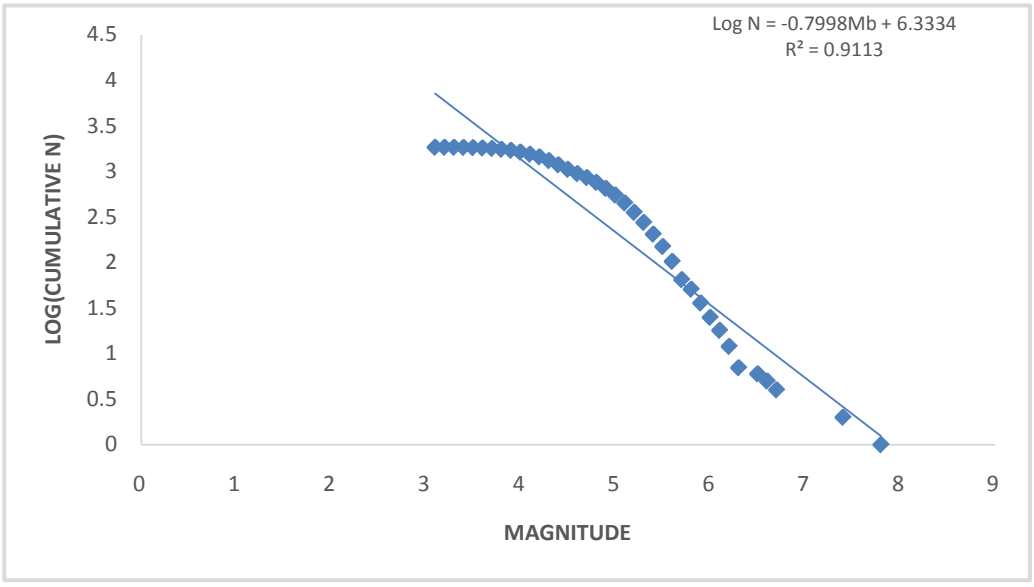

Figure 2. Frequency-Magnitude relationship for Shallow Earthquakes from 1961-2010

4. Results and Discussions

In order to investigate the variation of seismicity in the study area, the earthquakes were classified according to their focal depth as shown in Table 2. We note that shallow earthquakes have depth of 0-70km, intermediate earthquakes 70km-300km and deep earthquakes 300km-700km.

A scatter graph of Log (Cumulative N) versus magnitude gives the Frequency-Magnitude relationship for Shallow and Intermediate earthquakes from 1961-2010 as shown in Figure 2 and Figure 3.

The b-value for the shallow and intermediate earthquakes was computed from the slopes of the graphs in Figure 1 and Figure 2. The computed b- value for the shallow earthquakes was found to be 0.80 and for the intermediate earthquakes it was 0.74.

The Bar chart constructed in Figure 4 shows the Frequency-Magnitude distribution of 1955 events based on the focal depth for shallow and intermediate earthquakes respectively.

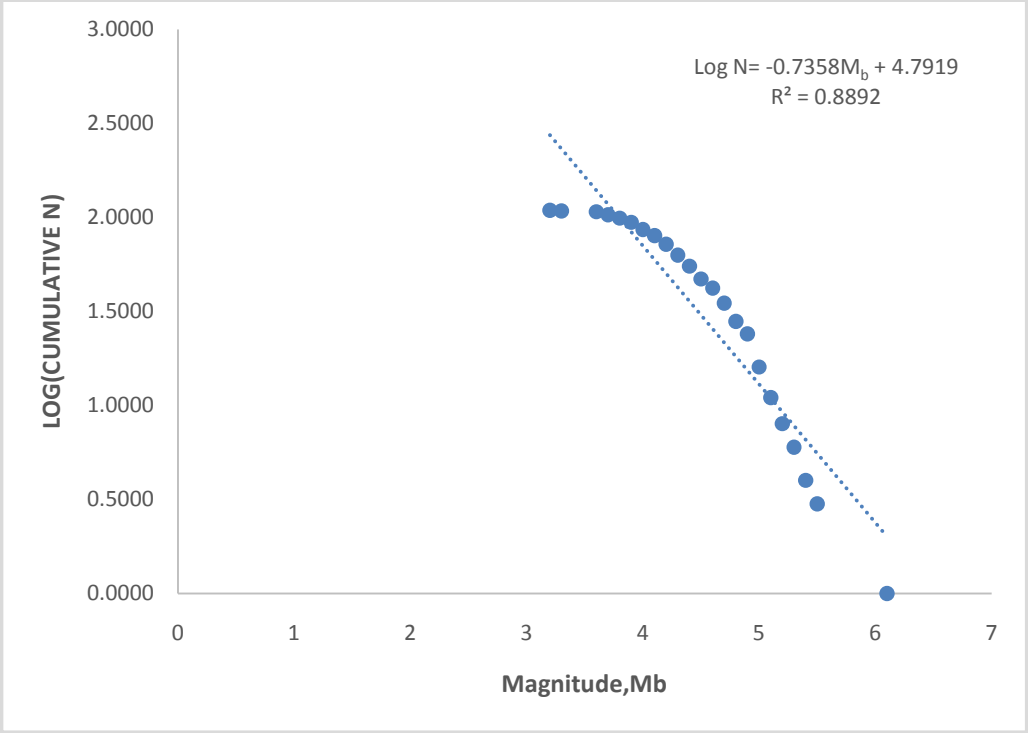

Figure 3. Frequency-Magnitude relationship for Intermediate earthquake from 1961-2010

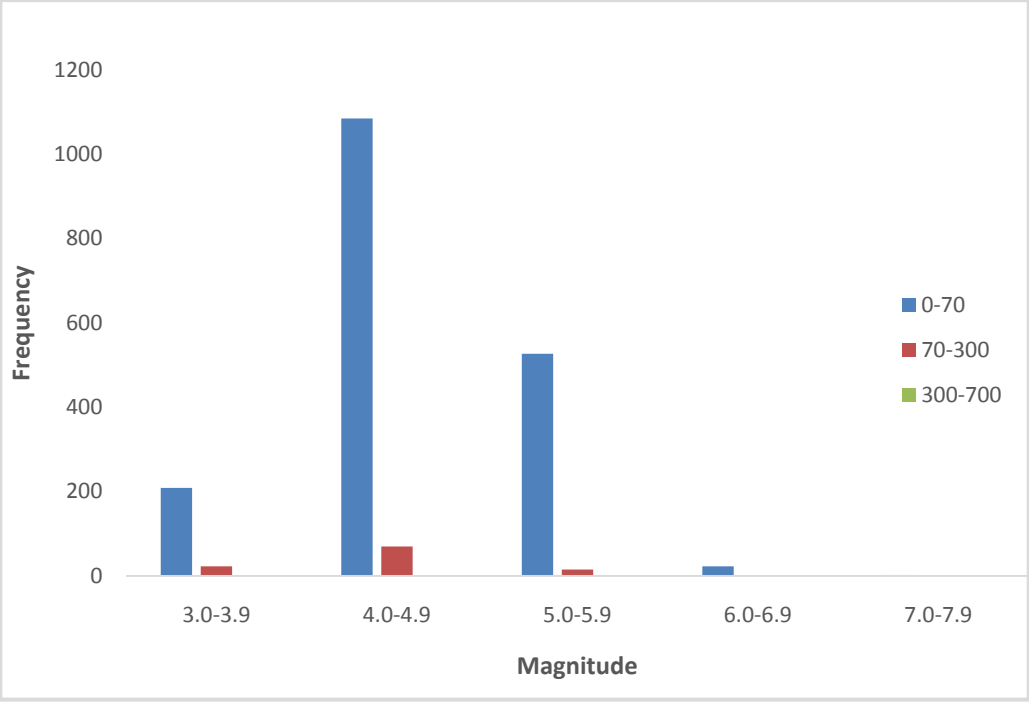

Figure 4. Frequency-Magnitude distribution of 1955 events in Taiwan Island region based on the focal depth from 1961-2010

5. Discussion

Observation from the data shows that for each magnitude range, the number of shallow focus earthquakes was more than the intermediate focus earthquakes in the study region. No deep focus earthquakes were found in the study area. Considering the shallow earthquakes, it was observed that earthquakes with magnitude 4.0-4.9 constitute (59%), 5.0-5.9 (29%), 3.0-3.9 (11%), 6.0 - 6.9 (1%), and 7.0-7.9 (0%), while, for intermediate earthquakes, earthquakes with magnitude 4.0-4.9 constitute (64%), 3.0-3.9(21%), 5.0-5.9 (14%), 6.0-6.9 (1%) and 7.0-7.9(0%).

This implies that, for shallow earthquakes, events with magnitude 4.0-4.9 (light) is the most frequent, followed by 5.0-5.9 (moderate), 3.0-3.9 (minor), 6.0-6.9 (strong) and the least frequent with magnitude 7.0-7.9 (major). While for intermediate earthquakes, events with magnitude 4.0-4.9 (light) were the most frequent, followed by 3.0-3.9 (minor), 5.0-5.9 (moderate), 6.0-6.9 (strong) and the least frequent with magnitude 7.0-7.9 (major). This study also revealed that majority of damages in Taiwan Island is caused by shallow earthquakes, since the shallower an earthquake, the more destruction it causes [13]. Furthermore, from the result shown in Table 2, about three (3) shallow earthquakes occur monthly and about two (2) intermediate earthquakes occur yearly in the Taiwan.

Furthermore, the b-value was calculated for shallow and intermediate focus earthquakes to be 0.80 and 0.74 respectively. According to Talwani (1988 and 1989), the low b-value is a characteristic feature of the intra-plate regions. The reason for this observation is that, within the plate, the rocks are not intensively fractured. Low b-value indicates localized high stresses which are favourable for future rupture. High and low shear stresses may cause earthquakes with low and high b-values respectively (Wyss 1973, Shorlemmer *et al*., 2005). But a-value is of less scientific interest, which indicates that the total seismicity rate of the region is high. However, one has to take caution because tectonic deformation and uncertainties of occurrence of earthquake are not well understood.

6. Conclusion

Taiwan is generally regarded as a region of high active seismicity because of the complex pattern in which two plates interact, that is, the collision of the Eurasian plate and the Luzon Island arc of the Philippine Sea plate in the southeastern zone of the region. It can be summarized from this study of the frequency of earthquakes for 50 years that the study area is characterized predominantly by minor, light and moderate earthquakes with the percentage of strong and major extremely low. The study revealed that for each magnitude range, the number of shallow focus earthquakes is more than the intermediate focus earthquakes in the study region. No deep focus earthquake was observed. The region is dominated by shallow earthquakes of magnitudes 4.0-4.9, followed by 5.0-5.9, 3.0-3.9, 6.0-6.9 and 7.0-7.9 being the least and intermediate earthquakes of magnitude 4.0-4.9, followed by 3.0-3.9, 5.0-5.9, 6.0-6.9 and 7.0-7.9 being the least. It therefore implies that the probability of strong and major earthquake occurring in the Taiwan Island region is low but one has to be careful because the entire process that leads to the occurrence of earthquakes is not well understood. The low b-value calculated for the region indicates high stress which is favourable for future rupture but the a-value is of less scientific interest which indicates whether the total seismicity rate of the region is high. The architects and civil engineers in this region are advised to continue to design and build earthquake resistant structures in view of the high seismicity of the region.

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References

[1] Alabi A.A, Akinyeme, D.A & Adewale A. (2013). Seismicity Pattern in South Africa from 1986 to 2009. *Earth science Research.* 2(2), 1-10.

[2] Brillinger D.R. (1993). Earthquake risk and insurance, *Environmetrics*, 4(1), 1-21.

[3] Bulletin of the Seismological Society of America (2001). The Largest Onland Earthquake to occur in Taiwan in the 20th century. 91(5).

[4] Campbell K.W, Thenhaus P.C, Barnhard T.P & Hampson B.D (2002). Seismic hazard model for loss estimation and risk management in Taiwan. *Soil Dynamics and Earthquake Engineering*, 22, 743-754.

[5] Chen C.C., Rundle J.B., Holliday J.R., Nanjo K.Z., Turcotte D.L., Li S.C., Tiampo K.F (2005). The 1999 Chi-Chi Taiwan, earthquake as a typical example of seismic activation and quiscence. *Geophys. Res. Lett.* 32, L22315.

[6] Chen, C.C. (2003). Accelerating seismicity of moderate sized earthquakes before the 1999 Chi-Chi Taiwan earthquake: testing time-prediction of self-organizing spinodal model of earthquakes. *Geophysics Journal International* 155, F1-F5.

[7] Loh, C.H. & Yeh, C. S. (1994). Earthquake Hazard Mitigation in Taiwan. *Proceedings of the WSSI Workshop on seismic Risk Management for countries of the Asia Pacific Region, INCEDE Report* 1994, 02, 147-153.

[8] Lowrie, W. (2007). Fundamentals of Geophysics. Cambridge University Press, England. First edition.

[9] Rau, R.J. (1992). Flexure modeling and Taiwan Tectonics, Masters Thesis, 131. State Univerity of New York at Birminghamton.

[10] Roecker, S.W., Y.H. Yeh and Y.B Tsai (1987). Three dimensiional P and S wave velocity struuctures beneathh Taiwan: deep structure beneath an arc-continent collision. *Journal Of Geophysics Research*, 92, 10, 574-10, 570.

[11] Schorlemmer, D., Wiemer, S. & Wyss, M. (2005). Variation in earthquake-size distribution across different stress regimes. *Nature*, 437, 539-542.

[12] Sheu, S.Y., Shieh, C.F., Shih, R.C. (2002). Detection of a non-local seismicity pattern prior to larger-size earthquakes in Taiwan. *Terr. Atmos. Ocean. Sci.*, 13,125-134.

[13] Talukdar, P & Barman, N.C (2012). Seismic Activity and seismotectonic correlation with Reference to Northeast India. *IOSR Journal of Applied Physics*, 4(3), 31-40.

[14] Tsai, Y.B (1986). Seismotectonics of Taiwan. *Tectonophysics* , 125, 17-37.

[15] Tsai, Y.B, Teng, T.L, Chiu, J.M, Liu, H.L (1977). Tectonic implications of the seismicity in the Taiwan region. *Memoir of the Geological Society of China* 2, 13-41.

[16] United States Geological Survey (2013). Earthquake Facts and statistics. Richter Earthquake Magnitude Classes.

[17] Wang J.H (1998). Studies of earthquake seismology in Taiwan during the 1897-1996 period. *Journal of the Geological Society of China* 41, 291-335.

[18] Wang, J.H., Chen, K.C. & Lee, T.Q. (1994). Depth distribution of shallow earthquakes in Taiwan. *Journal of the geological society of China* 37, 125-142.

[19] Wu Y.M, & Chen, C.C (2007). Seismic reversal pattern for the 1999 Chi-Chi, Taiwan, M_w7.6 earthquake. *Tectonophysics*, 429, 125-132.

[20] Wu, F.T. (1978). Recent tectonics of Taiwan. *J. Phys. Earth (suppl.)* 26, S265-S299.

[21] Wu, F.T., Chen K.C, Wang J.H, McCaffrey R. & Salzberg, D (1989). Focal mechanisms of recent large earthquakes and the nature of faulting in the longitudinal valley of eastern Taiwan. *Proc. Geol. Soc. China*, 32, 157-177.

[22] Yu, S.B., Chen, H.Y., & Kuo, L.C. (1997). Velocity field of GPS stations in the Taiwan area. *Tectonophysics*, 274, 41-60.