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Tidal Stress Triggering Earthquakes
Case Study The Eastern Part of the Indian Ocean

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ABSTRACT

Seismological studies indicate that almost all earthquakes occurrence are attributed to tectonic stresses. On the other hand, Earth tides represent the largest periodic stress variations within the Earth’s crust and deep layers. Although, the amplitude of the tidal stress is small compared to the tectonic stresses, tidal stress rate is comparable or even higher than the tectonic stress rate (Dieter Emter, 1997). This high rate tidal stress may

superimpose slow tectonic stress and act as trigger to the seismological activities. Many authors investigated tidal stresses as earthquake triggering agent. However, the obtained results are different from region to another.

In ocean region large earthquakes are usually occurred along high accumulated stresses tectonic plates. Large magnitude earthquakes along these regions may be accompanied with tsunamis. Tidal stresses through ocean are added by tidal loading due to variable movement of the water mass.

The tectonic active region located between the collision of Indian and Burmese plates has been selected as a case for the current study. This region is characterized by high seismic activity, with numerous large events ($M > 6.5$), resulted from this collision. In addition, The choice of our case study is due to the importance of Indian Ocean littoral regions where it should generate and pay attention to earthquake and Tsunami warnings especially after occurring of the 26th December 2004 Sumatra Tsunami.

Tidal deformation has been computed for the selected region using modern body tide model and Satellite derived global ocean tide model. Different statistical methods were applied to determine the degree of correlation between tidal deformations as triggered to the seismic activities. Magnitude and focal depths of the test events are considered on the correlation process. The study shows a higher degree of correlation of the tidal stresses to large deep events rather than of moderate shallow events.

INTRODUCTION

The lunar-solar attraction is responsible not only for the orbital motion, but also for the nearly periodic tidal motion of the Earth. This is because the Earth can be regarded as a large sphere of radius 6400 km, the lunar-solar attraction that changes in inverse proportion to square of the distance to the Moon or the Sun is not balanced throughout in the Earth by the inertia of its orbital motion. The difference between the attraction and the inertial force results in the tidal force that always tends to deform the Earth (Rongjiang Wang, 1997). The most obvious phenomenon which represents the Earth's response to the lunar-solar tidal force is the ocean tide, but also there are deformations of the solid Earth, called body tide.

Body tide is superimposed by surface forces due to the pressure of the harmonically varying ocean tide acting on the Earth and producing tidal loading. This loading effect is particularly strong in the coastal area but can be terraced even deep into the continent.

Whereas the body tide varies smoothly over the Earth's surface, the ocean tide loading is more irregular because of the discontinuity in the forcing function at the coastline. Although the spatial behavior of the two tidal effects is quiet different, it is difficult to distinguish between these tides because both are the result of the same astronomical input.

Most of the time, tides are responsible for the largest temporal variations in crustal stresses. Diurnal and semi-diurnal tides have amplitudes reaching 30 mbar and peak loading rates on the order of 20 mbar/hr. These tidal oscillations are superimposed on a tectonic loading rate of 1 mbar/hr or less. Except for the case of moonquakes, there appear to be no published correlations between seismicity and Earth tides that can withstand rigorous statistical scrutiny. Recently the critical point model of earthquakes has been invoked to suggest that the ratio of seismicity during times of increased tidal loading to times of decreased tidal loading takes on anomalously large values as the preparatory region of the earthquake approaches a critical state. This idea is based on the non-linearity of stress-strain behavior near macroscopic failure. The loading and unloading response become increasingly asymmetric as failure is approached.

Tidal Acceleration

The gravitational attraction of the Moon and Sun, as they and the Earth move with respect to each other, imposes periodic forces on the solid Earth, oceans and atmosphere. The response of each of these parts of the Earth to the tidal force affects almost all precise measurements of the Earth. For this reason, tides are important both for the correction of precise measurements and as an input signal for the evaluation of the structure and properties of the Earth.

The tidal acceleration $\vec{b}$ in an observation point P on the Earth's surface results from the sum of the gravitational acceleration $\vec{a}_P$ generated by a celestial body at point P and of the orbital acceleration $-\vec{a}_0$ due to the motion of the Earth, as shown in figure 1.

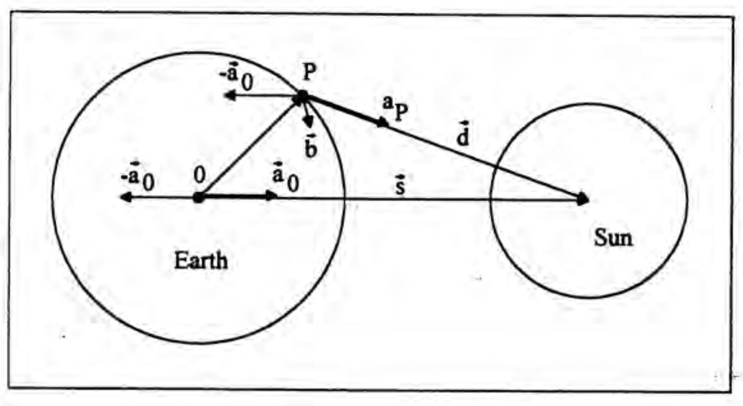

Fig.1: Tidal acceleration

Applying Newton's gravitational law, the tidal acceleration vector $b^{\rightarrow}$ is given by:

$$\vec{b} = \vec{a}_p - \vec{a}_0 = \frac{GM_b}{d^2}.\frac{\vec{d}}{d} - \frac{GM_b}{s^2}.\frac{\vec{s}}{s} \qquad (1)$$

The tidal acceleration vector $b^{\rightarrow}$ is, by definition, the gradient of the tidal potential V:

$$\vec{b} = \overrightarrow{grad}\,V = \frac{\partial V}{\partial \vec{r}} \qquad (2)$$

At the geocenter, where $r^{\rightarrow}=0$, the tidal potential vanishes and eq. (2) can be written as:

$$V = \frac{GM_b}{s}.\left(\frac{1}{d} - \frac{1}{s} - \frac{r.\cos\Psi}{s^2}\right) \qquad (3)$$

with ψ = geocentric zenith angle and eq. (3) can be expanded into Legendre polynomials $P_1(\cos\psi)$ (eg. Wenzel, 1997) as:

$$V = \frac{GM_b}{s}.\sum_{l=2}^{\infty}\left(\frac{r}{s}\right)^l P_l(\cos\Psi) \qquad (4)$$

ψ can be expressed by geocentric spherical coordinates of the station and of the celestial body as:

$\cos\psi = \cos\Theta \,.\, \cos\Theta_b + \sin\Theta \,.\, \mathrm{Sin}\,\Theta_b \,.\, \cos(\lambda-\Lambda_b)$ (5)

where ψ is the geocentric zenith angle of the celestial body, Θ is the geocentric spherical polar distance of the station, λ is the geocentric spherical longitude of the station, Θ_b is the geocentric spherical polar distance to the celestial body and Λ is the geocentric spherical longitude of the celestial body. Eqs. 4&5 indicate that, the tidal potential is position and time dependent.

The tidal potential V causes a radial shift Δ_r of the attracted point P. The corresponding mass displacement causes a deformation of potential V_d. Radial deformation Δ_r and the deformation of potential V_d are proportional to the tidal potential V.

The tidal potential of the elastic Earth V_d V_{el} can be described by the theory of Love (1909) (eg. Torge, 1989) as:

$$V_{el} = V_t + V_d - g\Delta_r = V_t(1 + k - h) \qquad (6)$$

where: Love's parameters k = k(r) and h = h(r) appear as proportion factors. k and h depend on the degree of the spherical harmonic expansion of the tidal deformation.

Tides and Earthquakes

There has always been a tendency for the thought of the tidal force to be attributed to earthquakes occurrence. Ocean tides were discussed as a cause for earthquakes already in the 17th century. But with the detection of Earth tides at the end of the last century, such investigations become possible. Estimates with realistic Earth models show that Earth tides are the reason for the largest periodic stress variation within the Earth’s crust and deeper layer. As the tidal stresses with their large rates are always present and superimposed with the slowly increasing tectonic stress they may finally act not as a cause but as a trigger of the seismological event. A simple trigger model works only during a special time segment of tectonic stress building and with a well defined critical stress level (Curchin and Pennington, 1987; Rydlek et al., 1992).

However, there many theories have discussed the possible relation between tides and earthquakes occurrence. Some of these theories are summarized as follow:

(1) The constant movement of the Earth's tectonic plates relative to one another and other phenomena such as volcanic processes gradually add strain to earthquake fault zones around the world. When that strain level reaches a certain point the fault zone rock layers fracture, resulting in a sudden release of much of their stored energy in the form of an earthquake.

(2) It is possible that with some percentage of earthquakes there is no distinct triggering mechanism which can be easily identified. However, it is my personal belief that with many powerful earthquakes, when a fault zone has accumulated enough strain energy that it is about to fracture on it own, different processes or phenomena can rapidly add enough additional strain to it to trigger an earthquake.

Those processes or phenomena would include shock waves from other powerful earthquakes occurring around the world, perhaps ocean tides and the solid earth tide, and the sun and moon gravity and Earth rotation related earthquake triggering mechanism being outlined in this theory section. I presently suspect that this mechanism might be responsible for the triggering of a good percentage of our powerful earthquakes.

(3) Once a year the sun and the Earth rotate about a shared center of mass which is close to the center of the sun. And once a month the moon and the Earth rotate about a shared center of mass which is somewhere beneath the surface of the Earth.

(4) Those rotations combined with the gravitational pulls of the sun and the moon on the Earth's crust and oceans cause crustal matter and ocean water to shift both towards and away from the positions of the sun and the moon in the sky. As a result there are crustal and ocean water tidal bulges on the sides of the Earth facing the sun and moon, and on the opposite sides of the Earth from them (high ocean tides and solid earth tides). (5) Also as a result of those crust and ocean water shifts, at locations 90 degrees away from the positions of the sun and the moon in the sky the Earth's crust and oceans are flattened or depressed to a certain extent (low ocean tides and solid earth tides).

(6) When the sun is 90 degrees to the east or west of the moon in the sky its gravitational pull on the Earth's crust and oceans works against the moon's gravitational pull related tide crests and troughs.

(7) Centrifugal forces associated with the rotation of the Earth on its North and South Pole axis and other phenomena such as friction attempt to reduce the amplitude of those tidal crests and troughs. And those opposing forces can result in sufficient strain energy being generated to trigger earthquakes in fault zones in certain locations when the fault zones have already accumulated enough strain that they are getting close to fracturing on their own.

(8) In a simplified picture, those fault zones where that earthquake triggering strain energy winds up being focused would be near the longitude of the position on the Earth's surface where the combined gravitational pulls of the sun and the moon are strongest, and 90, 180, and 270 degrees to the west of that longitude. However, as data in this report might indicate, those four longitudes may often be offset a certain amount to the east or west of an actual fault zone longitude by fault zone environmental factors and by ocean and solid Earth tide related forces etc.

(9) Because the gravitational pulls which the planets and other objects in space exert on the Earth have relatively low values in comparison with those of the sun and the moon, the planets etc. are probably not contributing significantly to earthquake triggering processes.

Case Study: The Eastern Part of the Indian Ocean

The earthquake and tsunamis of 26 December 2004 in 12 countries of the Indian Ocean have reportedly killed over 150 000 people, made an estimated five million persons homeless, resulted in massive displacement of population and caused extensive damage to infrastructure. Various values were given for the magnitude of the earthquake, ranging from 9.0 to 9.3 (which would make it the second largest earthquake ever recorded on a seismograph, after the 9.5 magnitude Great Chilean Earthquake of May 22, 1960), though authoritative estimates now put the magnitude at 9.15.

In May 2005, scientists reported that the earthquake itself lasted close to ten minutes when most major earthquakes last no more than a few seconds; it caused the entire planet to vibrate at least a few centimeters. Severe localized crop losses have also been reported, particularly in the Maldives and parts of Indonesia. At the national level, while all countries were affected, smaller countries such as Sri Lanka and the Maldives are likely to suffer relatively heavier economic consequences from the tsunami disaster. Moreover, the region is characterized by very high seismological distribution attributed to a very complex regional tectonic structures. On the other hand, the complicated marine environment could lead to high ocean tide loading stresses beside the body tide contribution. Thus, the eastern part of the Indian Ocean has been selected as a case study of the current research.

TECTONIC PLATES OF THE STUDY AREA

The Indian Ocean earthquake 2004 was unusually large in geographical extent. An estimated 1200 km (750 mi) of fault line slipped about 15 m (50 ft) along the subduction zone where the India Plate dives under the Burma Plate. The slip did not happen instantaneously but took place in two phases over a period of several minutes. Seismographic and acoustic data indicate that the first phase involved the formation of a rupture about 400 km (250 mi) long and 100 km (60 mi) wide, located 30 km (19 mi) beneath the sea bed - the longest known rupture ever known to have been caused by an earthquake. The rupture proceeded at a speed of about 2.8 km/s (1.7 mi/s) or 10,000 km/h (6,300 mph), beginning off the coast of Aceh and proceeding north-westerly over a period of about 100 seconds. A pause of about another 100 seconds took place before the rupture continued northwards towards the Andaman and Nicobar Islands. However, the northern rupture occurred more slowly than in the south, at about 2.1 km/s (4,700 mph), continuing north for another five minutes to a plate boundary where the fault changes from subduction to strike-slip (the two plates push past one another in opposite directions) thus reducing the speed of the water displacement and so reducing the size of the tsunami that hit the northern part of the Indian Ocean (Kostel and Tobin 2005).

The India Plate is part of the great Indo-Australian Plate, which underlies the Indian Ocean and Bay of Bengal, and is drifting northeast at an average of 6 cm/a (2 inches per year), figure 2 . The India Plate meets the Australasian Plate (which is considered a portion of the great Eurasian Plate) at the Sunda Trench. At this point the

India Plate subducts the Burma Plate, which carries the Nicobar Islands, the Andaman Islands and northern Sumatra. The India Plate slips deeper and deeper beneath the Burma Plate until the increasing temperature and pressure drive volatiles out of the subducting plate. These volatiles rise into the mantle above and trigger melt which exits the earth's mantle through volcanoes. The volcanic activity that results as the Indo-Australian plate subducts the Eurasian plate has created the Sunda Arc (Curray, 2002).

As well as the sideways movement between the plates, the sea bed is estimated to have risen by several meters, displacing an estimated 30 km^3 (7 cu mi) of water and triggering devastating tsunami waves. The waves did not originate from a point source, as mistakenly depicted in some illustrations of their spread, but radiated outwards along the entire 1200 km (750 mi) length of the rupture. This greatly increased the geographical area over which the waves were observed, reaching as far as Mexico, Chile and the Arctic. The raising of the sea bed significantly reduced the capacity of the Indian Ocean, producing a permanent rise in the global sea level by an estimated 0.1 mm (Lay et al, 2005). The Burma Plate, showing boundaries with the India Plate (the Sunda Trench) and the Sunda Plate (through the Andaman Sea). The Burma Plate is a small tectonic plate or microplate located in Southeast Asia, often considered a part of the larger Eurasian Plate. The Andaman Islands, Nicobar Islands, and northwestern Sumatra are located on the plate. This island arc separates the Andaman Sea from the main Indian Ocean to the west.

To its east lies the Sunda Plate, from which it is separated along a transform boundary, running in a rough north-south line through the Andaman Sea. This boundary between the Burma and Sunda plates is a marginal seafloor spreading centre, which has lead to the opening up of the Andaman Sea (from a southerly direction) by "pushing out" the Andaman-Nicobar-Sumatra island arc from mainland Asia, a process which began in earnest approximately 4 million years ago. To the west is the much larger India Plate, which is subducting beneath the eastern facet of the Burma Plate. This extensive subduction zone has formed the Sunda Trench.

TECTONIC HISTORY

In models of the reconstructed tectonic history of the area, the generally northwards movement of the Indo-Australian Plate resulted in its substantive collision with the Eurasian continent, which began during the Eocene epoch, approximately 50-55 million years ago (Ma). This collision of the India Plate portion with Asia began the organic uplift which has formed the Himalaya Mountains

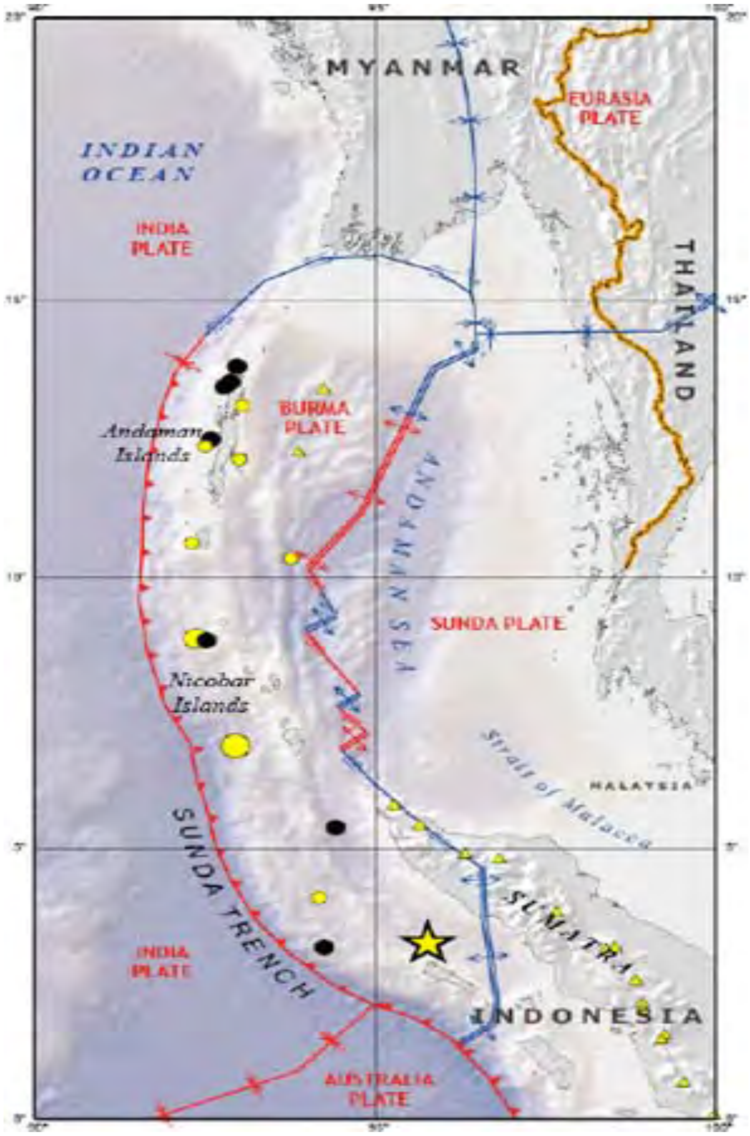

Fig.2 The Burma Plate, showing boundaries with the India Plate (the Sunda Trench) and the Sunda Plate (through the Andaman Sea) (after Lay et al., 2005)

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As the India Plate drifted northwards at a relatively rapid rate of an average 16 cm/yr, it also rotated in an anti-clockwise direction. As a result of this movement and rotation, the convergence along the plate's eastern boundary (the Burma-Andaman-Malay region) with Eurasia was at an oblique angle. The transform forces along this subduction front started the clockwise bending of the Sunda arc; sometime during the late Oligocene

(ca. 32 Ma) further faulting developed and the Burma and Sunda microplates began to "break off" from the larger Eurasian plate. After a further series of transform faulting, and the continuing subduction of the India Plate beneath the Burma plate, back arc spreading saw the formation of the marginal basin and seafloor spreading centre which would become the Andaman Sea, a process well-underway by the mid-Pliocene (3-4 Ma).

RECENT TECTONIC AND SEISMIC ACTIVITIES

On December 26, 2004, a large portion of the boundary between the Burma Plate and the Indo-Australian Plate slipped, causing the 2004 Indian Ocean earthquake. This mega thrust earthquake had a magnitude of 9.0. Over 1200 km of the boundary underwent thrust faulting and shifted an average of 15 m, with the sea floor being uplifted several meters. This rise in the sea floor generated a massive tsunami that killed approximately 275,000 people along the coast of the Indian Ocean.

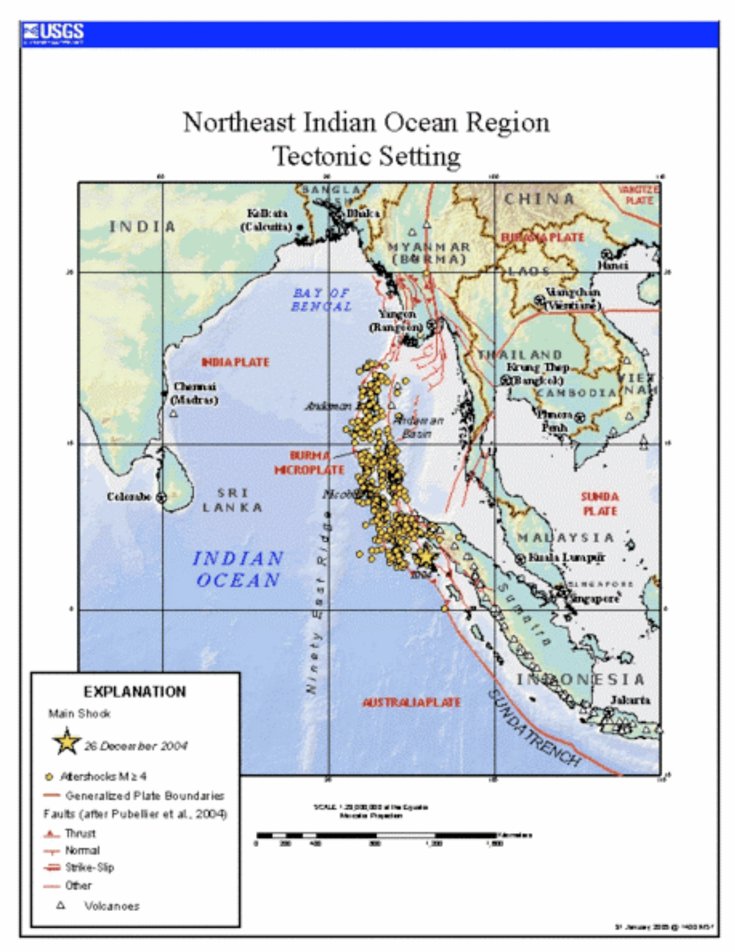

Fig. 3: Tectonic map showing the plat boundaries of the studying area, (USGS 2005).

2004 INDIAN OCEAN EARTHQUAKE:

The 2004 Indian Ocean earthquake, known by the scientific community as the Sumatra-Andaman earthquake, was an undersea earthquake that occurred at 00:58:53 UTC (07:58:53 local time) on December 26, 2004. The tsunami generated by the earthquake killed approximately 275,000 people, making it one of the deadliest disasters in modern history. The disaster is also known in Australia, Canada and the United Kingdom as the Boxing Day Tsunami.

Various values were given for the magnitude of the earthquake, a rare great earthquake, ranging from 9.0 to 9.3 (which would make it the second largest earthquake ever recorded on a seismograph), though authoritative estimates now put the magnitude at 9.15.

In May 2005, scientists reported that the earthquake itself lasted close to ten minutes when most major earthquakes last no more than a few seconds; it caused the

entire planet to vibrate at least a few centimeters. (CNN, 2005) It also triggered earthquakes elsewhere, as far away as Alaska (West et al., 2005).

The earthquake originated in the Indian Ocean just north of Simeulue Island, off the western coast of northern Sumatra, Indonesia. The resulting tsunami devastated the shores of Indonesia, Sri Lanka, South India, Thailand and other countries with waves up to 30 m (100 ft). It caused serious damage and deaths as far as the east coast of Africa, with the furthest recorded death due to the tsunami occurring at Port Elizabeth in South Africa, 8,000 km (5,000 mi) away from the epicenter.

Approximately 170,000–275,000 thought to have died as a result of the tsunami and the count is not yet complete. In Indonesia in particular, 500 bodies a day were still being found in February 2005 and the count was expected to continue past June (*CNN*, 2005). The true final toll may never be known due to bodies having been swept out to sea, but current estimates use conservative methodologies. Relief agencies warn of the possibility of more deaths to come as a result of epidemics caused by poor sanitation, but the threat of starvation seems now to have been largely averted (West et al., 2005). The plight of the many affected people and countries prompted a widespread humanitarian response.

QUAKE CHARACTERISTICS

The earthquake was initially reported as 8.6 on the Richter scale. The Pacific Tsunami Warning Center (PTWC) also estimated it at 8.5 shortly after the earthquake. On the moment magnitude scale, which is more accurate for quakes of this size, the earthquake's magnitude was first reported as 8.1 by the U.S. Geological Survey. After further analysis, this was increased to 8.5, 8.9, and 9.0 (USGS, 2004). In February 2005, some scientists revised the estimate of magnitude to 9.3. Although the Pacific Tsunami Warning Center has accepted this, the USGS has so far not changed its estimate of 9.0 (McKee, 2005). The most definitive estimate so far has put the magnitude at 9.15 (Hanson, 2005).

The hypocenter of the main earthquake was at 3.316°N, 95.854°E (3°19′ N 95°51.24′ E), some 160 km (100 mi) west of Sumatra, at a depth of 30 km (18.6 mi) below mean sea level (initially reported as 10 km). This is at the extreme western end of

the Ring of Fire, an earthquake belt that accounts for 81 percent of the world's largest earthquakes (USGS 2005). The earthquake itself (apart from the tsunami) was felt as far away as Bangladesh, India, Malaysia, Myanmar, Thailand, Singapore and the Maldives.

Since 1900 the only earthquakes recorded with a greater magnitude were the 1960 Great Chilean Earthquake (magnitude 9.5), the 1964 Good Friday Earthquake in Prince

William Sound (9.2), and the March 9, 1957 earthquake (USGS, October 20, 2003) in the Andreanof Islands (9.1). The only other recorded earthquake of magnitude 9.0 was in 1952 off the southeast coast of Kamchatka (USGS, October 24, 2003) (see Top 10 earthquakes). Each of these mega thrust earthquakes also spawned tsunamis (in the Pacific Ocean), but the death toll from these was significantly lower; a few thousand for the worst one, probably because of the lower population density along the coasts near affected areas and the much greater distances to more populated coasts.

Other larger mega thrust earthquakes occurred in 1868 (Peru, Nazca Plate and South American Plate); 1827 (Colombia, Nazca Plate and South American Plate); 1812 (Venezuela, Caribbean Plate and South American Plate) and 1700 (Cascadia Earthquake, western US and Canada, Juan de Fuca Plate and North American Plate). These are all believed to have been of greater than magnitude 9, but no accurate measurements were available in those days. Seismic Distributions map for the study region, (9=M ≥5, USGS 2005).

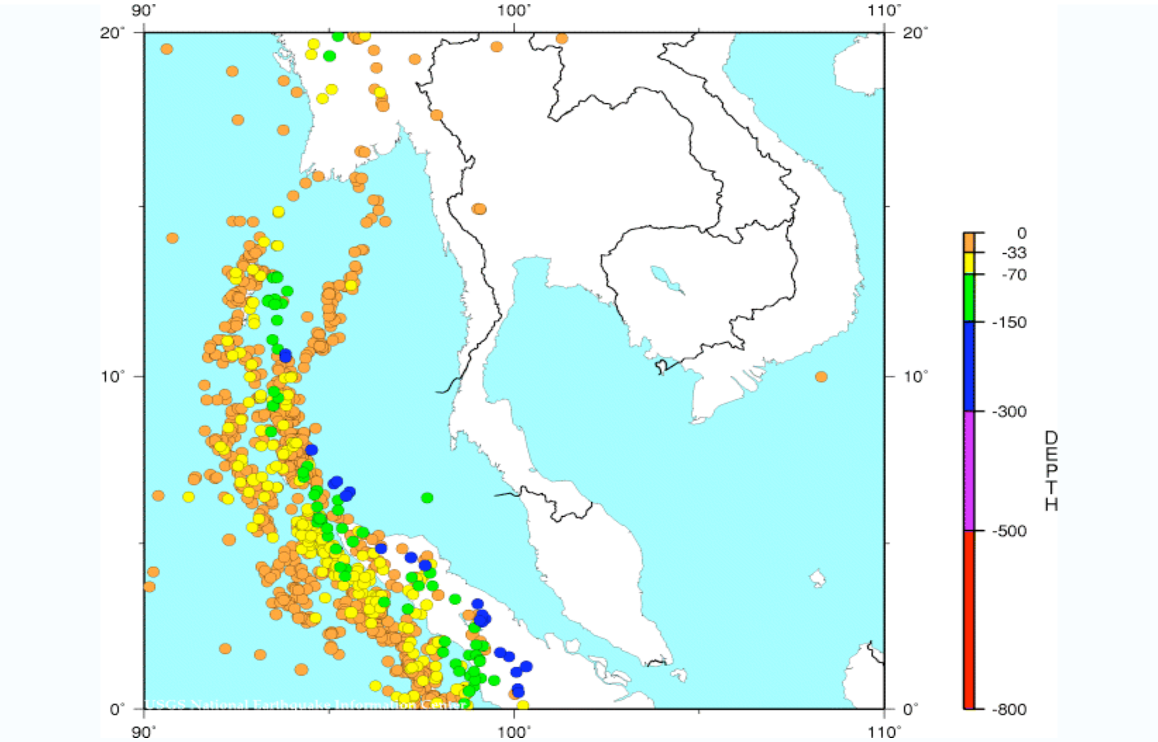

Fig. 4: Seismic Distributions map for the study region, (9=M≥5, USGS 2005).

Strategy of the Investigation

Many methods have been presented to find out a possible relation between tidal stresses and seismological activities in many reagions over the globe. In the current stu two methods have been used in order find possible correlation and to evaluate the degree of such correlation on the studied region. Firstly, is simply looking at the dy

periodicity whithn the observed seismic event and to compare it with the tidal perodicity using the synthetic tide model of the studied region. Secondely, is to find the time series correlation between the observed seismic events and the time series of the synthetic tidal stresses.

Tidal prediction of the selected region

Earth tide force is considered to be the only global phenomenon, which can be predicted accurately. The accuracy of predicting the tidal potential depends on the accuracy of the determination of the radius of the Earth, distance to the celestial body and its coordinates, which nowadays can be determined with a very high accuracy. Generally, computation of the functional of the tidal potential at a specific station and epoch can be carried out by the expansion of the tidal potential either by analytical spectral analysis or by numerical spectral analysis of the tidal potential generated by the celestial body to produce a tidal potential catalogue (amplitudes, phases and frequencies for tidal waves).

On the other hand, computation of the ocean tide loading deformation can be done using a model of the ocean. Nowadays, many accurate ocean tide models are available especially after the launch of TOPOX/Poseidon satellite mission (Zahran, 2000).

Thus, an accurate prediction of the tidal time function for the selected region is possible.

Zahran et al., 2005 introduced a synthetic tide parameter model for gravity and vertical and horizontal displacements. This synthetic model has been used to predict the tidal parameters at the selected region. In the present work the synthetic model, which uses Whar-Dehant body tide model (Dehant, 1987) and CSR3.0 ocean tide model (Eanes, 1994) was used.

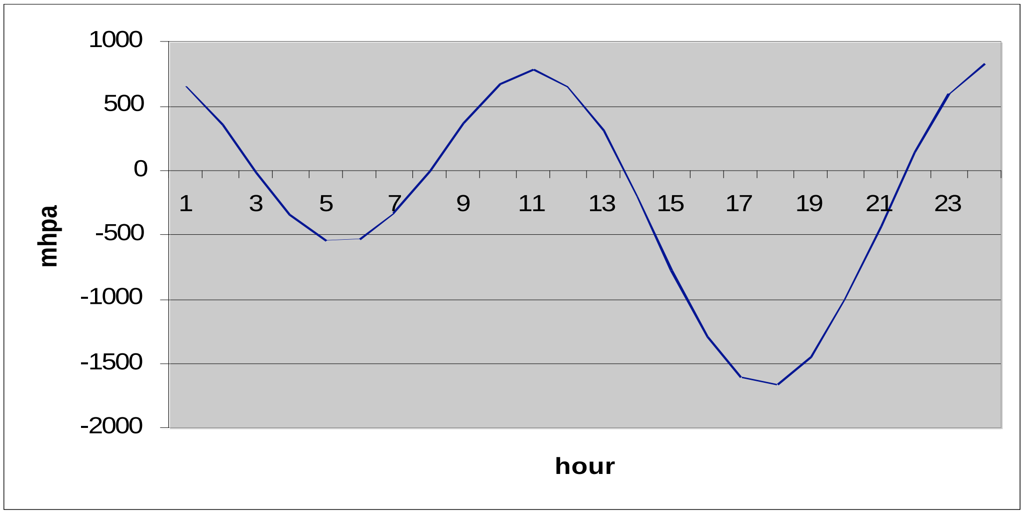

Fig. 5: Daily variations of the tidal stress at Sumatra region.

Figure 5 shows the daily variations of the tidal stress of the studied region, as computed using the synthetic tide parameter model

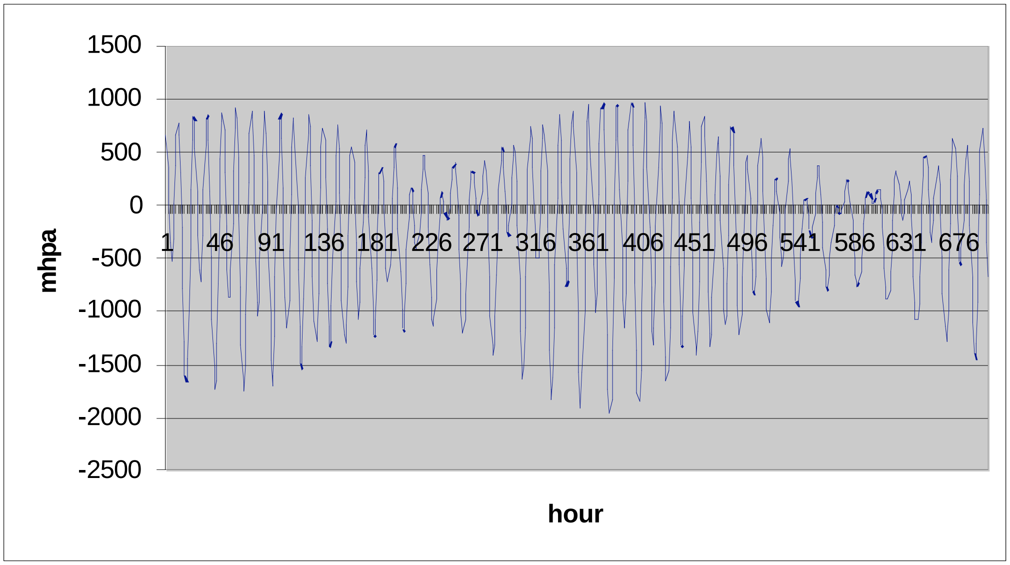

Fig. 6: Monthly variations of the tidal strain at Sumatra region.

The figure shows that the period of the tidal stress is mixed between semidiurnal and diurnal with a predominance of the semidiurnal periods. However, it is important to draw the long-period stress variations. Figure 6 shows monthly variations of the tidal stress at the studied region. The figure shows that the tidal stress range from -2000 to 1000 mhpa, this range is a relatively high stress range. The figure shows also a remarkable long periodic tidal stress and non uniformity of the tidal stress can be realized which may be due to the anomalous ocean tide loading along shore line.

Periodicity of seismic events

Periodicities in the time series of the seismic events could be obtained by the direct application of the Fourier Transformation (FT). This method has the potentiality to find the periodicity of a discrete events or the application of what so called Discrete Fourier Transformation (DFT). A number of seismic events of the study region were collected from the HSGS and NEIC international seismological catalogue, 2006. The used period is limited from 1990 to 2005 consedering that recent records are of accurate record and analysis. Figure 7 shows the DFT of the seismological events at the studied region. It is usually difficult to interpret this periodicity in the case of weak correlation.

Although, it can be easily realized that a significat maximum and minimum around the semidiurnal period, predominant tidal period on the studied region. On the other hand, diurnal tidal period could also be responsible but with some delay on the diurnal tidal band. The figure indicates also that tidal stress can trigger seismicity not only at a maximum stress but also at a minimum stress.

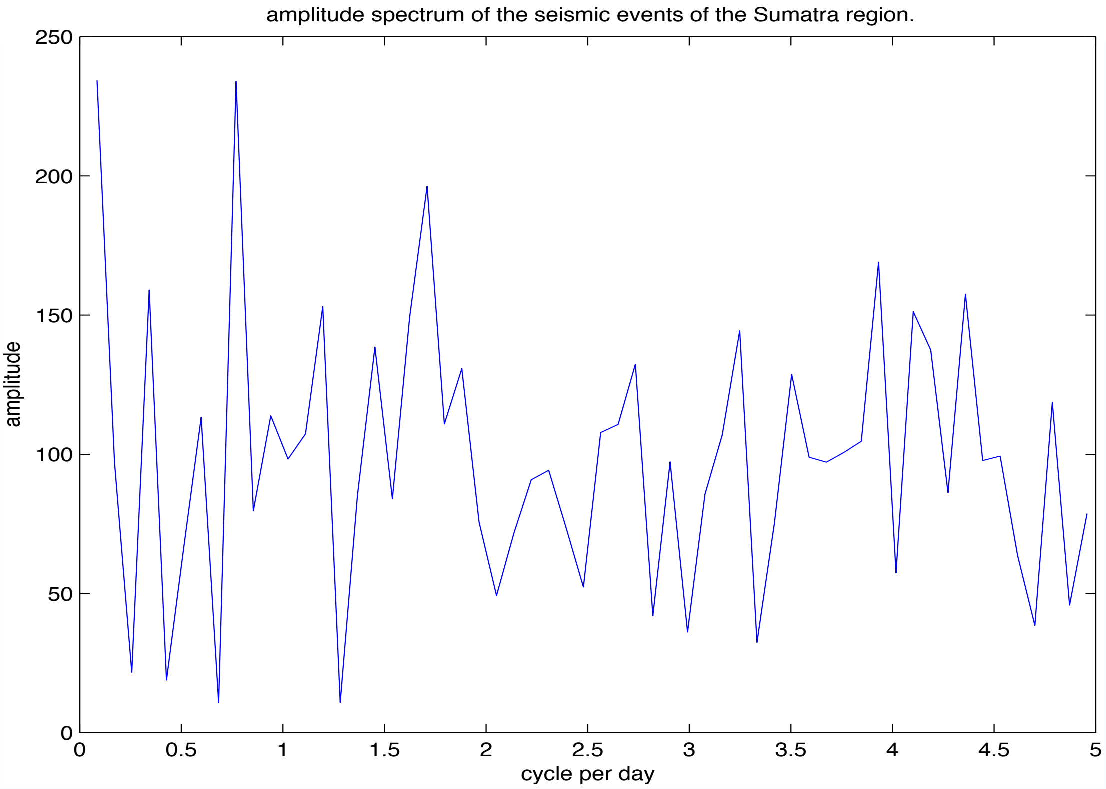

Fig. 7: DFT of the seismic events at Sumatra region fron 1990 to 2005.

Correlation between tidal stress and earthquake events

It is much more reasonable to find out the degree of correlation between the tidal stress and the earthquake events. This is because such correlation enables evaluating the relation between the tidal stress and the earthquakes occurrence quantitively. Moreover, such correlation considered the time and location of each event and inconsequence a simultinous consideration of the tidal stress amplitude normal to the tectonic feature. Finally, correlation computation enables also the consideraion of both magnitude and focal depth of the earthquke events. Table 1 shows the cross correlation betwee the tidal stress and earthquake events. The table shows a moderate correlation between the tidal stress and the events. Higher correlation is found to the shallow earthquakes, as tidal deformation increase as the distance to the Earth's center increase. On the other hand, tidal stress can trigger high magnitude earthquakes rather than weak eathquakes.

Table 1: Cross Correlations between the Tidal Stress and earthquake.

Earthquake depth, Magnitudes and tidal stress	**CC-factor**
shallow earthquakes	**0.423**
Medium earthquakes	**0.409**
Deep earthquakes	**0.393**
Earthquakes of Magnitudes < 6	**0.364**
Earthquakes of Magnitudes > 6	**0.412**

CONCLUSIONS

In the current research, tidal stress as triggered to earthquakes at Sumatra region has been studied. The selected region is characterized by seismological activities attributed to a complicated tectonic settings. Time series tidal stress has been computed using synthetic tide parameters model (Zahran et al., 2005) and correlated at number of earthquake events from 1990 to 2005 at the Sumatra region.

Based on results of the current study the following conclusions can be drawn:

- Tidal stress has magnitude less than tectonic stress but higher stress rate, thus it can trigger earthquakes in regions with shallow active tectonic.
- The area is characterized by mixed high lunar-solar tide and long periodic lunar-solar tide.
- Amplitude spectrum of the seismic events of the Sumatra region show significant spectrum close to the semidiurnal and diurnal periods, with the possible triggering at both maximum and minimum tidal stresses.
- Cross correlation of the seismic of the tidal stress to the shows a moderate correlation between them with higher correlation to shallow large earthquakes.
- It can be concluded that tidal stress can be considered as triggering factor to the seismic activity in Sumatra region and the study shows in general a positive results.

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