DAMPING OF THE EARTH' S SPHEROIDAL OSCILLATIONS AT SMALL n

GEOPHYSICS

1970

SovietRxiv

Abstract

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UDC 550.311

GEOPHYSICS

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DAMPING OF THE EARTH'S SPHEROIDAL OSCILLATIONS AT SMALL n

(Presented by Academician M. A. Sadovskii on 28 VII 1969)

In previous papers ([1,2]) we considered the damping of torsional and radial oscillations of the Earth. In the case of torsional oscillations, comparison of experimental data with theory made it possible, in broad outline, to determine the distribution of the dissipative function Q in the Earth' s mantle. Using the distribution of Q thus obtained and constructing a perturbation theory for the Earth' s radial oscillations, it proved possible to give an explanation of the anomalously large values of Q observed after the Chilean earthquakes for radial oscillations ([2]). This gives grounds for thinking that the distribution of Q obtained in ([1]) for the Earth' s mantle is close to the real sought distribution of the dissipative function. As all data indicate, Q in the Earth' s liquid core is at least an order of magnitude greater than Q for the mantle. Therefore at the present time, because of the insufficiency of experimental data, dissipation in the core has to be neglected.

In paper ([3]) a perturbation theory was constructed for spheroidal oscillations of the Earth. This made it possible to continue the investigation begun in ([1,2]) and to consider the damping of spheroidal oscillations of the Earth. Below we give the results of calculations for the fundamental tone up to $n = 27$ and the first 4 overtones for $n =$ 1-7. These oscillations are of interest because they depend substantially on the properties of the Earth' s core, whereas oscillations with large n are already noticeably displaced from the core into the Earth' s mantle.

As the computational model of the Earth, the Gutenberg-Bullen A (GBA) model was chosen. This model is described in detail in our preceding papers. It was also used in the works of Pekeris et al. (([4]), pp. 230-232). In the model the crust and mantle are divided into 34 layers with piecewise-constant parameters. The Earth' s core is liquid and is divided into 7 layers: the inner core, a transitional layer, and the outer core, consisting of 5 layers. In principle the number of layers could be increased, but for our purposes this is unimportant. The integration of the differential equations was carried out from the center of the Earth. In the first region—the inner core—exact solutions are known, which are expressed in terms of Bessel functions ([5]). Then the solution was continued by the Runge-Kutta method to the boundary of the core with the mantle and through the Earth' s mantle and crust to the surface, after which, by the formulas of the perturbation theory ([2]), derivatives of the frequency with respect to the parameters of the problem—the density, the compressional modulus, and the shear modulus in each layer (respectively $\chi_{\rho i}$, χ_{ki}, $\chi_{\mu i}$, i being the layer number)—were calculated. As usual, it was assumed that dissipation occurs only in shear processes and thus is determined only by the derivative χ_{μ}.

In the concrete calculations the GBA model is "coarsened." As stated above, it is assumed that dissipation in the core can be neglected, and the 34 layers of the crust and mantle are combined into four enlarged layers ($j = 1, 2, 3, 4$):

1. Zone A —crust ($0 \leq l \leq 38$ km).
2. Zone B —subcrustal zone ($38 \leq l \leq 300$ km).

Table 1

Variant	Q_1	Q_2	Q_3	Q_4	Variant	Q_1	Q_2	Q_3	Q_4
41	450	50	500	1000	5	450	100	500	1500
42	450	100	500	1000	6	450	100	500	1000
44	450	200	500	1000					

Table 2

n	Variant 41	Variant 42	Variant 44	Variant 5	Variant 6
	$l = 0$				
1	820	1000	1100	1200	870
2	1000	1300	1400	1600	1100
3	740	970	1200	1200	870
4	640	860	1000	1000	780
5	610	820	980	980	750
6	580	790	960	950	730
7	550	760	930	900	700
8	510	720	900	850	660
9	470	670	855	775	610
10	450	645	820	735	570
11	430	610	775	685	525
12	420	595	750	655	500
13	410	575	725	625	470
14	400	560	695	600	450
15	390	540	670	575	425
16	380	525	650	550	405
17	365	510	630	530	390
18	355	495	610	510	370
19	340	475	590	490	355
20	330	460	575	470	345

n	Variant 41	Variant 42	Variant 44	Variant 5	Variant 6
21	315	445	560	460	330
22	300	430	545	435	320
23	285	415	535	420	310
24	270	400	525	400	300
25	260	385	510	390	295
26	245	370	495	370	285
27	235	355	490	360	275

n	Variant 41	Variant 42	Variant 44	Variant 5	Variant 6
	$l = 1$				
1	1700	2100	2500	2500	1800
2	510	690	820	770	570
3	440	590	730	660	480
4	420	570	690	630	460
5	540	670	760	770	540
6	890	940	960	1100	780
7	930	940	950	1200	900

n	Variant 41	Variant 42	Variant 44	Variant 5	Variant 6
	$l = 2$				
1	760	890	970	1000	680
2	1100	1300	1500	1630	1100
3	760	1000	1300	1200	920
4	550	800	1100	910	720
5	350	550	780	580	480
6	240	390	580	400	330
7	210	350	510	350	290

n	Variant 41	Variant 42	Variant 44	Variant 5	Variant 6
	$l = 3$				
1	1500	1900	2100	2200	1500
2	680	1100	1200	1200	830
3	980	1200	1300	1400	930
4	510	690	840	780	570
5	460	640	790	710	530
6	430	600	740	660	500
7	310	480	670	520	420

n	Variant 41	Variant 42	Variant 44	Variant 5	Variant 6
	$l = 4$				
1	430	570	700	600	470
2	590	780	940	870	630
3	650	960	1300	1000	800
4	450	700	960	740	630
5	340	530	730	570	460
6	320	490	680	530	430
7	310	480	670	340	420

3. Zone C—transition layer ($300 \le l \le 1000$ km).
4. Zone D—lower mantle ($1000 \le l \le 2900$ km).

Let μ_{0i} denote the dimensionless shear modulus in the i-th layer and let $R_i = \chi_{\mu i}\mu_{0i}$, where the layers are counted from the center of the Earth. Then the quantities sought, calculated by us, are equal to

$$q^1 = \frac{2}{\chi_0}\sum_{i=40}^{41} R_i, \qquad q^2 = \frac{2}{\chi_0}\sum_{i=27}^{39} R_i, \qquad q^3 = \frac{2}{\chi_0}\sum_{i=18}^{26} R_i, \qquad q^4 = \frac{2}{\chi_0}\sum_{i=8}^{17} R_i, \tag{1}$$

where χ_0 is the dimensionless natural frequency.

The formula by which the damping Q was determined has the form

$$Q^{-1} = \sum_{j=1}^{4} q^j Q_j^{-1},$$

where Q_j $(j = 1, 2, 3, 4)$ is the distribution of the dissipative function in the Earth' s mantle ([1]). In ([1]) we considered the trial distributions Q_j given in Table 1.

On the basis of the experimental data presently available, the best distribution Q_j in the mantle is given by variant 6. The results of calculations for spheroidal oscillations ${}_lQ_{sn}$ ($n = 1$—7, $l = 0, 1, 2, 3, 4$) are presented in Table 2.

The most substantial result of the present calculations should be considered the large values of Q obtained for spheroidal oscillations with small n. The existing uncertainties are unlikely to change the quoted results for Q by more than $100 \div 200$. Thus, we have ${}_0Q_{sn}$ ($n = 1$—7) ~ 1100—700, variant 6.

If we turn to the experimental data ([4], pp. 33—59; 106—114), it turns out that Q_{sn} ($n = 2$—7) $\sim 400 \div 300$. These experimental values of ${}_0Q_{sn}$ are determined with insufficient confidence. It seems to us that they are simply erroneous. This is also indicated, in particular, by Smith ([6]) in his report prepared for the XIV General Assembly of the International Union of Geodesy and Geophysics. Smith points out that a careful review of the old data showed that nonstationary noises (background) could have substantially affected the measured values of Q for the lower tones of spheroidal and torsional oscillations, and that the previously published values of Q were substantially underestimated in comparison with the real quantities. The results given in Table 1 are precisely what orient experimenters toward the real values of ${}_lQ_{sn}$ that should be expected from observations.

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Received
14 VII 1969

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Note: Figure translations are in progress. See original paper for figures.