VARIATIONS OF ELASTIC ENERGY IN EARTH-MOON SYSTEM AND THEIR CORRELATIONS WITH EARTHQUAKES AND MOONQUAKES

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The Earth oceanic and elastic shells are deformed due to lunar-solar attraction, due to non-inertial rotational effects in pole motion and others. Different types of tides are observed on the Earth. They are caused by gravitational attraction of moving core (rigid and liquid). In classical approximation all these tides are described by linear theory of elasticity. And full effect of Earth deformations is presented as linear superposition of all pointed tides. Tensile state of the Earth is characterized by the elastic energy stored in superposition of tides.

We have obtained formulae for elastic energy of tide superposition. Full energy is not additive sum of elastic energies of separated tides and contains additional terms of mutual character.

For example mutual action of the Moon and Sun on the Earth generates additional energy with maximal value about 91.6% of elastic energy which is generated by the Moon ($E_M$). Full elastic energy of the lunar-solar tides is in diapason 212.6%W - 75.2%W. This big change is observed every orbital period of the Moon. These additional terms of energy are very important. So pointed variation in 137.4% $E_M$ sufficiently big and leads to remarkable periodic variations of elastic energy. So pointed variation in 137.4% $E_M$ sufficiently more then variation of energy caused by eccentricity of the Moon orbit 67.8% $E_M$. Full variation of the elastic energy achieves 209.4% $E_M$. Also superposition of rotational tide with lunar-solar tides leads to additional elastic energy terms.

Part of elastic energy dissipates and goes to warm energy and to energization of different natural processes in definite rhythms. Analytical formula for energy and power of the tidal deformations was obtained. Spectral analysis of the elastic energy of the lunar-solar tides was fulfilled. In given paper we have shown that variations of tidal energy demonstrate clear correlations with events of earthquakes and moonquakes.

Formula for elastic energy. On the base of the classical solution of the problem of elasticity for model of the Earth with concentric mass distribution the evaluations of the tidal energy and power of Earth lunar-solar and rotational deformations, including their joint effect, were obtained. Let us consider the system of external celestial bodies with respect to the deformable Earth: $P_i$ ($\sigma = 1, 2, ..., N$). Full energy of deformations of the Earth due to attraction of the planets is determined by formula [1]:

\[
E_d = \sum_{i=1}^{N} \sum_{\sigma=2}^{N} \epsilon_{\sigma} \left( \frac{m_i}{r_i^{\sigma+1}} \right)^2 + 2 \sum_{i,j=1}^{N} \sum_{\sigma=2}^{N} \epsilon_{\sigma} m_i m_j \frac{r_i^{\sigma+1}}{r_j^{\sigma+1}} P_i(S_\gamma)
\]

$S_\gamma$ is the angle between radius-vectors of the planets $P_i$ and $P_j$, $r_i$ is a distance between the centres of mass of the sun and planet $P_i$; $m_i$ is a mass of this planet; $\epsilon_{\sigma}$ is an elastic parameters.

Taking into account only lunar-solar and rotational tides for elastic energy of Earth deformations we obtain following formula:

\[
E_d = E_M + E_S + E_R + 2\sqrt{E_M E_S} P_2(\cos S) \quad \text{(1)}
\]

Here $S$ is an angle between geocentric directions to the Moon and the Sun; $\gamma_M$ is an angle between geocentric direction to the Moon and Earth axis of rotation; $\gamma_S$ is an angle between geocentric direction to the Sun and Earth axis of rotation; $r_M$ is a distance between centers of mass of the Earth and the Moon; $r_S$ is a distance between centers of mass of the Earth and the Sun; $\Omega$ is an angular velocity of the earth rotation, $\omega = 0.72921 \times 10^{-4}$ rad/s.

Evaluations of elastic energies. Saving only main second harmonics of tidal elastic energy on the base of formulae (1) for known parameters of Earth-Moon system we obtain following evaluations: $E_M = 5.473 \times 10^{23}$ c.g.s.e. is elastic energy of the Earth caused by the Moon attraction; $E_S = 1.148 \times 10^{23}$ c.g.s.e. is elastic energy of the Earth caused by the Sun attraction; $E_{R_M} = 2\sqrt{E_M E_S} = 5.0132 \times 10^{23}$ c.g.s.e. is an elastic energy of the Earth caused by its rotation.

Variations of lunar-solar tidal energy. In case circular Moon and Sun orbits maximal and minimal values of the energy of lunar and solar tides are determined by formulae:

\[
E_{SM}^{\max} = E_S^{(2)} + E_M^{(2)} + 2\sqrt{E_S^{(2)} E_M^{(2)}} = 11.6342 \text{ c.g.s.e.}
\]

\[
E_{SM}^{\min} = E_S^{(2)} + E_M^{(2)} - \sqrt{E_S^{(2)} E_M^{(2)}} = 4.1144 \text{ c.g.s.e.}
\]

So variation of elastic energy is

\[
\Delta E_{SM} = 3\sqrt{E_S^{(2)} E_M^{(2)}} = 7.5198 \times 10^{23} \text{ c.g.s.e.}
\]

Lunar eccentricity variations of the Earth tidal energy (pericenter-apocenter positions) is determined by formula
\[ \Delta E_M^{(2)} = E_M^{(2)} \left[ \frac{1}{(1-e_M^2)^2} - \frac{1}{(1+e_M^2)^2} \right] = 3.7084 \times 10^{23} \text{c.g.s.e.} \]

Solar eccentricity variations of the Earth tidal energy (pericenter-apocenter positions)

\[ \Delta E_S^{(2)} = E_S^{(2)} \left[ \frac{1}{(1-e_S^2)^2} - \frac{1}{(1+e_S^2)^2} \right] = 0.2314 \times 10^{23} \text{c.g.s.e.} \]

Full variation of the tidal energy is \(1.14596 \times 10^{23} \text{c.g.s.e.}\)

**Power of tidal processes.** Resultant evaluations of powers of the tidal deformations:

\[ N_{SM} = 1.1789 \times 10^{11} \text{Wt}, \quad N_M = 0.3142 \times 10^{11} \text{Wt}, \]
\[ N_S = 0.0015 \times 10^{11} \text{Wt}, \quad N = 1.4946 \times 10^{11} \text{Wt}. \]

For power of mutual rotational and lunar-solar deformations of the Earth we obtain following formal evaluations

\[ N_{RM}^{\text{max}} = \frac{6\pi}{T} \sqrt{E_E E_M} \sin^2 \theta_{\text{min}} = 0.8963 \times 10^{15} \text{Wt}, \]
\[ N_{RM}^{\text{max}} = \frac{6\pi}{T} \sqrt{E_E E_M} \sin^2 \theta_{\text{max}} = 2.0310 \times 10^{15} \text{Wt} \]

and their difference will be

\[ \Delta N_{RM}^{\text{max}} = \frac{6\pi}{T} \sqrt{E_E E_M} (\sin^2 \theta_{\text{max}} - \sin^2 \theta_{\text{min}}) = 1.1347 \times 10^{15} \text{Wt}. \]

Here \(\theta_{\text{min}}\) and \(\theta_{\text{max}}\) is extreme values of inclination of Earth axis of rotation with respect to normal to the plane of lunar orbit. \(T\) is a period of lunar motion.

**Remark.** Evaluations of powers connected with global rotational deformation have formal character here. In reality in present epoch we can not observe this composition of deformations. In result of own evolution the elastic rotational energy was disappeared. But more fine effects of interaction and superposition of deformations caused of Earth rotation variations of course have place in reality and must be studied.

**Correlations of earthquakes and moonquakes with variations of tidal energy.** We have studied theoretical curves of change of tidal energy of lunar-solar tides on the Earth and terrestrial-solar tides on the Moon in period 1971-1977 years. It was shown that moments of energy variations caused by pointed mutual actions coincide (or close) to moments of big earthquakes (with magnitude 7 and 8) and moonquakes. It is important to note that mutual term of elastic energy controls and dictates seismic process. Of course earthquakes and moonquakes are observed not for all pointed tidal variations. Probably it is caused by process of accumulation of seismic energy. But in any case we can predict in definite statistical sense future big earthquakes and moonquakes. In result of analysis of theoretical curve of elastic energy of lunar-solar tides we have determine date of possible big earthquakes in 2003 years. These date are: 10-11 July; 21 July; 1 August; 4 August; 8-9 August; 19 August; 28 August; 4 September; 15-16 September; 26 September; 6-7 October; 15-16 October; 25 October; 3-4 November; 6-7 November; 12-13 November; 23 November; 2 December; 8 December; 12-13 December; 21-22 December; 31 December. In same date moonquakes can be expected on the Moon. Given approach does not let us to determine region of earthquakes but let us to analyze date of extreme perturbed states of the Earth caused by gravitational influence of external celestial bodies.

Barkin’s work was accepted by grant SAB2000-0235 of Ministry of Education of Spain (Secretaria de Estado de Educacion y Universidades) and by RFBR grant 02-05-64176.

**References.**