TIDAL INFLUENCE THROUGH LOD VARIATIONS ON THE TEMPORAL DISTRIBUTION OF EARTHQUAKE OCCURRENCES

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ABSTRACT. Stresses generated by the body tides are very small at the depth of crustal earthquakes ($\sim 10^2$ N/m^2). The maximum value of the lunisolar stress within the depth range of earthquakes is 10^3 N/m^2 (at depth of about 600 km). Surface loads, due to oceanic tides, in coastal areas are $\sim 10^4$ N/m^2. These influences are however too small to affect the outbreak time of seismic events. Authors show the effect on time distribution of seismic activity due to ΔLOD generated by zonal tides for the case of M_f, M_m, S_{sa} and S_a tidal constituents can be much more effective to trigger earthquakes. According to this approach we show that the tides are not directly triggering the seismic events but through the generated length of day variations. That is the reason why in case of zonal tides a correlation of the lunisolar effect and seismic activity exists, what is not the case for the tesseral and sectorial tides.

1. EARTHQUAKES AND TIDES

In the second half of the 1980s correlation between seismic activity and tidal effect was described e.g. by Shierly (1988) for large earthquakes in Southern California and in the Alaska-Aleutian region, by Weems and Perry (1989) for moderate and large earthquakes in the Eastern USA. Zugravescu et al. (1989) show the distribution in time of earthquake occurrence and their correlation with lunisolar effect in two limited regions, namely in the seismic area of Vrancea (Romania) and in the eastern part of Crete (Greece). Dionysion et al. (1993) also detected significant correlation between the time of seismic events and the tide-generated stress for a small seismic region. Recently Stavinschi & Souchay (2003) found a significant correlation between the seismic activity of Vrancea area and the tidal effect in case of long-periodic zonal tides (especially for the M_f wave). Different investigators pointed out that the tidal triggering of earthquakes is connected to the type of the tectonics of the focal area: Varga and Grafarend (1996), Cochran et al. (2004) found correlations for shallow-dipping thrust events. There are authors who described the evidence of the dependence of aftershock sequences on Earth tides (Souriau et al., 1982). The most evident is the existence of tidal triggering in the case of volcanic earthquakes (Rydelek et al., 1988). Recent publications emphasize that the tides can only help to trigger earthquakes, because the stresses caused by this phenomenon are smaller by about three orders of magnitudes than those of tectonic origin (Young and Zürn, 1979, Varga and Grafarend, 1996). Stresses generated by the body tides are very small in the depth of crustal earthquakes ($\sim 10^2$ N/m^2). The maximum value of the lunisolar stress within the depth range of earthquakes is $\sim 10^3$ N/m^2.

This value is reached however at the depth of 500-600 km only. Surface loads generate stresses at and near to the Earth's surface. Stresses produced by the oceanic load in coastal areas are 10^2 N/m^2 $-$ 10^4 N/m^2. The positive statistical correlation between tidal variations and shallow focus ($\leq$30 km) earthquake occurrences can be explained in many cases by the loading influence of oceanic tides close to coastal areas.

2. SEISMICITY AND ENERGIES OF THE EARTH

The radiated seismic energy is

$$E_R = \frac{\Delta\sigma_s}{2\mu} M_0 \tag{1}$$

and the seismic moment

$$M_0 = \mu DS \tag{2}$$

where μ - the medium's rigidity ($\sim$30 GPa), S - fault area, D - displacement offset, $\Delta\sigma_s$ - average seismic stress drop (range from 1 to 10 MPa, typically $\sim$3 MPa)

The seismic energy is related to the earthquake magnitude M is

$$\log E_R = 11.8 + 1.5M \tag{3}$$

3. INFLUENCE OF TIDES AND EXTERNAL LOADS ON THE SEISMICITY

To determine the normal (radial) and tangential (horizontal) stresses two auxiliary relations were introduced by Molodensky (1953): $N = N[r, \rho(r), \mu(r), \lambda(r)]$ and $M = M[r, \rho(r), \mu(r), \lambda(r)]$, where $\rho(r), \mu(r), \lambda(r)$ are the density and the Lamé parameters. They are increasing with depth through the depth range of interest from the viewpoint of earthquakes and reach a value of 10^3 N/m^2 at the depth of 500-600 km. Due to relatively low magnitude of Earth tide generated stresses near to the surface ($\leq 10^2$ N/m^2) the probability of their influencing effect on earthquake occurrences is small. In case of attempts to correlate the lunisolar effect to seismological events we must remember also that the lunisolar effect itself, and consequently the normal and tangential stresses produced by it, are functions of geographical latitude and significant phase shift appear between the theoretical tidal potential and the generated stresses.

Since earthquakes are shear fracture processes and therefore mainly controlled by the maximum shear stress $\tau = (N - M)/2$ in the focal area it may safely be assumed that also shear stress components of external forces have the main triggering effect. The fracture strength is dependent also on the hydrostatic pressure $p = (N + 2M)/3$. It may be taken also in consideration, but as a minor trigger effect. At the surface p can be of the same order as the surface load and their depth penetration is a function of the size of the loaded area (Figure 1). The static surface load is 10^2 N/m^2 (1 mbar).

4. INFLUENCE OF TIDES ON SEISMICITY THROUGH ΔLOD

In Section 3 it was shown that stresses generated by the solid earth tides are of the order of 10^2 N/m^2, while the loads due to oceanic tides can approach 10^4 N/m^2. On the other hand the elastic stresses accumulated in the earthquake foci and realised during seismic events are (10^6-10^7) N/m^2. The reason while the correlation between long-periodic zonal tides and the time distribution of the earthquake activity often was detected (see Section 1) by different researchers is that the tides are not directly triggering the seismic events but through the generated length of day variations.

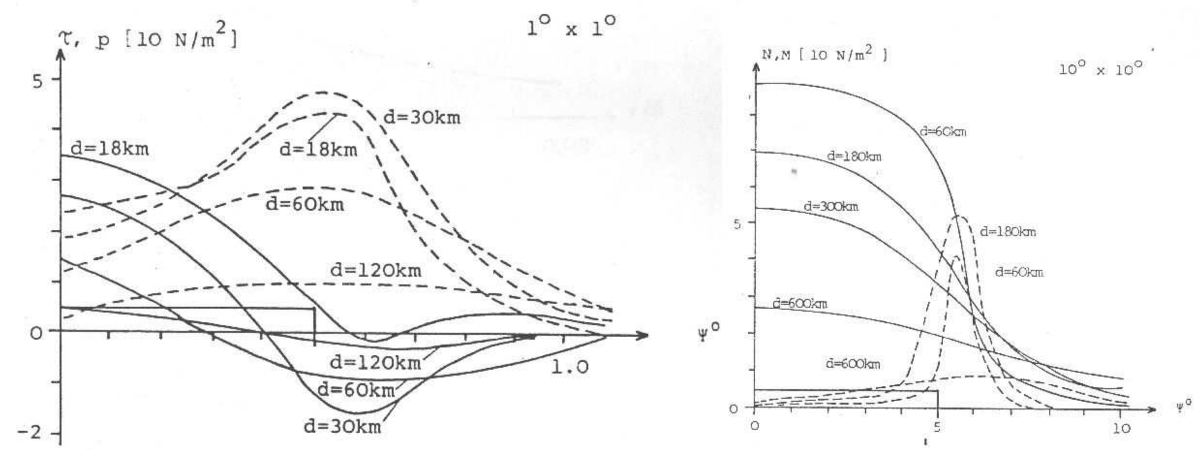

Figure 1: Hydrostatic (solid line) and maximum shear (dashed line) stresses at different depths (d) acting on different spherical segments ($1^\circ \times 1^\circ$ and $10^\circ \times 10^\circ$), Ψ^0 is the spherical distance.

In Table 1 the average ΔLOD values calculated by Defraigne & Smits (1999) are shown. Using this values the rotation energy variations (ΔE_{rot}) can be calculated with

$$\Delta E_{rot} = \frac{1}{2} C \omega^2 \Delta \omega = \frac{1}{2} C \omega^2 \frac{\Delta LOD}{LOD} \tag{4}$$

It can be seen from the last column of Table 1 that the ΔLOD variations due to zonal tides are of the order of (10^{19}-10^{21}) J. The most significant is the energy variation in case of tidal waves M_f, M_m, S_{sa} and the tidal wave with period 18.6 year. The radiated earthquake energy E_R estimated with the use (3) is in case of magnitudes M=6.0, 7.0, 8.0, 9.0 6.3×10^{13}J, 2.0×10^{15}J, 6.3×10^{16}J and 2.0×10^{16}J respectively. The comparison of ΔE_{rot} and E_R suggests that the energy variations caused by ΔLOD probably can influence the temporal distribution of the seismic activity, because they energies are significantly above the earthquake energies.

Tidal wave	**Period (days)**	**ΔLOD(10^{-4} s)**	**ΔE_{rot}(10^{20} J)**
year 18.6	6798.37	-0.1257	3.100
S_a	365.26	0.0222	0.547
S_{sa}	182.62	0.1400	3.453
M_{sm}	31.81	0.0304	0.750
M_m	27.55	0.1589	3.920
M_{sf}	14.76	0.0264	0.651
M_f	13.66	0.3008	7.4200
M_{stm}	9.56	0.0109	0.2689
M_{tm}	9.13	0.0576	1.4209
M_{sqm}	7.10	0.0092	0.2269
M_{qm}	6.86	0.0076	0.1875

Table 1: Variation of energy of rotation due to zonal tides.

As a first experimental attempt three different areas were investigated with the use of power spectra of earthquake occurrences at a frequency band 8106.7-8.0 day/cycle for the time-interval 1964-2002. The area of North France-Great Britain (3256 earthquakes) is characterised by reduced seismic activity. On the contrary the Aleutian (13ă500 earthquakes) and Honsu (6600 earthquakes) regions are very active. In every three cases the anomalies caused by zonal tidal constituents are not significantly above the "noise level" of the power spectra. It seems to us that in the future a more detailed investigation is needed. First of all it should be remembered that different types of earthquakes are differently reacting to the triggering effect of the types (Section 3).

It is shown since long that at periods from 24 hours to some years the reaction of the Earth to external influences can be described by deformations of an elastic medium. Due to the fact that ΔLOD caused by zonal tides generates flattening variations, the elastic stress accumulation is different at different latitudes. Between the equator and latitude 48.2° (critical latitude) the azimuthal stresses are dominant above the meridional ones, while at higher latitudes the role of these two stress components is similar. It also should be remembered in case of future studies that the amplitude of vertical component of zonal tides is dependent on $\sin^2\phi$ (ϕ is the latitude), the NS component depends on $\sin^2\phi$, while the amplitude of EW component is independent from the latitude.

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