

Triggering of great earthquakes: calculation and analysis of combined tidal effect of the Moon and Sun

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Abstract. The largest part of solid minerals (with the exception of those which are at the earth's surface) is being extracted world-wide by surface and underground mining techniques, with adits, mines and other mine workings being used. A considerable amount of mineral deposits (including oil reservoirs) is located either close to a fault-line or immediately within the zone of high seismic activity. To prevent economic and environmental damage under the effect of an earthquake, thorough seismic monitoring of the area must be performed, as well as the study of all possible mechanisms of an earthquake occurrence.

In analysing the trigger effect of moon- and sun-induced tidal forces on seismic activity, six great earthquakes which occurred close to equatorial latitude over the last 15 years have been considered. Based on the positions of the Sun and Moon during the day relative to the point mass, the maps of horizontal, vertical components and vector of gravitational forces per unit mass have been plotted. The developed technique can be applicable to a set of methods to study integration and stress unloading mechanisms at the boundaries of block structures.

1. Introduction

Great earthquakes are known to have devastating consequences. The earthquake which occurred near the eastern coast of Honshu, the largest and most populous island of Japan, on 11 March 2011 provides an example of such disastrous effect. It caused a major radiation accident rated level 7 on International Nuclear and Radiological Event scale. This event prompted a worldwide response in many environmental organizations due to its huge impact on people's health and environment.

It should be noted that mineral deposits can also be located in seismic zones and their development may involve factors which can damage both environment and health of people. For example, if Sakhalin oil platforms are exposed to an earthquake followed by a tsunami, they can be damaged, which, in its turn, can lead to an ecological disaster similar to the Gulf of Mexico oil spill in 2010.

In this respect, the study of all possible mechanisms of earthquake occurrence is of great importance. The effect of tidal forces induced by the Sun and Moon can be regarded as one of these mechanisms. One of the possible tidal effects on the Earth's shells is considered in [1]. The purpose of the present research is to detect the trigger effect of tidal forces in great earthquake occurrence. Some data from [2] concern numerical modeling of trigger effect induced in geological environment and seismic waves that are generated as a result of it.

2. Physico-mathematical Modeling

The following is the data from [3]. Horizontal and vertical components of tidal force vector are calculated, with angle θ taken into account.



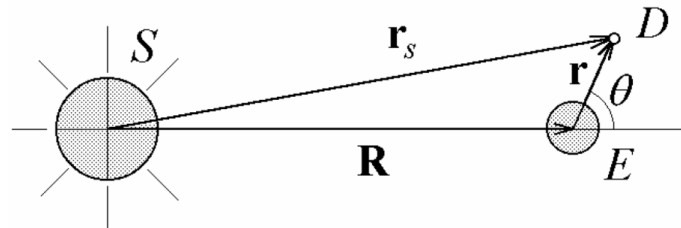


Figure 1. Variables r and θ used to define a point location near the Earth surface [3]

$$F_{hor} = -3G \frac{mM_{sun}}{R^3} r \cos \theta \sin \theta =$$

$$= -\frac{3}{2} G \frac{mM_{sun}}{R^3} r \sin 2\theta \quad (1)$$

$$F_{vert} = G \frac{mM_{sun}}{R^3} r (3 \cos^2 \theta - 1) =$$

$$= \frac{3}{2} G \frac{mM_{sun}}{R^3} r (\cos 2\theta + \frac{1}{3}) \quad (2)$$

As follows from the formulas (1, 2), maximum values of horizontal component are observed when $\theta = 45^\circ$ and 135° , whereas in case of $\theta = 0^\circ, 90^\circ, 180^\circ, 270^\circ$ they are zero. The corresponding extrema of a vertical component are offset by 45° .

Let us consider the case illustrated in figure 2. Equatorial latitude being considered, the value of horizontal component of tidal force induced by the Sun and Moon and affecting a point will be calculated using the formula (1). In the first case, (Sun effect) θ_1 angle will be applied, while in the second case (Moon effect) – θ_2 angle. The total value of horizontal component will be identified by summing these two quantities. In the same way, the vertical component will be calculated using the formula (2).

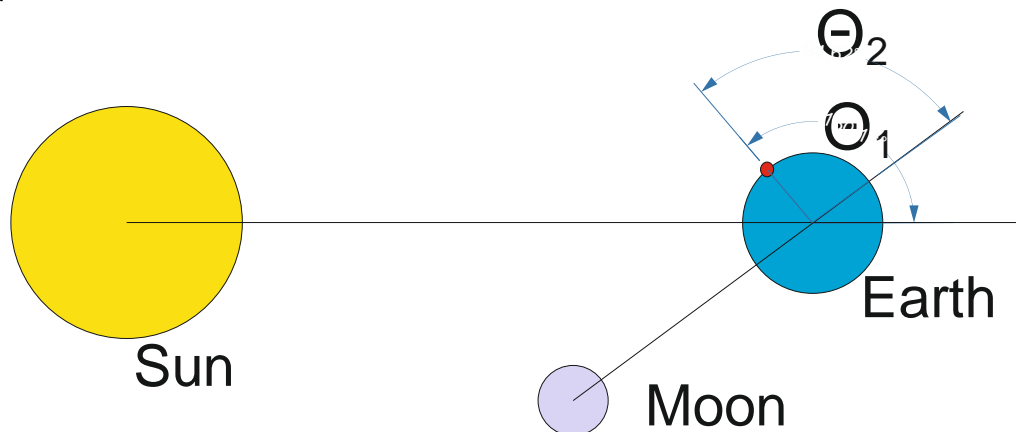


Figure 2. Example of relative positions of Moon and Sun with respect to a point location on the Earth surface

The value of vector sum tidal forces was determined by the formula $F = \sqrt{F_{hor}^2 + F_{vert}^2}$. The obtained values are presented in figure 3.

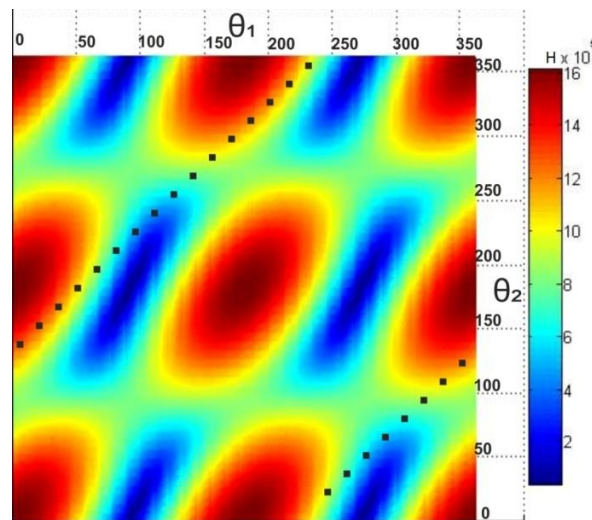


Figure 3. Values of vector sum tidal forces (the combined effect of the Moon and Sun).
Axis: $x - \theta_1$ values, $y - \theta_2$ values.

Legend:



Daily variations (measurement interval – 1 hour)

3. Correlation of Tidal Forces with Earthquakes

The effect of tidal forces on great earthquakes which occurred near the equatorial latitude will be further analyzed. Over 10 events were selected. Table 1 summarizes the reference data on those which were used in calculations.

Table. Earthquakes selected for calculations

N	Location	Ms	Date	Time (UTC)			Latitude	Longitude
				h	M	s		
1	Indonesia	8.8	26.12.2004	0	58	48	3.39	95.84
		7.3	26.12.2004	4	21	26	6.8	92.86
		6.1	26.12.2004	19	19	55	3.08	93.49
2	Japan	9.1	11.03.2011	05	46	23	38.32	142.37

The technique to determine the effect of tidal forces on the earthquake epicenter immediately at the time of its occurrence consists in the following.

Using the known latitude and known earth angular velocity, the time correction for an earthquake epicenter (accurate to second's time difference compared to Greenwich) was determined. Based on this correction, the exact local time of earthquake occurrence was calculated, and this value was referred to, when calculating θ_1 angle, which defines Sun's location relative to the given point at the shock moment by the formula (3).

$$\theta_1 = t \cdot v_s \quad (3)$$

t – local time of the earthquake, v_s – Earth's angular velocity (15 degrees/hour).

The elongation angle between the Moon and the Sun was determined (figure 4). To define the relation of α angle and that of α' elongation angle the formula is given in [4] and is presented as follows:

$$\cos \alpha' = \cos \alpha - \frac{a}{r} \sin^2 \alpha \quad (4)$$

Subsequently, based on the given angle which defines Moon location relative to the epicenter point at the moment of the shock, θ_2 angle was calculated. Finally, considering θ_1 and θ_2 angles, it is possible to calculate the value of horizontal and (vertical) component of tidal force as well as the value of its vector sum.



Figure 4. Elongation angle α between Moon and Sun

To understand the degree of tidal force effect on an earthquake it is necessary to observe the changes in values of vector sum tidal forces over some period before the event. It should be considered that at every moment not only θ_1 and θ_2 angles but also distance to the Sun and the Moon change, as well as the tilt of the Earth's axis relative to these two bodies. The changes in tidal forces at earthquake epicenter points are shown figure 5.

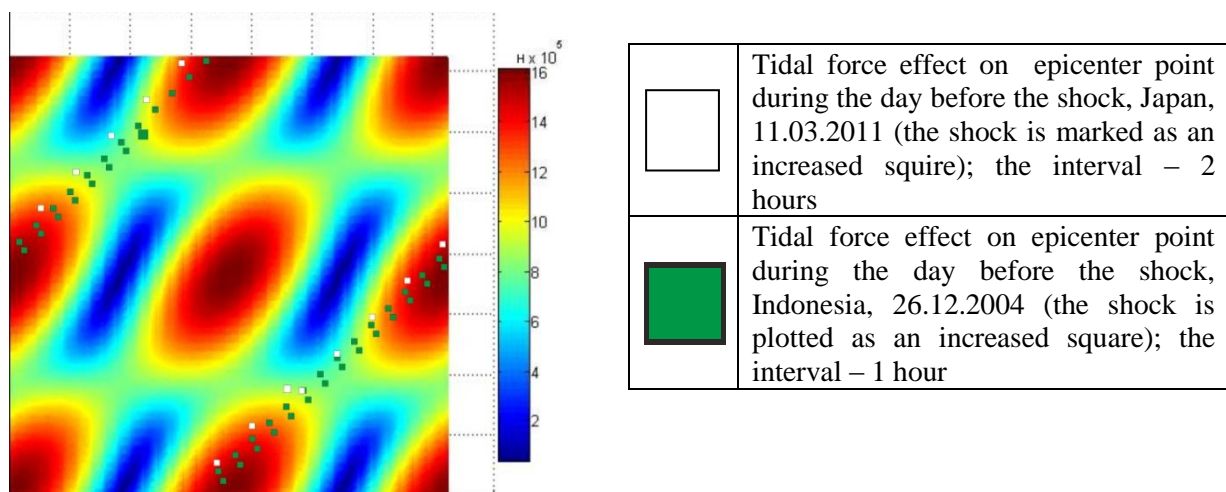


Figure 5. Variation of vector sum tidal forces (calculated for epicenter points of earthquakes in Indonesia and Japan)

4. Conclusion

The investigations carried out by both Russian and foreign researchers [5] show that the effect of tidal forces in triggering earthquakes is generally not great. However, any researcher can hardly ever deny that the tides affect the stress field processes in the crust. Moreover, it is quite significant to study any possible mechanism which triggers earthquakes in the regions regarded as zones of the highest seismic activity (Japan, Indonesia). Based on the positions of the Sun and Moon during the day relative to the body under study which is referred to as a point mass, the maps of horizontal, vertical components and magnitudes of gravitational forces per unit mass have been plotted. Furthermore, the analysis of tidal

force effect on epicenter points of several great earthquakes which occurred near the equatorial latitudes has been made.

The present research can be applied to a set of methods when studying integration and stress unloading mechanisms which act at the block structure boundaries, as well as for more precise understanding and numerical description of earthquake generation.

References

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